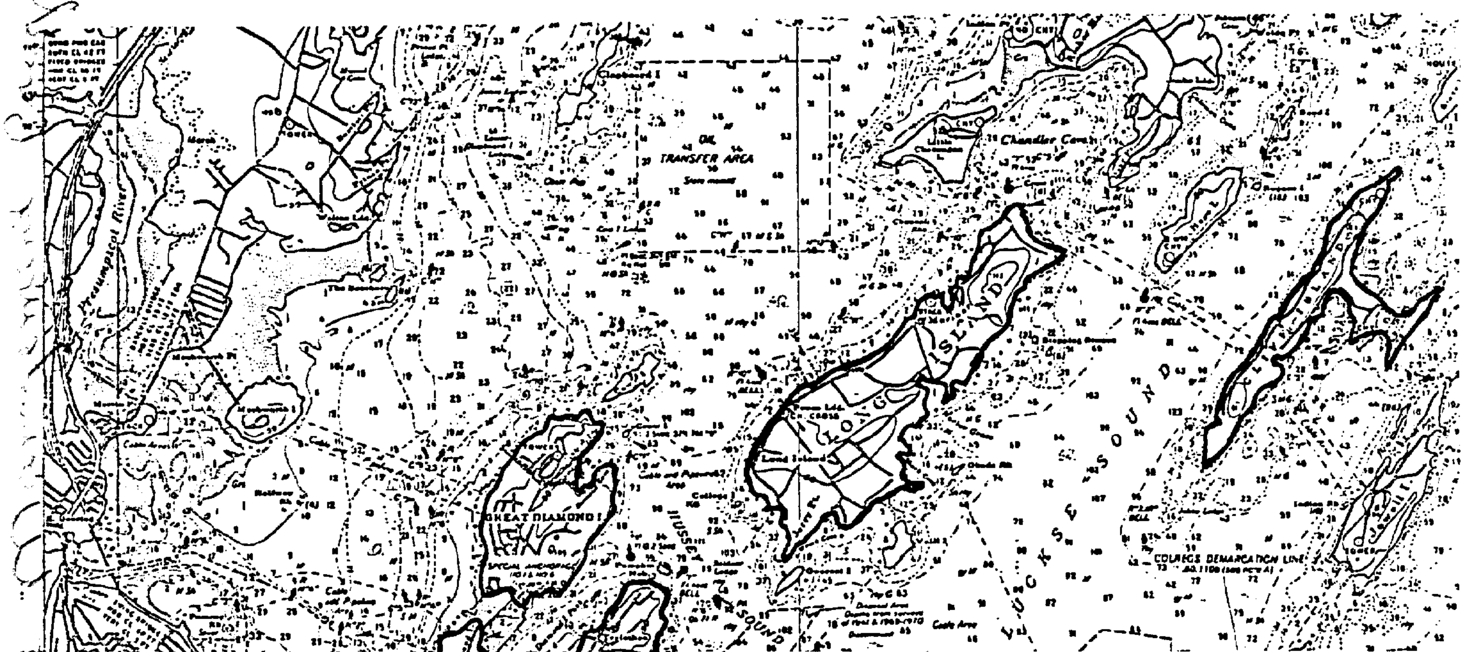
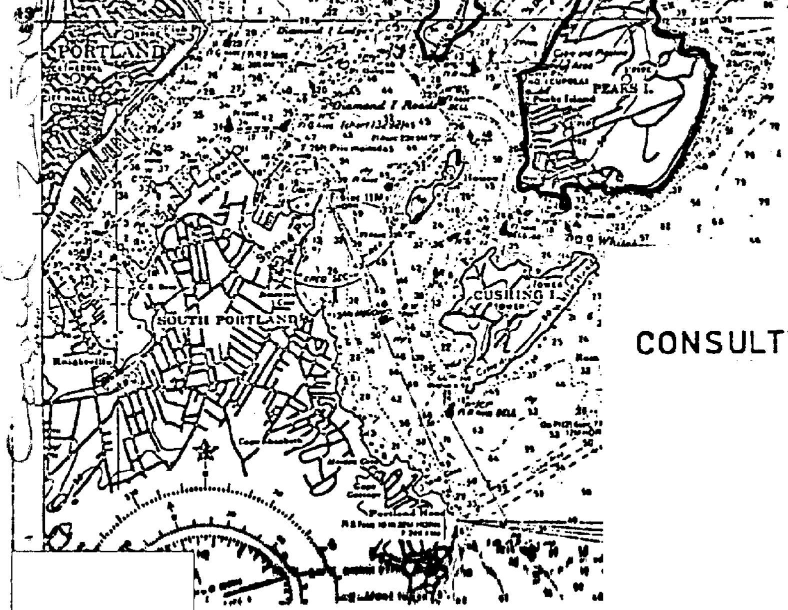
# CITY OF PORTLAND ISLAND GROUND WATER MANAGEMENT STUDY




PREPARED BY

ROBERT G. GERBER, INC.

CONSULTING CIVIL ENGINEERS AND GEOLOGISTS

17 WEST STREET

FREEPORT, MAINE 04032

AUGUST 1986

TD
403
.C58
1986

Property of CSC Library

ROBERT G. GERBER, INC.
17 WEST STREET • FREEPORT, MAINE 04032
207-865-6138

11 September 1986

Mr. Joseph Gray, Director
Dept. of Planning and Urban Development
City Hall
Portland, Maine

U.S. DEPARTMENT OF COMMERCE NOAA
COASTAL SERVICES CENTER
2234 SOUTH HOBSON AVENUE
CHARLESTON SC 29405-2413

Re: Transmittal of Ground Water Management Study for the Portland Islands

Dear Mr. Gray:

In accordance with our contract, we have completed a ground water management study for several of the islands located within the City of Portland. The islands in this study include Peaks Island, Long Island, Cliff Island, Great Diamond Island and Little Diamond Island. This study was supported by financial assistance provided by a grant from Maine's Coastal Program, through funding provided by the U.S. Dept. of Commerce, Office of Coastal Zone Management, under the Coastal Zone Management Act of 1972, as amended. Matching funds were provided by the City of Portland.

PURPOSE

The study had several objectives:

a) assemble as much data as possible on the island ground water resources;

b) undertake reconnaissance-level investigations and develop simulation models to describe the way in which ground water originates and moves on the islands;

c) locate known and potential sources of ground water contamination on the islands;

d) propose ground water management goals and objectives and recommend ways to implement them.

The results of our study are transmitted herewith. In this letter of transmittal, we provide an executive summary of our findings.

GROUND WATER OCCURRENCE AND MOVEMENT ON THE ISLANDS

All ground water on each island we studied originates from rain and snow that falls on the land surface of the island. While most of this precipitation is lost because of surface run-off, evaporation, or use by vegetation, a small portion becomes "ground water" when it seeps into the ground to saturate the soil and fill narrow cracks in the underlying bedrock or ledge. Once in the soil or ledge, the ground water generally moves downhill and either discharges to a local wetland or stream, or travels all the way to the ocean to discharge near the shoreline. Water is in turn evaporated from the ocean (or other more distant areas) then returned to the land surface in the form of rain or snow. This "hydrologic cycle", as it is called, is depicted in Figure

TD403 .C58 1986
17157805
DEC 23 1996

Property of CSC Library

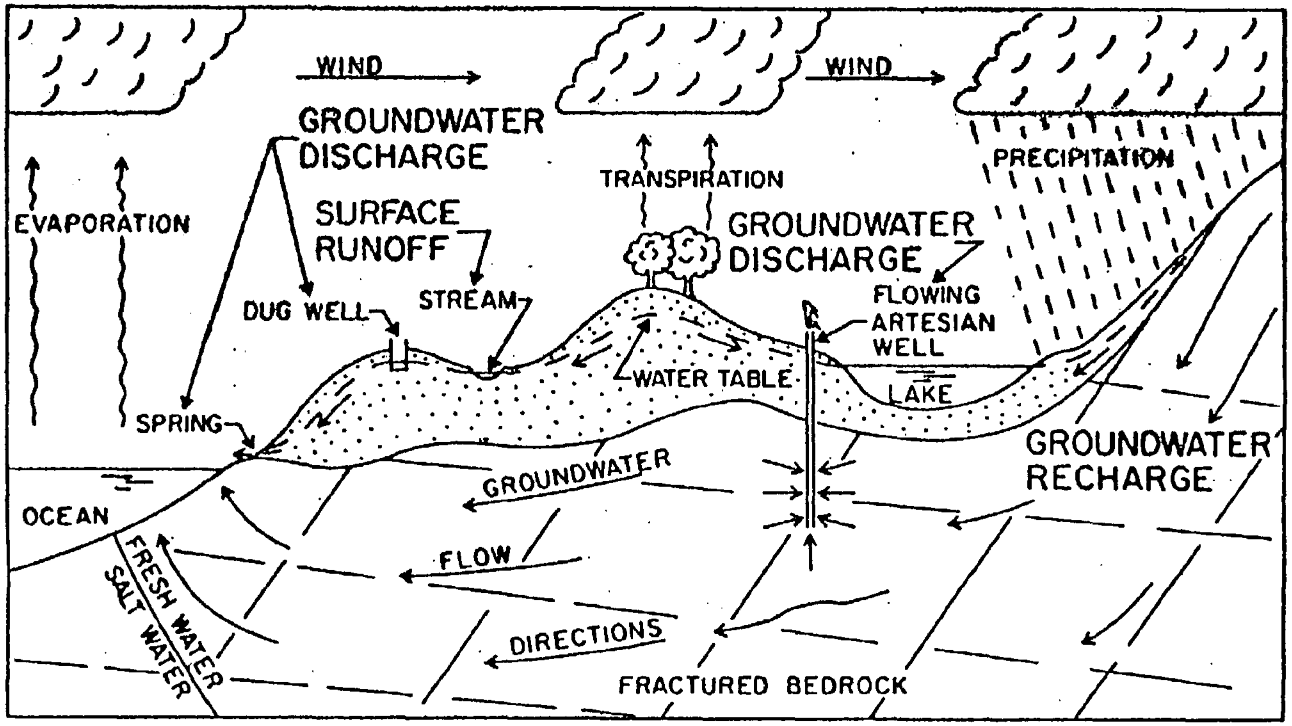



FIGURE I. The hydrologic cycle.[3] (Caswell, 1978, Fig. 1, p. 3)

When a saturated body of soil or ledge has sufficiently open and interconnecting voids or cracks to yield a quantity of water to wells at a cost that people are willing to pay to obtain ground water, that body is defined as an "aquifer". As a well draws water, the aquifer is recharged by the continued infiltration of water from soil and/or bedrock above and to the sides of the well. Wells that are pumped faster than the natural recharge rate of the aquifer will go dry or, in coastal areas, will pull ocean (salt) water into the aquifer.

There are two separate, but interconnected types of aquifers on the islands: a) those in the soil, or "surficial" deposits; and b) those in the ledge, or "bedrock". Except in those areas where there is no soil cover over ledge, precipitation or snow melt must infiltrate and travel vertically downward through the soil before it can pass into the bedrock. In gravel soils, most precipitation can enter the soil immediately, although almost half the annual precipitation is captured by plants or lost again to evaporation. In clay soils, as little as 5% of precipitation is able to infiltrate the soil and pass through to the underlying bedrock. Where sand or gravel deposits have sufficient saturated thickness (preferably greater than 10') and where a dug well can collect ground water originating as rainfall over a minimum of about 5 acres of land, then a dug well can supply a single-family house with sufficient water for domestic use. However, in most cases on the islands, dug wells are not feasible and homeowners must rely on drilled bedrock wells for their water supply.

Bedrock aquifers in Casco Bay absorb water into cracks or "fractures" on the higher parts of the island. On the average, about 8% of the precipitation falling on the Portland islands moves through the fractures to become ground water flow in the bedrock aquifer. These fractures may be very narrow (50 microns wide) openings in the rock along the planes of the ancient sedimentary layers in the rock (which may now be tilted to a nearly vertical attitude), or may be cracks resulting from rock breakage during the rock flexure that has taken place during the several hundred million years that the rock has been formed, and then moved around on the earth's surface. Figure II shows typical "fracture" patterns and how a bedrock (or "artesian") well might intercept these fractures to obtain water. As shown on Figures I and III, ground water entering the rock at the highest point of the island flows nearly straight down, deep into the earth before turning sideways, then upwards to discharge at the saltwater interface. Ground water entering the rock near the edge of an island stays shallow and will discharge just above or below the high tide line.

Salt water intrusion is a problem of particular concern on islands. Salt water corrodes plumbing fixtures, is unhealthy to drink, and is very expensive to treat to make it fit to drink. Fresh water in the form of ground water, because it has a lower density than salt water, will float on top of salt water. A thick zone of brackish ground water occurs near the salt water interface shown on Figure III, due to mixing caused by tidal fluctuations and by ground water moving along the saltwater interface. The theoretical salt water interface is located about 40 times the depth below Mean Sea Level as the surface of the ground water is elevated <u>above</u> Mean Sea Level. Therefore, the saltwater interface is very deep under the center of an island where the

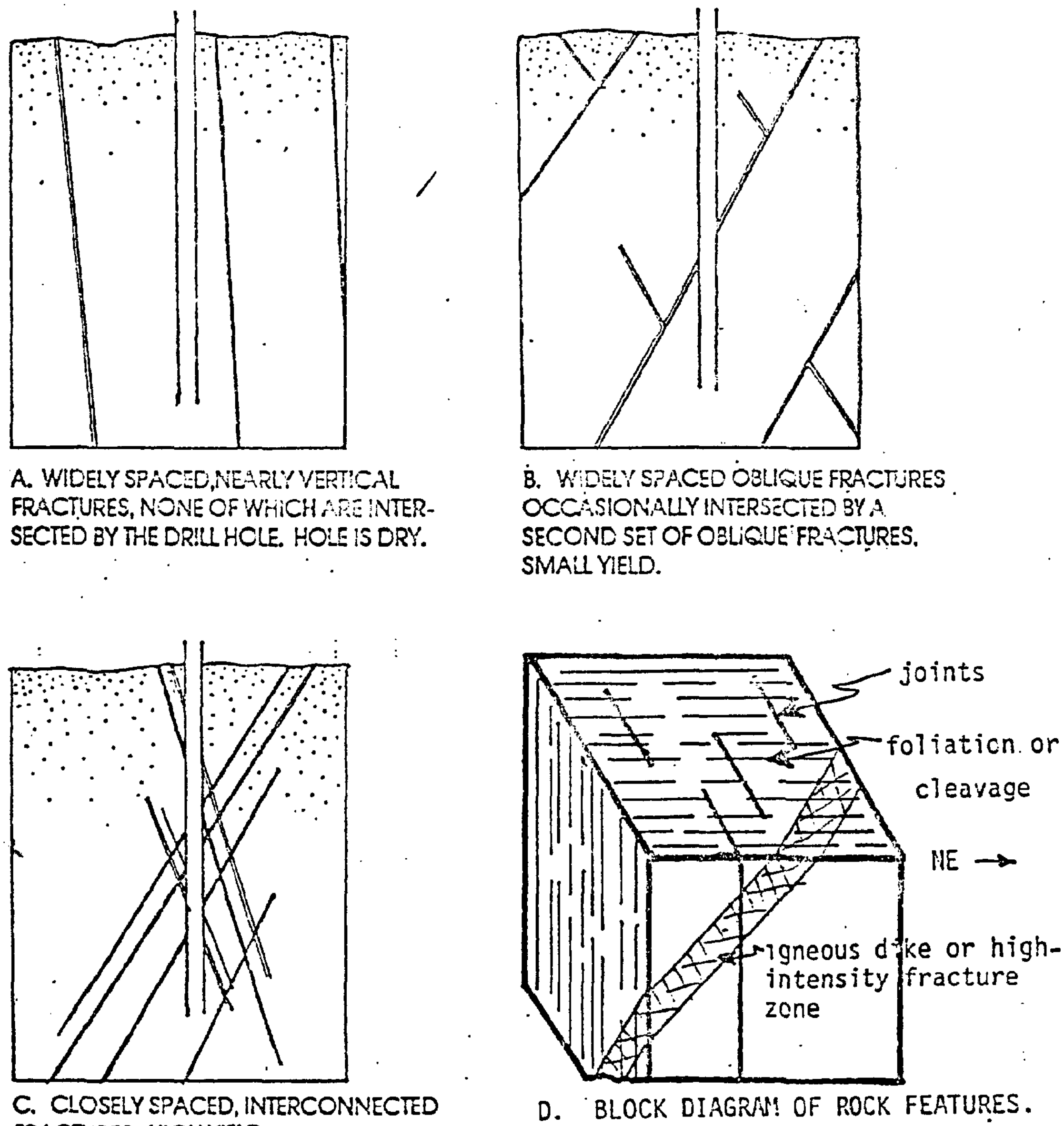
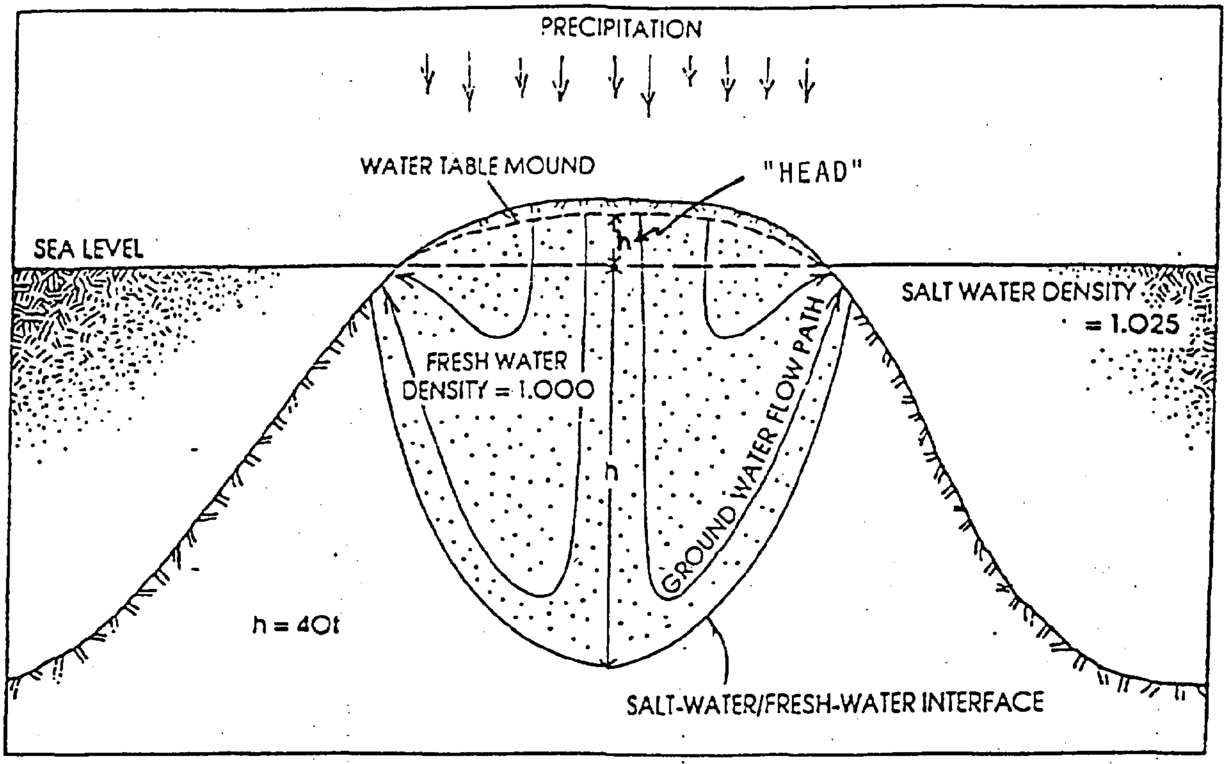


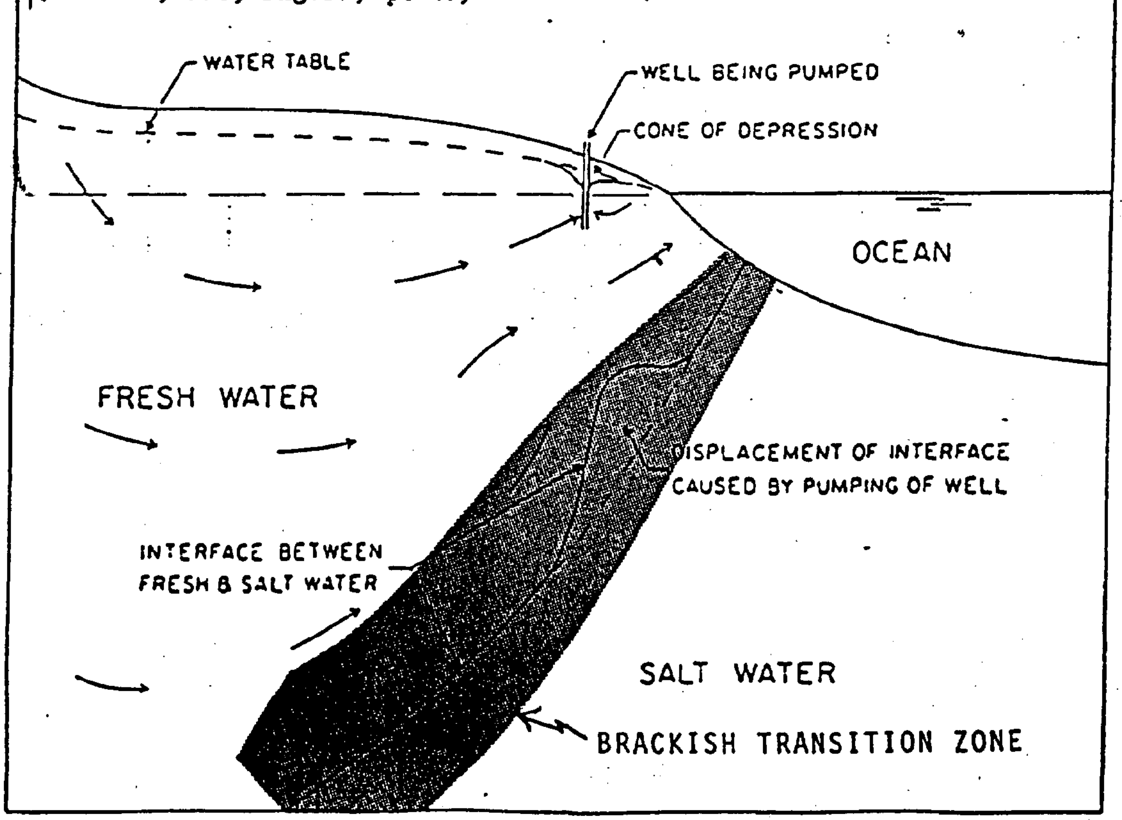

FIG. 11 The first two examples show fracture geometries causing poor yields in bedrock wells in Maine, while the third is an example of a high-yield fracture geometry.
(adapted from Caswell, 1978, Fig. 61, p. 87)

FIGURE III Response of Ground Water at the Salt-water Interface




Schematic cross section of an oceanic island showing lens of fresh water. The water table mound is maintained by precipitation. (Caswell,1978, Fig.36, p.46)

Idealized ground water flow near the fresh water/salt water interface. (Caswell,1978, Fig.37, p. 47)



surface of the ground water may be close to, say, 80' above Mean Sea Level. However, the closer to the shoreline, the shallower the saltwater interface becomes. As shown on the bottom of Figure III, when a well is being pumped and draws down the ground water surface, salt water is displaced upward towards the well.

STUDY METHODS

This study was conducted from January through June 1986 by Robert G. Gerber, Inc., (RGGI), Consulting Geologists and Civil Engineers, who were awarded the work after a competitive bidding process. Almost all members of the RGGI staff were involved at one time or another in the work. Robert Gerber was Project Manager and heavily involved in the data interpretation, computer modeling, development of ground water management recommendations, and report writing. Steven Pinette assisted in project management, conducted the bedrock field mapping, did much of the computer modeling, and wrote portions of the technical report. William Holland did the photolineament analysis. James Hillier conducted field mapping, and assisted in report preparation. Susan Tolman did the drafting for the project.

Information on the ground water was collected from the available geologic literature, from private sources such as the Long Island Association, through circulation of a water supply questionnaire on Long and Cliff Islands (most of Peaks and the Diamond Islands are supplied by Portland Water District), and through field mapping and aerial photo interpretation done specifically for this project. Data developed from the questionnaires were compiled on a computer spreadsheet for statistical evaluation. Maps are given in the report showing the locations of each well for which we have information are given in the report. A number next to a well is keyed to the actual data given in an appendix of the report. Field mapping and aerial photo interpretation was done to develop new, more detailed information on the soils and bedrock geology of the islands. Water quality records stored at the Maine Public Health Laboratory were reviewed to develop statistical information on well water quality on the islands.

Since the soil cover on the islands is generally thin and discontinuous, and since about 80% of the private wells are drilled into rock, we concentrated our efforts on the bedrock aquifer, which is continuous under the islands. We developed a computerized ground water simulation model of each island to simulate how ground water moves, where ground water enters the rock and where it discharges from the rock, and how fast the ground water moves. The models simulate the elevation of the bedrock aquifer ground water surface and are capable of simulating the spread of contaminants throughout the bedrock aquifer. The models were calibrated with acceptable accuracy to known bedrock ground water table elevations on Long and Cliff Islands. Since there were no well data for Peaks and the Diamond Islands, the models have not been verified to any degree of accuracy on those islands.

The ground water management goals and objectives were developed in consultation with the Portland Planning Department's and City Engineer's staff. These represent the accumulated knowledge of 15 year's worth of Mr. Gerber's experience in advising municipalities and water districts on ground water management techniques.

## STUDY FINDINGS

The geology of the islands is fundamental to the understanding of ground water occurrence and movement. We have developed geologic maps of both the soils and the bedrock for each island. The soils are subdivided by their origin and texture, since these factors most closely affect the ability of precipitation to infiltrate the soil and also the speed with which ground water is transmitted from one point to another. Based on our experience, laboratory measurements of the properties of similar soils, and knowledge gained from other computer simulations having good calibration, we have assigned average precipitation infiltration rates to each soil group which are used to estimate recharge to the soils and to estimate the amount of dilution that precipitation will provide to any contaminants leaked to the ground water.

The principal soils on the islands include: a) a thick silty, stony soil called "glacial till", which was laid under the last continental ice sheet 13,000 to 20,000 years ago; b) thin stony, sandy soil developed from water washing through glacial till; c) a stratified sand or gravelly sand deposited by meltwater streams flowing off the glaciers 13,000 years ago; and d) interbedded fine sand, silt, and clay deposited 13,000 years ago when the ocean was 250' higher than at present. The stratified sands and gravels make the best surficial aquifers; the tills are intermediate in favorability; and the clay-silts are least productive.

Based on our field mapping and the water supply questionnaire results, we have prepared maps showing the thickness of the soil deposits on the islands. Dug wells would only be reliable where soils are relatively thick (say 10' or greater). Soils are typically less than 5' thick except in large areas on the west shore of Peaks Island and on the northern and southwestern portions of Long Island. Because of the relatively thin soils over most of the islands studied, the surficial aquifers are only of minor importance to the islands as a water source. On a set of maps we prepared called "Special Features Maps", we have shown the locations of sites in surficial deposits where above-average thickness and coarse texture favor developing wells in the surficial deposits.

The bedrock geology of the islands is complex, but began more than 500 million years ago when sediments were being deposited into a sea while nearby volcanoes were erupting. These sediments and volcanic materials were deposited initially in a relatively flat-lying position, layer upon layer. However, later movements of the earth's crust involving continental plate movement and mountain building episodes "cooked" the sediments (thus changing the mineralogy) and tilted the layers so that what were flat lying beds are now almost vertical. The strains that accompanied all of this earth movement created the fractures in the rock that transmit the ground water.

The bedrock aquifers were divided according to different bedrock types, which are differentiated by origin and the different minerals that make up the rock. Based on data we obtained from the Long Island well survey, it appears that at least one rock type, the Cape Elizabeth Formation, produces wells that produce more water when pumped (called yield and expressed in gallons per minute) than other rock types. In addition, we have found that certain rock types naturally produce more iron and manganese (which will stain laundry and sinks and may also smell like sulfur) than other rock types. Many of the drilled wells on Cliff Island are located in a rock zone that hosts much iron and manganese.

After measuring the orientations of hundreds of fractures in the rock, we concluded that ground water movement is favored along the sheet-like layering in the rock that is now tilted almost vertically. The orientation of these many fine laminations, if one were to stand over the rock and look down at a horizontal exposure displaying the tilted layers, is northeast-southwest, along the long axes of the islands. There are short, relatively widely-spaced, fractures that are oriented nearly vertically and trend northwest-southeast, perpendicular to the rock layering. However, we believe that these do not conduct water so readily as the high density of fracture planes between the layers. We estimate that about 10 times as much water may move along the layers as across the layers, all other factors being equal.

There are narrow, linear zones in the rock that may vary from 1 to 100 feet wide, that may have above-average ability to transmit water. In addition to direct observation of these zones on the shoreline (the rock may be so fractured that it looks like soil), the presence of these zones can also often be detected by interpretation of aerial photographs, satellite imagery, and an airborne radar technique. We have used these types of photographs to identify the bedrock zones that may produce high yield wells. Where two or more of these narrow zones cross, there is a particularly good chance that the rock is sufficiently fractured to produce many gallons per minute. Bedrock well yields in excess of 10 gallons per minute are considered "high yield". We have identified these linear zones on the bedrock geology maps and shown localized areas where these zones intersect on the "Special Features" maps. Although these zones may be capable of producing many gallons per minute, caution must be used since sustained pumping at high rates may produce salt water intrusion.

Typical bedrock well yield on Long Island is about 5 gpm, which is about average for the coast of Maine. Cliff Island wells produce above average yields. Typical bedrock well depth on the islands is about 100', whereas 175' is average for the coast as a whole.

Ground water quality is known in some detail for Long Island. In 1985, 104 of the wells on the island were tested more-or-less simultaneously for common health- and esthetic-related water quality parameters. For this study, we sampled five wells on Cliff Island for similar parameters. Although the ground water quality on Cliff Island did not seem to show much human-generated contamination, iron and manganese are very prominent in the ground water on Cliff, due to the mineralogy of the bedrock. The Long Island water quality results found that almost half the wells tested had some coliform bacteria, and over 1/3 of the wells had nitrate-nitrogen concentrations significantly above what would be typical of uncontaminated ground water. It appears that high densities of subsurface sewage disposal systems and/or malfunctioning systems have caused this degradation of ground water. On the "Special Features" maps, we have identified sections of Long and Cliff Islands where subsurface sewage disposal systems are suspected of contaminating wells. In addition, we have identified other known or potential sources of contamination such as large petroleum storage tanks and landfills. It is important to note that there are very few cases of reported salt water intrusion in the island wells. Some local chloride contamination may be due to road salting or sand/salt storage.

On the islands studied, it would rarely take longer than 5 years for a particle of water to move from the highest point in the bedrock aquifer to discharge in the ocean. If a contaminant is introduced at a steady rate into the aquifer, it eventually attains a steady-state (constant) concentration at each point in the aquifer. Concentrations would be higher in the source area and decrease with distance from the source. About 63% of the final steady state concentration would be obtained in the first year near the source of the contamination. Therefore, contaminants can spread rapidly in the bedrock aquifer.

GROUND WATER MANAGEMENT RECOMMENDATIONS

There are numerous reasons why the City should develop its own ground water management plan. The federal government will not do the job, and the State policy relative to bedrock aquifers is either nonexistent or in a very early conceptual stage. The Maine Dept. of Environmental Protection only regulates the ground water impacts of large developments. Maine uses the common law concept of "absolute ownership" in dealing with ground water, which essentially gives any land owner the right to remove as much ground water from under his property as he wishes, regardless of the effects on adjacent landowners. The State Subdivision Statute gives the City the right to control ground water impacts in developments covered by the statute, but no guidance is given to Planning Boards in making the determination as to whether a development "will not, along or in conjunction with existing activities, adversely affect the quality or quantity of ground water" (30 MRSA Subsection 3M).

We recommend the following two goals for the Portland islands ground water management plan:

I. PRESERVE QUANTITY--Preserve the recharge rate to the island aquifers to the extent practical such that ground water tables are not significantly lowered and saltwater intrusion does not occur to either existing or future well sites.

II. PRESERVE QUALITY--Protect ground water quality so that it will meet the State of Maine Primary Drinking Water Standards. Where the quality is presently inferior to those Standards, the goal is to restore the ground water to a quality equal to or better than the Safe Drinking Water Standards.

It is important to note that these goals are in line with both State and Federal policy with respect to ground water management.

Under each goal, we have described a series of objectives that describe how each goal should be met. For each of these objectives, we suggested an implementation plan. This implementation plan may not include all possible ways to meet the objectives, but it should give the City a start in the right direction.

Some highlights of the objectives are given below.

I. PRESERVE QUANTITY

Minimize loss of recharge and augment, if possible. This must largely be accomplished through control of new development.

Reduce excessive and progressive lowering of the ground water table. This will be accomplished through zoning densities and development impact review under site plan review. We recommend that no development be allowed to create a ground water drawdown of over 10' beyond the limits of the property on which the development is located.

Do not exceed the safe yield of the aquifers. The recharge to the bedrock aquifer is limited--it will supply only enough water to support an average overall island density of about 1 dwelling unit per acre.

The City's existing zoning system generally accomplishes this density balance except for the grandfathered lot size provisions, densities for the island business zone, and the IR-3 zone (with projects lacking public water). Consideration should be given to adjust these densities in light of a one-dwelling-per-acre goal.

Develop a long-term monitoring program that will continue to collect well data and will monitor long-term trends in ground water elevations. A monitoring program is essential to the success of any management program. We suggest that well data now be required as part of the building permit application. Further, we recommend that the Dept. of Parks and Public Works take at least quarterly water level readings in wells at strategic places around the islands. Some monitoring wells will have to be installed as part of this program.

Provide education to island residents and island visitors concerning the need to conserve water, reduce demand, and preserve and enhance recharge. We envision that a pamphlet would be produced for wide distribution to the island property owners.

II. PRESERVE QUALITY

Prevent ground water degradation to the extent possible by setting appropriate zoning policy that will not result in ground water contamination, and by strictly controlling the impacts of developments through subdivision and site plan reviews. In addition, we recommend that periodic inspection of subsurface sewage disposal systems take place to look for malfunctions. Furthermore, we recommend that the City pass an ordinance requiring that whenever a dwelling or business changes ownership that if the building disposes of sewage through a subsurface system, that a Licensed Site Evaluator be retained to inspect the system and if it is found to be malfunctioning, then the new owner will not be allowed to occupy the building until the system is upgraded according to the Plumbing Code. Eventually, existing substandard subsurface sewage disposal systems should be replaced with modern systems designed to conform with the Plumbing Code.

An important, but potentially controversial, policy concept that we recommend is that all the islands should be treated as if they will someday have to be self-sufficient in terms of both water supply and sewage disposal capability. Therefore, we recommend that Peaks Island and the Diamond Islands be developed only with types and densities of uses that could theoretically be supported by water supplies that could be developed on the islands and that densities also be limited to allowable densities under the assumption that subsurface sewage disposal might be necessary. We recommend discouraging "overboard discharges", even if treated, not only because of potential impacts on marine life, but also because water taken from the ground is not returned to the ground. When overboard sewage discharges are permitted, we recommend that the minimum lot size be increased by 50%.

Zoning policy should be set such that if an entire island is developed to its maximum permitted density, that ground water quality will still meet Safe Drinking Water Standards.

Control the effects of developments such that any discharge to ground waters (including "non-point source" effects) will not result in ground water quality leaving the site's property exceeding one-half of the difference between the quality of the ground water entering the property and the Safe Drinking Water Limits for the applicable physical, chemical, and biological standards. This will insure that no one developer uses all of the ground water's capability to treat and dilute contaminants, and it also allows room for error in measuring background quality and in predicting the ground water impact.

Control the storage and disposal of materials that can affect ground water quality by generally restricting them to bedrock aquifer "discharge areas" or by requiring extra precautions.

Develop an emergency response plan for reacting to accidental chemical or petroleum spills by training key island residents and giving them the equipment and mainland support necessary to react properly.

Control non-point sources of contamination such as resource mining, petroleum storage tanks, road de-icing chemicals, agricultural practices, and abandoned wells. We make a number of recommendations for dealing with each of these potential contaminant sources, including a suggestion that the City periodically inspect all petroleum tanks on the islands.

Develop a remedial action plan for improving ground water quality where it is presently contaminated. We have documented that certain areas of Long Island have ground water tainted by subsurface sewage disposal systems. Some of the systems that are causing the problems may be antiquated and malfunctioning. There is money available through the DEP to solve localized sewage disposal problems. Furthermore, the City may have to establish a low interest loan program to assist island property owners in upgrading their systems, which is an expensive process on the islands.

Develop a long-term ground water quality monitoring plan. As with the "PRESERVE QUANTITY" monitoring objective, it will be important to monitor ground water quality trends over the long-term to measure progress on the plan.

Develop a public education plan. We envision that information on how the property owner can affect his ground water quality will be part of the suggested brochure we discussed under the "PRESERVE QUANTITY" goal.

SUMMARY

There is a modest ground water resource available, primarily in the bedrock aquifers on the Portland islands, that will supply sufficient water to support an overall density of about 1 dwelling unit per acre. The water quality is affected by naturally-occurring iron and manganese and by localized problems associated with subsurface sewage disposal systems. A ground water management plan has been recommended which, if implemented, should correct some of the current problems, and preserve sufficient ground water of drinking water quality to serve future generations. Additional ground water data are necessary, particularly on Peaks and the Diamond Islands.

Respectfully submitted,

ROBERT G. GERBER, INC.

STATE OF MAINE ROBERT GRAHAM GERBER 3165 REGISTERED PROFESSIONAL ENGINEER

Robert G. Gerber

STATE OF MAINE ROBERT GRAHAM GERBER 110 CERTIFIED GEOLOGIST

Robert G. Gerber, P.E.
& Certified Geologist

Enc: 35 copies of final report

# CITY OF PORTLAND
# ISLAND GROUND WATER MANAGEMENT STUDY

To

Department of Planning & Urban Development
City of Portland, Maine

Financial assistance for preparation of this document was provided by a grant from MAINE'S COASTAL PROGRAM through funding provided by U. S. Department of Commerce Office of Ocean and Coastal Resource Management, under the Coastal Zone Management Act of 1972, as amended.

By

Robert G. Gerber, Inc.
Consulting Civil Engineers and Geologists
17 West Street
Freeport, Maine 04032

August 1986

TABLE OF CONTENTS

TABLES



FIGURES

APPENDICES

CITY OF PORTLAND
ISLANDS GROUND WATER MANAGEMENT STUDY
BACKGROUND RESEARCH AND DATA COLLECTION

# 1.0 INTRODUCTION

## 1.1 PURPOSE

Due to their character and geographic setting, the Portland islands are subject to significant development pressures which have the potential to impact adversely the quantity and quality of ground water. The purpose of this study is to provide a ground water management plan which will encourage the wise use of the ground water resources of the islands while permitting a level of development consistent with the limitations of the resource. The study has the following objectives:

a) assemble as much data as possible on the island ground water resources;

b) undertake reconnaissance-level field investigations of the hydrogeology and develop computerized simulation models to describe the ground water flow on the islands;

c) locate known and potential sources of ground water contamination on the islands;

d) propose ground water management goals and objectives and recommend ways to implement them.

This study was sponsored by the City of Portland Department of Planning and Urban Development. Financial assistance for the preparation of this document was provided by a grant from MAINE'S COASTAL PROGRAM through funding by U. S. Department of Commerce Office of Ocean and Coastal Resource Management, under the Coastal Zone Management Act of 1972, as amended. Matching funds were provided by the City of Portland. The study was performed by Consultant Robert G. Gerber, Inc., of Freeport, Maine.

## 1.2 ORGANIZATION OF THE REPORT

The report is divided into 3 major sections. The first section presents and discusses the background hydrogeologic data collected for the study. Topics discussed in this section include the bedrock and surficial geology of the islands, and water supply and water quality data for the island homes not serviced by the Portland Water District. The second section of the report evaluates the hydrogeology of the islands utilizing a widely-used and well-documented computerized ground water flow and solute transport simulation model. The third and final section of the report proposes a ground water management plan to protect the quantity and quality of the islands' ground water and recommends ways to implement this plan.

Upon completion of each of the 3 major sections, we submitted an interim report to the staff of the City of Portland Division of Planning and Urban Development for their review and comments. In addition, meetings were held between representatives of Robert G. Gerber, Inc., and representatives of the City of Portland Division of Planning and Urban Development and the Department of Public Works to discuss each section of the report and to solicit additional comments regarding the organization and content of the report.

There are many tables, figures, and appendices that summarize pertinent findings of the study. These should be examined closely whenever they are referred to in the text. For the person with no prior knowledge of ground water, we have provided an elementary introduction in the Executive Summary. In addition, we have provided a glossary of terms and primer on ground water hydraulics in the appendices of this report.

## 1.3 METHODS

This study was conducted from January through June 1986 by Robert G. Gerber, Inc. (RGGI), Consulting Geologists and Civil Engineers, who were awarded the work after a competitive bidding process. Almost all of the members of the RGGI staff were involved at one time or other in the work. Robert G. Gerber, Registered Professional Engineer (#3165) and Certified Geologist (#110), served as the Project Manager and was heavily involved in the data interpretation, computer modeling, development of ground water management recommendations, and report writing. Steven R. Pinette, RGGI Staff Geologist, assisted in project management, conducted reconnaissance bedrock field mapping on the islands, reduced and interpreted bedrock fracture data, assisted with data compilation and evaluation, did much of the computer modeling, and wrote portions of the technical report. William R. Holland, RGGI Senior Geologist, performed the photolineament analysis, assisted with the drafting of the figures dealing with the surficial geology of the islands, and assisted with the ground water modeling. James E. Hillier, RGGI Staff Geologist, assisted with the drafting and graphics preparation, and conducted a reconnaissance soil survey on Cliff Island. Jerry K. Rawcliffe, RGGI Staff Geologist, assisted with the drafting and conducted a reconnaissance soil survey on Peaks Island. Susan Tolman did the majority of the drafting for the project. Neill and Gunter, Inc., of South Portland, Maine did the photographic reduction of the full-scale map figures. J.H. French and Son, of Brunswick, Maine printed the photo-reduced figures. McFarland Associates of North Windham, Maine performed water quality analyses for 5 well samples taken from Cliff Island.

## 1.4 ISLAND GROUND WATER OCCURRENCE

The Portland Islands derive their ground water only from the precipitation that falls on the islands. No ground water comes from the mainland. There are two different types of ground water reservoirs (called "aquifers") on the islands: soil and bedrock. About 30-40% of the soil aquifer volume contains ground water. Only about 0.1% to 1% of the bedrock aquifer volume contains ground water. Aquifer "recharge" areas generally occur on the higher parts of the islands. Except in areas where there is no soil, all precipitation must first pass through soil before reaching the bedrock. The percentage of precipitation that enters the soil differs with soil type. Sands and gravels accept 50-60% of precipitation (the rest is lost to evaporation and plant use); but clays accept only 5% of precipitation (most of the rest runs off or is lost to the atmosphere). Ground water generally moves downhill under the force of gravity and discharges to a local stream or wetland, or to the ocean near the shoreline.

A unique aspect of the island ground water is the dynamic equilibrium established with the adjacent sea water. Fresh ground water, because it is less dense, "floats" as a lens on the salt water beneath. The depth to the salt water is approximately equal to 40 times the height of the ground water level in a well ( the "potentiometric surface", or simply, the "water table") above Mean Sea Level. Anything that lowers the water table will allow the salt water to rise under the island.

## 2.0 BEDROCK GEOLOGY

### 2.1 INTRODUCTION

The major topographic elements of the Portland Islands are controlled by the underlying bedrock structure, since the soil cover is thin in all but a few places. Since 79% of the islands' private supplies are drilled wells in ledge or "bedrock", it is important to understand how ground water moves in the bedrock. A study of the bedrock geology is essential in this regard.

Crystalline bedrock is essentially almost impermeable, prohibiting the passage of enough ground water to develop a successful household well. It is the "fracture porosity" that renders the bedrock first capable of transmitting and releasing ground water for human use; and second, receptive to recharge by downward percolating rainfall and snow meltwater. A representative bedrock fracture porosity in the unweathered crystalline Maine rock is 0.1%. In other words, one-tenth of one percent of the bedrock mass consists of openings through which ground water can migrate.

The greatest volume of bedrock ground water travels along the numerous small fracture openings along laminations oriented parallel to the grain of the thinly-layered metamorphic rocks on the islands. The bedrock is also broken from place to place by "joints", planes of tensional fracture in the bedrock along which no lateral movement has occurred. Joints commonly occur as sharp, steeply-inclined cracks cutting across the laminated grain of the bedrock. Spacing between these cross-cutting joints is generally on the order of 1' to 5'. Also cross-cutting the laminations are "dikes", composed of fine- to medium-grained mafic (dark-colored igneous) rock, which occur as 1' to 10+' wide tabular bodies oriented parallel to some of the steeply-dipping joints. Dikes are not abundant on the islands. They generally are moderately to intensely jointed and may be significantly more permeable than the adjacent rock type. Consequently, they may be zones of higher than normal well yield. "Faults" are fractures along which the rock on one side of the fracture has moved relative to the rock on the other side of the fracture. Wells drilled in fault zones are generally associated with above-average localized well yield. Dikes and faults are of local importance on the islands. Both may serve as conduits for contaminant migration and sea water intrusion in the bedrock aquifer.

In areas of bedrock masses where the laminations in the schist or gneiss are tightly bonded and few cross-cutting joint fractures occur, little ground water will be available for the development of a successful bedrock well. Conversely, in areas or rock types where the rock parts readily along laminations, is closely broken by cross-cutting joints, is intruded by intensely jointed mafic dikes, and/or is situated in a fault zone the high fracture porosity will permit the development of numerous high-yield bedrock wells. In these areas, porosity may be several percent.

Since joint fractures commonly contain somewhat wider openings between their walls than the openings found along the narrow lamination partings in the layered rocks, bedrock wells which encounter joints may yield more ground water than those which encounter only lamination openings. However, because the non-fractured interval between joints is normally much greater than that between lamination partings, several times as much ground water in the bedrock aquifer as a whole moves northerly or southerly along the lamination partings than moves east or west along the cross-cutting joint fractures. Richard (1976) estimated that there are 30 to 40 times more lamination or foliation partings than joints per volume of rock at High Head in Harpswell located to the northeast of the study area. Modeling by Gerber and Rand (1980) with field verification in the Cape Elizabeth Formation in Wiscasset indicated that aquifer transmissivity was 5 to 10 times greater along the direction of the rock foliation than perpendicular to foliation in a rock that was not heavily jointed.

Our knowledge of the bedrock geology of the Portland Islands was obtained from our reconnaissance mapping on the individual islands used in conjunction with the bedrock geologic map of the Casco Bay area by Professor Arthur M. Hussey II of Bowdoin College. Professor Hussey (Hussey, 1981) identified ten (10) different formations of metamorphic rocks and one (1) type of igneous rock on the Islands (refer to bedrock geologic maps presented as Figures 1 through 4). The metamorphic rocks are defined predominantly as gneiss, phyllites, and schists composed of sequences of layered or laminated rock types created by the transformation and recrystallization of originally bedded deposits of mud, sand, and volcanic materials. The igneous rock consists of tabular-shaped intrusive segments (1'-20' thick in shortest dimension) of non-layered volcanic diabase (mafic dike).

Most of the bedrock on the Portland Islands is classed generally as gneiss, schist, or phyllite. "Gneiss" is a laminated rock type made of bands or lenses of fairly massive, non-foliated granular minerals which alternate with bands of strongly foliated, flaky minerals. "Schist", is a strongly foliated, laminated rock type which splits readily into thin flakes or sheets due to the well-developed parallelism and relatively high content of platy minerals (such as mica). "Phyllite" is a fine-grained schist. "Limestone" is present as two (2) relatively thin bands on Great Diamond Island.

As reflected by the strong north-northeast fabric of the islands in Casco Bay, the trend of the bedrock layering or banding also is oriented northeasterly. Due to ancient mountain-building forces, the bedrock layers have been tilted to almost vertical attitudes, so that laminations in the schists and banding in the gneiss are almost upright, extending from the surface nearly straight down to great depths. Much of the rain and snow meltwater that percolates downward into cracks and fractures at the surface of the layered bedrock then migrates as ground water in a southerly or northerly direction along passageways created where the rock has split along its grains parallel to laminations or banding. The significance of the foliated, laminated, or banded character of the bedrock, therefore, is that the multitude of narrow partings along the bedrock layers contain and transport ground water which can be tapped and pumped from wells drilled into the bedrock. The bedrock mass which contains this recoverable ground water is referred to as the "bedrock aquifer".

## 2.2 BEDROCK TYPES

As shown on the attached bedrock geologic maps of the Portland Islands (Figures 1-4), the bedrock on the Islands is divisible into eleven (11) geologic units, including one igneous rock type and ten (10) metamorphic rock types. Of these 11 units, 10 are enumerated for this study as bedrock aquifers; the tabular diabase dikes present on most of the five (5) islands are not regarded here as aquifers because of their geographically very small and localized areas. The bedrock units present in the study area are differentiated by mineralogy as described below (modified after Hussey, 1981). The designation "GUC" in parentheses after each unit name refers to the "Geologic Unit Code" that we have assigned for purposes of differentiating the bedrock units in terms of their separate potential as aquifers.

<u>Tabular Diabase Dikes (GUC 1)</u> -- Dark brown to greenish black weathering equigranular and porphyritic mafic intrusive.

<u>Jewell Formation (GUC 2)</u> -- Light and dark gray, sulfidic and non-sulfidic muscovite-biotite-chlorite-garnet phyllite locally with staurolite, andalusite, and chloritoid. Includes greenish chlorite phyllite.

Spurwink Limestone (GUC 3) -- Thin, ribbony-bedded medium gray metalimestone with thin quartz-biotite-chlorite phyllite interbeds.

Scarboro Formation (GUC 4) -- Light and dark gray sulfidic and non-sulfidic muscovite-biotite-chlorite phyllite interbeds.

Scarboro Formation (GUC 5) -- Thin ribbon-bedded metalimestone, essentially like Spurwink Limestone.

Diamond Island Formation (GUC 6) -- Black rusty-weathering quartz-muscovite-graphite phyllite.

Spring Point Formation (GUC 7) -- Mostly medium greenish gray chlorite-actinolite-plagioclase-schist and phyllite, locally with agglomeratic fragments of light gray metafelsite tuff and greenish gray chlorite phyllite.

Spring Point Formation (GUC 8) -- Minor well bedded light to medium gray quartzo-feldspathic biotite-hornblende granofels.

Cape Elizabeth Formation (GUC 9) -- Mostly medium gray thin, poorly to moderately well bedded quartz-plagioclase-biotite-muscovite-garnet phyllite, with lesser interbedded muscovite-biotite-garnet schist.

Cushing Formation (GUC 10) -- Light to medium gray quartz-plagioclase-biotite-muscovite gneiss locally with well preserved relict pyroclastic structures including agglomerate and quartz and/or plagioclase crystal tuff. Locally moderately well, thin- to medium-bedded.

Cushing Formation (GUC 11) -- Very rusty weathering lenses of quartz-plagioclase-muscovite gneiss and schist.

The differences in bedrock types which are used to discriminate among the several metamorphic rock formations relate predominantly to the mixture of minerals contained in the rock. The Jewell and Scarboro Formations are thinly-laminated or flaky schists, containing a relatively high content of mica minerals. The Diamond Island Formation is also a micaceous schist that is distinguished by its black, sooty color and its content of iron sulfide and graphite. The Cape Elizabeth Formation, with relatively less mica content and more granular quartz, feldspar, and quartzite beds than these three other schist formations, is a relatively more thick-bedded, less flaky schist than the others. The predominant minerals in the two gneiss formations, Spring Point and Cushing, are quartz and plagioclase feldspar with relatively minor biotite mica. The Spring Point gneiss ranges from thin- to thick-bedded. The Spring Point and Cushing Formations also contain beds or belts of thin-bedded or gneissic amphibolite, a layered rock made principally of the mineral hornblende, a dark-green to black silicate mineral having a relatively high iron content.

As shown on Figure 1, most of the Peaks Island bedrock is composed of the non-sulfidic quartz-feldspar gneiss of the Cushing Formation. The sulfidic, rusty weathering schist and gneiss of the Cushing Formation occurs along relatively thin belts trending north-northeasterly along the interior sections of the island. The Cape Elizabeth Formation occurs along the northwestern shoreline of the island. Similarly, most of the bedrock on Long and Cliff Islands is composed of the non-sulfidic quartz-feldspar gneiss of the Cushing Formation (see Figures 2 and 3, respectively). On Long Island the sulfidic, rusty weathering schist of the Cushing Formation occurs along two relatively thin northeasterly trending belts near the northwestern and southeastern shores of the island. The Cape Elizabeth Formation occurs on the northern and southwestern ends of the island. On Cliff Island, the Cape Elizabeth Formation occurs along the southeastern shore of the island where it appears to be in-folded with the Cushing Formation. The Spring Point and Scarboro Formations occur on the peninsula on the southeastern shore of Cliff Island. On Great Diamond Island (Figure 4) the majority of the bedrock is composed of the Spring Point and the Jewell Formations which occupy the southeastern and northwestern portions of the island, respectively. The Spurwink Limestone, the Scarboro Formation (limestone and phyllite members), and the Diamond Island Formation occur as relatively thin northeasterly trending units between these two units. The majority of Little Diamond Island is composed of the Spring Point Formation. A small amount of the Diamond Island Formation occurs along the southeastern shore of the island. Several formations shown on Figures 1-4 contain within them belts of rock which are characteristically rusty on exposed surfaces, due to the oxidation of iron sulfide minerals contained in them.

## 2.3 BEDROCK FRACTURES

The three types of fractures which are of consequence in evaluating the bedrock ground water regimes on the Portland Islands are partings along the bedding or lamination planes in the schists and gneiss, joints in all rock types, and faults in all rock types. Mafic dikes are very sparsely distributed and appear to have minimal impact on both the localized or the regional ground water regime. While the greatest volume of bedrock ground water moves through the individual islands along steeply-inclined, north northeast-trending lamination partings, joints and faults may locally yield significant volumes to drilled wells. Most of the joint fractures on the islands are very steeply-inclined cracks which cut almost directly across the north-northeast trend of the bedrock layering. They are commonly spaced on the order of less than 1' to 5'. Occasionally, however, joint zones are found in which numerous joints split the bedrock at closely-spaced intervals. Because of their high fracture porosity, joint zones may not only constitute important high-yield bedrock aquifers but also offer ready avenues for human or salt-water contamination.

Fault fractures occur in the bedrock at several locations on the islands. Most are very minor cracks of short length along which the bedrock displacement is on the scale of inches. The faults mapped by Hussey (1981) and those mapped during our field reconnaissance are shown on Figures 1-4. Major faults can be important bedrock aquifers if the structural deformation caused by the fault movement was sufficiently intense to create a zone of bedrock crushing and fracturing in and adjacent to the plane of fault slippage, resulting in a zone of high fracture porosity.

### 2.4 TOPOGRAPHIC LINEAMENTS

Topographic lineaments are straight or gently-curved depressions or topographic "breaks" in the ground surface that may reflect trends or zones of closely-spaced fracturing in the underlying bedrock. Such zones may have sufficiently high fracture porosity to constitute important bedrock aquifers. Our viewing of the Portland Islands in stereoscopic-pair aerial photos has revealed numerous photolineaments, as shown on Figures 1-4, which may reflect zones in which the bedrock is relatively closely fractured. A few of these photolineaments are associated with high yield bedrock wells (discussed in Section 5.3.2.6). The paucity of water-well records for the areas corresponding to the majority of the lineaments precludes our judging their potential as aquifers. However, there has been much success in Maine in locating high yield bedrock wells at the intersection of 2 or more photolineaments.

## 3.0 SURFICIAL GEOLOGY

The surficial deposits of the Portland Islands are not so important as the bedrock as aquifers in terms of their potential to provide water for domestic use. Slightly less than 21% of the water supplies surveyed by questionnaire on Long and Cliff Islands are obtained from dug wells and springs in soil. This contrasts with another Maine coastal town--Verona--where a study similar to this one found that 50% of the water supplies were from dug wells and springs. One of the obvious reasons for the lower percentage of dug wells over drilled wells on the Portland Islands is that there is a relatively thin soil covering over most of the islands. The conditions that usually should be present to provide a reliable dug well include a saturated soil depth of at least 5 to 10 feet, and a recharge area of 10 or more acres. These criteria are not met in many areas on the islands.

The soil cover material is very important, however, in determining the rate of recharge to the bedrock aquifer. Unless the bedrock is exposed, all precipitation must pass through soil to reach and recharge bedrock aquifers. The texture, compactness, and thickness of the soil directly determine the rate of recharge to or discharge from a bedrock aquifer.

In the following sections, the term "soil" is used rather loosely to include all surficial material. Pedologists normally restrict the term "soil" to only the top several feet of the surficial material that has been weathered and has developed specific soil "horizons".

## 3.1 PREVIOUS WORK

Leavitt and Perkins (1934) were the first to investigate the surficial deposits of Maine in any systematic manner. The next useful soil mapping was that done by the Soil Conservation Service which published their soil survey in 1974. Although these pedological maps deal only with the upper several feet of the surficial units, we have found them useful in delineating areas of thin soil over bedrock, and areas of glaciomarine fine sands and clay-silt. More recently Dr. Geoffrey Smith of the Maine Geological Survey published a surficial geologic map (1977) which includes the Portland Islands. Smith's map focuses more on the geologic character and glacial origins of the deposits than does the Soil Conservation Survey map.

For the purposes of this study we are interested primarily in differentiating the surficial units on the basis of horizontal and vertical hydraulic conductivities as well as on the basis of texture. Consequently, we have differentiated the deposits according to their average hydraulic conductivities as shown in Figures 5-8. We relied on the published soils and surficial geology maps for our information on the surficial deposits of the islands. We conducted aerial photo interpretation and limited field checking to supplement these data. Figures 5-8 divide the surficial units present on the Portland Islands into seven (7) major types according to origin, hydraulic conductivity, and thickness.

All but one of the surficial deposits found on the Portland Islands were formed during either the advance or retreat of the last major continental glaciation of Maine. An ice cap formed over northeastern North America--the Laurentide Advance of the Wisconsinan Stage of the Pleistocene Epoch--and expanded within Maine about 22,000 years ago. By 17,000 years ago, the ice sheet had reached its maximum extent (Georges Banks) and by 13,000 years ago, the ice had receded to the Maine coast. The glacier had depressed the surface of the earth and the earth was slow to rebound during glacial melting with the result that fine sand, silt and clay were deposited on the present land when it was under sea water which was temporarily as much as 240 feet above present sea level. Eventually the land rebounded so that Casco Bay had risen above present sea level by about 10,000 years ago. During the process of sea level lowering, small beaches developed at various levels on what are now upland hills and terraces. Wave action re-worked materials such as glacial till and left local sand and gravel deposits over the surface of bedrock or other underlying surficial units.

## 3.2 SURFICIAL DEPOSITS AND THEIR HYDRAULIC CHARACTERISTICS

Soil deposits are differentiated into Geologic Unit Codes (GUC) on the basis of their average ability to accept precipitation infiltration. This relates to the ability of the soils to dilute contaminants and also to the potential to recharge the underlying bedrock. Table 2 summarizes the soil types and their ability to accept precipitation recharge. Figures 5 through 8 show the distribution of soils on the island and also summarize the precipitation infiltration potential.

### 3.2.1 Thick Silty Glacial Till (GUC 12)

Glacial till was deposited directly during the passage of the major ice advance or a smaller ice lobe advance during the period 22,000 to 13,000 years ago. As ice moved along the base of the glacier, it gouged out bedrock, ground it into material of different sizes, and mixed many materials together. These rock fragments--cobbles, gravel, sand, silt, and clay--were embedded under or within the ice and were plastered onto the land at various places, and then overridden and compacted by the weight of as much as several thousand feet of ice or let down to the land surface when the glacier melted.

The percentage of silt and clay in a soil sample is one of the most important factors controlling permeability. Another major controlling factor is the density of the material. An additional very important factor is the presence of joints or fissure planes. Although there are no test data available on the tills occurring on the Portland Islands, we can infer their average properties by correlation to similar nearby terrains where testing has been performed. We estimate that the hydraulic conductivity of the thick silty till on the islands is between $10^{-5}$ to $10^{-7}$ cm/sec; however, a fissured till may have a bulk permeability that is 10 to 100 times greater. We estimate the average effective porosity to be about 25 to 35%. The average recharge rate for the thick glacial till is approximately 15% of the average annual precipitation, or 0.23 gallons per minute (gpm) per acre.

### 3.2.2 Thin Sandy Glacial Till (GUC 13) and Exposed Bedrock and Thin Soils (GUC 18)

Much of the interior portions of the islands are covered by a layer of till less than 5' thick overlying bedrock. Most of the shoreline areas around the islands are exposed bedrock or are covered by a thin (less than 2') covering of soil. Most of this thin soil covering is a variety of sandy glacial till. Some of this thin soil can be classified as "melt-out" or "ablation" till, and some is till that has been washed and reworked by wave action.

Ablation and melt-out tills formed when the debris frozen in or carried on top of a glacier was let down to the land surface at the time when the glacier melted. Since meltwater was usually flowing from the glacier at this time, some water sorting and washing out of silt and clay particles often occurred. Ablation tills are usually only several feet thick, but where they are thicker they have often been mined for gravel. Wave-reworked till may look very similar to ablation till and for our purposes can be considered to behave in a similar manner with respect to ground water.

These thin soil areas accept precipitation recharge and conduct ground water more readily than thick tills. The soil matrix typically contains 10 to 30% silt and clay. Permeability ranges from $10^{-3}$ to $10^{-5}$ cm/sec. Effective porosity is 30 to 35%. Although the soil is sandy, it is thin, and shallow bedrock encourages rapid precipitation runoff and inhibits ground water storage. For till less than 5' thick, we estimate that the average recharge is approximately 25%, or 0.57 gpm per acre. For areas where the till is less than 2' thick, about 15% of average annual precipitation could potentially infiltrate into bedrock through the thin soil. This translates to 0.34 gpm per acre as an average recharge rate for the Portland Islands.

Although the thin till is usually too thin to allow the development of a dug well, deeper zones of soil may occur locally in small, narrow troughs in the bedrock surface where successful wells can be dug. These localized soil pockets are too small to be individually identified at the scale of our study.

### 3.2.3 Glaciomarine Clay-silt (GUC 14)

During the time when the last glacier had retreated north of the Casco Bay region but when the sea level was still elevated relative to the present day level, the silt and clay that was carried in the glacial meltwaters was settling to the ocean floor in much the same fashion that muds accumulate in the bays today. This particular geologic unit is called the "Presumpscot Formation". Glaciomarine clay-silts are thin where they occur, except along portions of the northwestern shoreline on Peaks Island.

The clay-silts have 80 to 100% silt and clay content. Where the soil lies below the permanent water table, it is a sticky soft blue-gray material referred to as "blue marine clay". Where it lies above the permanent water table, it is a stiff, fissured olive-colored soil that becomes brick-hard during droughts. Fine sand lenses may occur within this unit. Below the permanent water table, clay-silts, unlike some tills, will usually not be fissured. Therefore, the bulk permeability of the clay-silts will usually be ten times less than that of the lowest permeability till. Although the porosity of the clay-silts is high--about 50%--its specific yield is only about 3%.

We estimate that 5% of average annual precipitation will infiltrate through the thick clay-silt deposits, which represents about 0.11 gpm per acre. Because of their low permeability and specific yield, clay-silt deposits usually make very marginal sites for dug wells, unless sand lenses are present.

The juxtaposition of silty glaciomarine deposits over till is often associated with springs and seeps. The top of till surface was often water-worked and left somewhat sandy before it became blanketed by the glaciomarine sediments. In the lower elevations, such as along streams, ground water flowing along the interface of the till and glaciomarine deposits will be under pressure (since recharge is occurring higher on a hill and the silty clay acts to confine the water flow beneath it). Where the glaciomarine deposits are thin, such as along eroded streambeds, the ground water flow will break through to form a spring. When sufficient areas of recharge can be found, these springs will flow year-round.

### 3.2.4 Glaciofluvial, Glaciomarine, and Recent Marine Sand and Gravel (GUC 15)

Sand and gravel deposits comprise a large portion of the surficial deposits on all of the islands studied, except for Cliff Island where only a relatively small area is covered by sand and gravel. These deposits readily conduct water and form excellent aquifers for dug wells where sufficient recharge area is present and salt-water intrusion is not a problem. We estimate that gravel and medium to coarse sand can accept and transmit 50% of average annual precipitation, or 1.14 gpm per acre.

### 3.2.5 Glaciomarine Silt and Fine Sand (GUC 16)

Only two (2) relatively small areas on Peaks Island are covered by what is mapped as glaciomarine silt and fine sand. Thus, this deposit has little importance as a surficial aquifer in this study area. We estimate that these deposits can accept and transmit 30% of the average annual precipitation, or 0.68 gpm per acre.

### 3.2.6 Swamp Deposits (GUC 17)

Swamp deposits are very localized and of only limited areal extent on Peaks, Long, and Cliff Islands. No swamp deposits are mapped on Great and Little Diamond Islands. Swamp deposits are composed largely of peat mixed with variable amounts of clay, silt, and sand. These deposits are rather permeable near the surface but decrease in permeability with depth. The rate of recharge to or discharge from underlying geologic units is not limited by the permeability of the swamp deposits. Most swamp deposits will either overlie low permeability glacial till, or glaciomarine clay-silt.

Swamp deposits will have a deleterious effect on local ground water quality. Chemical and biological reactions in bogs produce a water that is high in color, organic acids, iron, manganese and hydrogen sulfide.

## 3.3 THICKNESS OF SOIL

One of the items of interest that can be obtained from drilling records is the depth to bedrock at the drilling site. This information enables the geologist to contour the soil thickness and the surface of the bedrock. When there is a sufficient number of data points available in an area to do this contouring, a number of features that are important to hydrogeology can be identified, such as the presence of deep bedrock troughs that may contain sand and gravel aquifers and the thickness of the soil which will influence the susceptibility of the bedrock aquifer to contamination by ground surface activities.

Figures 9-12 show the inferred soil thickness contours for the islands in this study. On Long and Cliff Islands the well survey data provide an indication of the soil thickness (estimated as equal to the length of well casing). In addition, we used limited field checking and interpretation based on soil types to augment these data. On Peaks, Great Diamond, and Little Diamond Islands our soil thickness interpretation is based primarily on surficial geologic maps, limited soil boring data obtained from consultant reports, and on limited field checking.

## 4.0 GROUND WATER AND WELL SUPPLIES

Our survey of the Portland Islands water supplies consisted of distributing well survey questionnaires to the property owners of record on Long and Cliff Islands. Peaks, Great Diamond, and Little Diamond Islands utilize the Portland Water District public water supply and, therefore, only very limited well data would be available from these islands. The data from our well survey are summarized in Appendix A. We submitted 659 well questionnaires, one for each tax lot, to the property owners. No distinction was made with regard to developed and undeveloped parcels when distributing the questionnaires. There were a total of 84 respondents to our questionnaire--approximately 13% of the total number of questionnaires distributed--representing 56 respondents on Long Island and 28 respondents on Cliff Island. The Long Island questionnaires were augmented with identical questionnaires used during a study of the Long Island landfill impact.

The water source locations from the survey are shown in Figures 13 and 14. Of the wells and springs for which we did obtain information, approximately 79% were drilled wells (artesian wells) into bedrock. The remaining water supplies were mostly dug wells. Figures A-1 and A-2 show the statistical distribution of well types on Long and Cliff Islands, respectively.

Although the information obtained from lay people in a survey such as this is obviously not so accurate as that which would be obtained from trained geologists, the information is nevertheless useful for many types of analysis. When handling this much data, a few errors will occur, such as in plotting of well locations, but the overall conclusions will not be affected.

### 4.1 ANALYSIS OF BEDROCK WELL DATA

#### 4.1.1 Introduction

Appendix A summarizes the numerical data on well reports collected for this study for the wells on Long and Cliff Islands, categorized in terms of the geologic formations in which the wells obtain water. In order to facilitate data presentation and analysis, each geologic formation has been assigned an identification code number referred to as the Geologic Unit Code (GUC) (1-11 for bedrock and 12-18 for soils; refer to Figures 1-4 and 5-8, respectively). The information summarized by Appendix A was derived primarily from Water Supply Questionnaires submitted by individual landowners.

### 4.1.2 Bedrock Well Yield

The distribution of the bedrock well yields on Long Island as determined from questionnaire response is shown on Figure A-3. Additional, but overlapping data from Hans Hansen, well driller, are given on Figure A-4.

The distribution of bedrock well yields on Cliff Island as determined from questionnaire response is shown on Figure A-5.

Long Island bedrock wells display yields which are typical for coastal Maine. Cliff Island bedrock well yields are higher than is typical for coastal Maine. Some of the high yields reported on Cliff Island are associated with potential fracture zones which we have identified as photolineaments (see Section 5.3.2.6 for discussion).

### 4.1.3 Bedrock Well Depths

The distribution of bedrock well depths for Long Island is shown on Figure A-6. Additional, but overlapping data from Hans Hansen, well driller, is given on Figure A-7.

The distribution of well depths for Cliff Island is shown on Figure A-8.

The average well depths for both of these islands are shallower than the average for the Maine coast, which is about 175'.

### 4.1.4 Bedrock Wells Differentiated by Geologic Unit Code

On Long and Cliff Islands, the majority of the drilled bedrock wells occur in Geologic Unit Code 10 (quartz-feldspar gneiss belonging to the Cushing Formation). The statistical distribution of bedrock wells according to geologic unit code for Long and Cliff Islands is shown on Figures A-9 and A-10, respectively.

Average bedrock well yields on Long Island are on the order of 50% greater for wells drilled in the Cape Elizabeth Formation (GUC 9) than in the Cushing Formation (GUC 10 and 11). The summary statistics from the well questionnaires for bedrock well yield data presented by Geologic Unit Code are shown below:

| | Yields | | |
|---|---|---|---|
| GUC | 9 | 10 | 11 |
| Mean | 7.56 | 4.98 | 4.80 |
| Standard Deviation | 6.73 | 7.38 | 3.54 |
| Number of Cases | 9 | 26 | 5 |

### 4.1.5 Water Quality

#### 4.1.5.1 Water Quality as derived from the Aquifer

The water quality data obtained for this study were derived from files of water quality tests at the Maine Department of Human Services, from a water quality survey conducted by the residents of Long Island (Figure B-1), and from our own sampling of five (5) domestic wells on Cliff Island. The water quality data obtained from the Long Island residents survey and from our own sampling on Cliff Island are presented in Appendix B. The data from the Maine Department of Human Services are presented in Appendix C. The important water quality parameters to consider in each of these data sources and their respective concentration levels which we believe indicate deteriorated water quality are listed as follows:

| | | |
|---|---|---|
| Nitrate | >1 | mg/L |
| Iron | >0.25 | " |
| Chloride | >50 | " |
| Copper | >0.01 | " |
| Manganese | >0.05 | " |
| Coliforms | >1 colony per plate | |

It is important to note that copper is usually derived from copper plumbing and not from the environment. The maximum contaminant level for copper based on secondary drinking water standards set by the Maine Department of Human Services are 1.0 mg/L. The nitrate-N drinking water limit set by the Maine Department of Human Services, Division of Health Engineering is 10 mg/L but concentrations in contaminated ground water are usually >1 mg/L. Nitrate and coliform concentrations in ground water are generally related to the amount of biological decomposition and subsurface sewage disposal wastes present in the environment. Maximum contaminant levels for manganese and iron in secondary drinking water standards set by the Maine Department of Human Services are 0.05 mg/L, and 0.3 mg/L, respectively. Iron and manganese concentrations are generally related to the decomposition of an iron- and manganese-rich sulfide mineral present in the bedrock. The secondary drinking water standard for chloride is 250 mg/L but chloride concentrations commonly correlate with sodium concentrations in the environment. Chloride concentrations in excess of 50 mg/L generally indicate salt water intrusion, road salt contamination, or sewage contamination, and the associated sodium concentrations will probably exceed the recommended limit of 20 mg/L standard for public drinking water supplies.

For the 104 water quality tests obtained by the Long Island residents, the cases where the concentration levels exceeded our recommended screening level are as follows:

| Parameter | No. of Cases Exceeding | Percent |
|---|---|---|
| Nitrate | 35 | 34 |
| Iron | 16 | 15 |
| Chloride | 3 | 3 |
| Copper | 5 | 14 |
| Manganese | 30 | 28 |
| Coliforms | 51 | 49 |

Please note that some wells may exceed our recommended screening level for more than one parameter.

It is apparent from the above data that a relatively large percentage of wells on Long Island are being impacted by nitrate and coliform. As mentioned previously, since concentrations of these 2 parameters are related mainly to the amount of biological decomposition and subsurface sewage disposal, roughly one-half of the wells surveyed on Long Island appear to be affected by biological wastes of some sort, probably subsurface sewage disposal system effluent. High iron and/or manganese concentrations in some of the wells appears to be related to the bedrock type in which the wells were drilled. Locally, the bedrock on Long Island contains an iron- and manganese-rich sulfide mineral which releases iron, manganese, and sulfide gas upon weathering.

For the 5 water quality samples which we obtained on Cliff Island, the cases where the concentration exceeded our recommended screening concentration re as follows:

| Parameter | No. of Cases Exceeding | Percentage |
|---|---|---|
| Nitrate | 0 | 0 |
| Iron | 3 | 60 |
| Chloride | 0 | 0 |
| Copper | Not Analyzed | --- |
| Manganese | 4 | 80 |
| Coliforms | Not Analyzed | --- |

The iron and/or manganese concentrations in 4 of these wells (1 well tested had an iron and manganese filter) indicate that a water quality problem related to these two elements exists on Cliff Island. According to Mr.

Roger Berle of Cliff Island, many of the Cliff Island residences report tap water with a sulfide odor and/or a bad taste. Our bedrock mapping reconnaissance of the island indicates that the Cape Elizabeth Formation which is in contact with the Cushing Formation along much of the eastern shoreline (refer to Figure 3) contains an iron- and manganese-rich sulfide mineral which, as mentioned previously, releases iron, manganese, and sulfide gas upon weathering. Although the majority of the bedrock wells on the island are drilled in the Cushing Formation at the surface, they are near to the contact with the Cape Elizabeth Formation and at depth they may tap that formation. The complex geometry generated from the deformation of the rocks during several mountain building events may have resulted in changes in bedding dip with depth, i.e., with depth the Cape Elizabeth Formation may have only a moderate west-northwesterly dip beneath the Cushing Formation, whereas, at the surface the contact between the 2 bedrock formations is nearly vertical. If this setting is accurate, wells drilled through the Cushing Formation could intersect the Cape Elizabeth Formation if they are drilled deeply enough. It is instructive to note that the only well with low iron and manganese is located on the northwestern shore farthest away from the Cushing/Cape Elizabeth Formations contact.

For the 96 water quality test records obtained from the Maine Department of Human Services, Division of Health Engineering, the cases where the concentration levels exceeded our recommended screening level are as follows:

| Parameter | Number of Cases Exceeding | Percent |
|---|---|---|
| Nitrate | 12 | 13 |
| Iron | 14 | 15 |
| Chloride | 3 | 4 |
| Copper | 5 | 5 |
| Manganese | 15 | 16 |
| Coliforms | 34 | 35 |

In addition, on Long Island 4 cases of hydrocarbon and/or gasoline well contamination are reported. These are probably related to leaking petroleum storage tanks.

In summary, salt water intrusion does not appear to be a major problem affecting the ground water quality in the bedrock aquifer on Long and Cliff Islands at present. A number of wells on Long and Cliff Islands have undesirably high concentrations of iron and manganese. These are naturally occurring and they are present in higher concentrations in particular bedrock zones tapped by the individual wells. Between 15% and 30% of the ground water sampled has above-background nitrate and 40%-50% has coliform bacteria, indicating a significant problem with subsurface sewage disposal systems, at least on Long and Cliff Islands.

### 4.1.6 Water Levels in the Bedrock Wells

Water level information for the bedrock wells was obtained from the water supply survey questionnaire for Long and Cliff Islands. The average water level below the ground surface for the bedrock wells is approximately 18'. These water level measurements were not all made during the same month and, therefore, they represent a yearly average, at best. In Maine, water levels in bedrock wells typically range from 0' to more than 20' below ground surface depending on the geology of the aquifer and on the time of year the measurement is made. Seasonal water level fluctuations in excess of 10' have been recorded by the U.S. Geological Survey in some of their bedrock index wells.

## 5.0 GROUND WATER HYDROGEOLOGY

### 5.1 INTRODUCTION

As an aid to the evaluation of the hydrogeology on each of the 5 islands we have utilized a well-established numerical computerized ground water modeling technique to supplement traditional analytical models. Numerical models offer two major benefits to the City which cannot be provided using analytical techniques. First, numerical methods allow much more sophisticated analysis of any aquifer condition than do the use of analytical methods and hand calculations. This is because aquifer properties are allowed to vary in space over a study region, while analytical methods frequently involve many simplifying assumptions and are incapable of handling heterogeneities in an aquifer. The second benefit is that once developed, a model is easily updated as new data become available. In this way, each model becomes a constantly evolving resource management tool which can be used to address issues which were beyond the scope of this project, or site-specific problems that currently do not exist.

As mentioned previously in this report, the soil cover overlying the bedrock on much of these islands is thin and does not constitute a substantial, continuous aquifer. Since most of the ground water supply available on the islands is from an underlying bedrock aquifer, this is the aquifer we chose to simulate for each island within the finite-difference grid on Figures 15-18.

Background data discussed previously were used to construct some of the data sets required as model input. Some of the other parameters required by the model were derived from generally accepted average values found in textbooks; other parameters were estimated based on our experience from other similar studies which we have conducted.

### 5.2 DEVELOPMENT OF THE SIMULATION MODELS

Following the completion of the data collection program, Robert G. Gerber, Inc., completed the data analysis which culminated in the development of ground water simulation models for the bedrock aquifers on each of the 5 islands. Great and Little Diamond Islands were evaluated in the same model due to their close proximity and connection by a sand bar, which is exposed at low tide.

We have used a well-documented, widely-used, finite-difference, 2-dimensional computerized model which couples ground water flow equations with hydrodynamic solute transport equations to simulate the regional ground water flow and localized solute transport in ground water. We developed this model for each island and simulated the steady-state potentiometric (also called "piezometric") elevations and the flow rates at points in the modeled area under a reasonable range of aquifer parameter (e.g., transmissivity) values. The potentiometric or piezometric surface elevation in an aquifer is that elevation to which water would rise in a well that is placed into the aquifer. We developed models that approximately reproduce measured water levels in the bedrock aquifers. An error of 10' between predicted bedrock aquifer potentiometric surface elevations and measured water elevations is acceptable for bedrock aquifers considering the methods of data collection used, the seasonal ground water fluctuations (reported water levels were measured during different months of the year), the inaccuracies inherent in estimating well ground elevations from the enlarged USGS topographic maps, and the sparseness of the data base.

The basic steps in developing the simulation models including model selection, model conceptualization, discretization and parameterization, and model verification, are discussed below.

### 5.2.1 Model Selection

We have used the U.S. Geological Survey solute transport and dispersion model (Konikow and Bredehoeft, 1978) in this study to perform ground water flow and solute transport simulations in the bedrock aquifers underlying each island. This is a widely-used, digital, 2-dimensional computerized model with a block-centered finite-difference grid which couples ground water flow equations with hydrodynamic solute transport equations. The models are composed of rectangular gridded areas, the outlines of which are shown on Figures 15-18.

The Konikow & Bredehoeft model uses the Finite Difference Method (FDM) to solve the ground water flow equations. The Method of Characteristics (MOC) is coupled with the FDM to solve the solute transport equations. In these two methods, the governing partial differential equations are approximated by algebraic equations relating unknown variables at discrete nodes. (The "node" is a point located at the center of each grid block.) The MOC evaluates a partial differential equation of hyperbolic type, by reducing it to an ordinary differential equation which defines a "characteristic" curve for the unique set of conditions specified. This ordinary differential equation is solved by numerical integration. The mathematical theory and development of both the FDM and the MOC are discussed in Huyakorn and Pinder (1983). The specific mathematical development and other aspects of the computer model is given in Konikow and Bredehoeft, (1978).

### 5.2.2 Model Conceptualization

The development of any ground water simulation model requires the selection of the limits of the area to be modeled; a decision regarding how adjacent aquifer interactions should be handled; a decision as to how to simulate ground water recharge and discharge; the determination of how flow is constrained at the limits or other "boundaries" of the model; and a decision regarding how to introduce contaminants into the aquifer in order to evaluate their impact. We evaluated only the "steady-state" condition for this study--i.e., the aquifer behavior under the long-term average recharge conditions. The use of the steady-state case is common involving solute transport problems taking more than one year of simulation. As one can see on Figures 15-18, contaminants would take several years to move through the bedrock aquifer from the high points of the islands to the shore. Transient (i.e., unsteady flow) simulations can be made with the model but it would be necessary to calibrate the model storativity to actual records of water level fluctuations in the aquifer; however, we have no such information at present.

The thick soil is taken into special account by treating it as an "adjacent aquifer". Recharge to the bedrock aquifer enters as infiltration through an overlying soil due to head (ground water elevation) differences between the adjacent soil aquifer and the underlying bedrock aquifer, unless an unsaturated zone separates the aquifers (see Appendix D for more discussion of this concept). Depending on the type of soil cover and the soil thickness, there is a range of approximately 5% (for marine clay) to 50% (for sand and gravel) of the average annual precipitation rate that may pass into the bedrock aquifer. Exposed bedrock or soils less than 2' thick do not store precipitation to pass through to the bedrock. In this situation the bedrock only receives an estimated recharge of about 10% of the average annual precipitation.

Ground water is discharged from the bedrock aquifer as leakage into the overlying soil aquifer. The leakage rate per unit area is calculated as the difference between the potentiometric levels in the soil and the bedrock, multiplied by a leakage parameter which is equal to the vertical permeability of the soil divided by its saturated thickness. In the case where the soil is thin, more permeable than the rock, or non-existent, the leakage parameter is artificially imposed using the vertical hydraulic conductivity of the bedrock. The leakage parameters used in the different areas of the model are given on the computer printouts and can be estimated by dividing the effective vertical permeability for the representative soil types by the soil thickness given on Figures 9-12.

There are 2 basic limitations inherent in the Konikow and Bredehoeft model's treatment of the ground water "leakage" from the soil to the bedrock which could cause the model to simulate unrealistic amounts of recharge to the bedrock aquifer. First, since the leakance is directly proportional to the "head" difference ("head" is the potentiometric level, or the water level in a well opened at a specific aquifer depth range) between the bedrock aquifer and the overlying soil, the model will incorrectly simulate the leakage rate from the soil into the bedrock if the head in the bedrock aquifer declines below the bedrock surface. More sophisticated models can be used to overcome this model simplification at such time as the data base and the City's needs justify additional levels of sophistication. Second, the leakance values of high permeability soil could artificially allow more recharge to a portion of the aquifer than the rock itself would receive.

We overcame these two model limitations by limiting the maximum recharge rates in various portions of the islands to values that would realistically correlate to the capabilities of the overlying soil types. By preserving the use of the "leakage" concept in the early model development, however, we were able to define recharge versus discharge areas and allow for less than maximum potential recharge to occur in those areas of the aquifer not capable of accepting recharge at the maximum soil rate. We preserved the use of the leakance concept in the model discharge areas where it would perform correctly.

The outer edge of each model was treated as a "constant head" boundary condition where the piezometric level in the bedrock aquifer is constant over time. The piezometric surface at the constant head nodes defining the perimeter of the modeled areas was set on a Mean Sea Level elevation equal to 0'. Alternatively, the outer boundaries of the models could have been treated with leakage occurring through the overlying ocean sediments and the fluctuating tide levels could be simulated at the boundary. However, the thickness of the sediment layer overlying the bedrock adjacent to the islands is very poorly known and the simulation of the tidal cycles (which would have to include spring and neap tide cycles) is very complex. It is appropriate, however, to assume a constant head boundary close to the island since about 90% of the discharge would take place within our defined forced discharge areas. In reality, some bedrock aquifer discharge would take place far from the edge of the islands.

The process of simulating the application of contaminants to the bedrock aquifer in Figures 15-18 required us to introduce the contaminant from various potentiometric surface high points (shown on Figures 19-22) into the bedrock aquifer as leakage from the overlying soil or by direct infiltration into the rock if there is no soil cover. Only those potential contaminant source areas which coincide with areas of the model where leakage is taken into the aquifer (the "recharge" areas of the bedrock aquifer) were simulated as the source areas for solute entering the bedrock aquifer. The bedrock aquifer contaminant movement was then simulated for periods of 2 to 5 years. In all solute transport simulations, the solute was considered to be a "conservative" solute--i.e., no account was taken of chemical reaction, adsorption, or other removal mechanisms that may occur with certain contaminants within the aquifer.

### 5.2.3 Discretization and Parameterization

Model discretization and parameterization involve laying out the model grid on the area to be modeled, selecting the cell size (the "cells" are the rectangular regions which comprise the grid), and selecting the initial aquifer properties for each element or node of the model network. In this study, the model area is designed to cover at least one cell width beyond the shoreline of each island. Square cells with 400' side dimensions were chosen to represent the model area. On Cliff and Long Islands, this size allows the model to represent the aquifer in the detail that is commensurate with the amount, areal density, and quality of the hydrogeological data base. More or fewer data would allow smaller or larger cells, respectively. Due to their similar settings, cell sizes on Great and Little Diamond, and Peaks Islands were chosen to be the same as on Long and Cliff Islands.

The major aquifer properties that must be defined for the steady-state condition are transmissivity, aquifer thickness, the leakage parameter for the adjacent aquifer, effective porosity, and the water table elevation in the adjacent overlying soil aquifer. The basis for identifying and selecting the parameters is discussed in detail in the following section and in Section 5.3.

### 5.2.4 Model Verification

Model calibrations and verification were made through a series of computer runs by successively varying aquifer properties through a reasonable range of values, and by evaluating the results to determine whether the predicted potentiometric surface (ground water levels) and flow rates were reasonable and agreed with field data. In most model simulations of this type, reasonable results can only be obtained when all major inputs are within one order of magnitude of their true values. This is often also the range of error in measuring these properties (such as permeability). Therefore, it is usually possible to develop these types of model with only limited and scattered field data.

Beginning with our best estimates of the horizontal and vertical permeabilities of the different soil and bedrock units, we made 15 runs of the model for Long Island and compared the results with drilled bedrock water level data obtained from the well survey data. In addition, we evaluated the amount of "recharge" induced into the aquifer by each combination of parameters. We know that a reasonable range of precipitation recharge is 5 to 15% of the average normal precipitation rate. We used the Long Island model to perform the initial sensitivity analysis for the study area because there are more drilled well water elevation data with which to compare predicted heads. Of the 15 initial calibration runs, only 2 of the runs yielded realistic results. We selected one of these two combinations of parameters for the models on Peaks, Cliff and Great and Little Diamond Islands.

Goodness-of-fit was determined for Long and Cliff Island (the only islands for which well data are available) by calculating the mean and standard deviation between predicted and reliable observed heads and by calculating average "precipitation recharge" over the recharge areas and comparing it with a reasonable estimate of 5%-15% expected recharge. The values are given below:

| | Difference Between Predicted And Observed Heads | | Calculated Average Recharge As % of Average Annual |
|---|---|---|---|
| | Mean | Standard Deviation | |
| Long Island | 9.3' | 6.6' | 7.7% |
| Cliff Island | 6.0' | 4.7' | 8.5% |
| Peaks Island | No comparison possible | | 8.4% |
| Diamond Is. | No comparison possible | | 7.4% |

There are no field data available from which any solute transport simulations in the bedrock aquifer could be verified. The transport of contaminants in the surficial aquifer was modeled as leakance into the bedrock.

## 5.3 HYDROGEOLOGIC FINDINGS

### 5.3.1 Surficial Aquifers

#### 5.3.1.1 Thickness

Figures 9-12 indicate that the majority of soil in the study area is less than 5' thick. On Peaks and Long Islands, relatively large areas are covered with soil in excess of 5' thick. Two areas on Peaks Island and 2 areas on Long Island have soils interpreted to be greater than 10' thick. The methods used for determining soil thickness are discussed in Section 3.3.

#### 5.3.1.2 Hydraulic Conductivity

Hydraulic conductivity is defined as the mass rate of flow of a fluid through a porous media under a unit hydraulic gradient (water table slope of 45°). From laboratory and field permeability tests from our other studies on the soil types similar to those present in the study area, and from our surficial aquifer ground water flow models in other areas of Maine, we assume the following values for the vertical hydraulic conductivity of the soils in the study area:

| Soil Type | Vertical Hydraulic Conductivity |
| --- | --- |
| Thin Sandy Glacial Till | 1.6 x $10^{-5}$ ft/sec |
| Thick Silty Glacial Till | 1.6 x $10^{-7}$ " |
| Glaciomarine Silty Sand | 1.2 x $10^{-5}$ " |
| Glaciomarine Thin fissured clay-silt | 3.3 x $10^{-8}$ " |
| Glaciofluvial Sand and Gravel | 4.6 x $10^{-4}$ " |
| Swamp Deposits | 3.3 x $10^{-7}$ " |

These values of hydraulic conductivity were used to calculate the leakances discussed in Section 5.2.2 for the surficial aquifer.

5.3.1.3 Precipitation Recharge

Typical recharge values obtained from our studies of surficial materials in Maine (e.g., Gerber and Rand, 1982) were used to derive the values given in Section 3.0 for the various soil types.

5.3.1.4 High Yield Zones

As mentioned in Section 3.0, a high-yield zone in a surficial aquifer should be located in very permeable sand and gravel, with a saturated thickness of 5-10 feet, and a recharge area of 10 or more acres. None of these criteria were met on Great, Little Diamond, and Cliff Islands.

The northwestern end of Long Island has an area of thick sand and gravel that may have some potential as a surficial high-yield aquifer. In the southwestern part of the island, there is another area of sand and gravel draped over the island. The saturated thickness of this deposit is probably thin and the convex topography is not conducive to concentrating recharge to assure a sustained high yield.

There are a few areas on Peaks Island of sufficient thickness of sandy soils and sufficient recharge area to warrant designation as "potential" high yield sand and gravel aquifer zones on Figure 23. However, we do not believe that yields would exceed 50 gpm. Furthermore, water quality may not be acceptable without treatment for iron and manganese removal for the two potential sand and gravel aquifers shown surrounding swamps on the island. The anaerobic decomposition of organic material normally releases high concentrations of iron and manganese into the ground water.

5.3.2 Bedrock Aquifer Properties

5.3.2.1 Thickness

The thickness of the bedrock aquifer is not well defined. Ground water flow may occur at depths as great as 1000' in fractured crystalline rock aquifers in Maine. However, as a result of our analyses of deep bedrock wells in other areas of Maine, we conclude that the depth of significant flow for most bedrock aquifers is about 300' which we arbitrarily chose as the aquifer thickness for purposes of the ground water solute transport modeling. (Drilled well depths on the islands generally do not exceed 250'.) This thickness is of the correct order of magnitude and facilitates translation of permeabilities to transmissivities. The bedrock flow models use transmissivity rather than permeability which makes the aquifer thickness unimportant in the steady-state flow model simulations that we have made as part of this study. Only in the solute transport model does the assumption of thickness affect the contaminant travel times. Within the accuracy of these types of models, the assumption of 300-foot thickness is certainly appropriate for our analysis.

5.3.2.2 Porosity

As discussed in Section 2.1, we have estimated the average porosity of the bedrock aquifer to be 0.1%. Studies reported in the literature indicate that this is a representative value for fractured crystalline rock which is present on the islands. However, as noted earlier, zones of high fracture density could have fracture porosities varying from 1 to 10%.

5.3.2.3 Transmissivity

Initial bedrock aquifer transmissivities were chosen by assuming a 300' aquifer thickness, as discussed above, and initial transmissivity of $5 \times 10^{-4}$ ft/sec in the N40°E direction, and $5 \times 10^{-5}$ ft/sec in the N50°W direction. These values are consistent with field-measured values from our other studies.

From measurements obtained on bedrock fracture orientations on each island, we conclude that the orientations in the study area display a pronounced bimodal distribution. This suggests that the bedrock aquifers underlying each island will behave anisotropically, i.e., certain orientations will have greater transmissivity than others. Rose diagrams of the fracture orientations obtained for each of the islands in the model areas (Figures 15-18) indicate that the majority of fractures encountered are steeply-dipping, closely-spaced cleavage (lamination) oriented approximately N40°E and nearly perpendicular steeply-dipping joints oriented between N50-60°E. ("Strike" is the line formed by the intersection of the inclined plane with the horizontal plane; "dip" is the angle of inclination of the plane from the horizontal measured perpendicular to the strike). Each ray in the diagrams represents a 10-degree interval. The length of the spokes indicate the relative percentage of total fracture strike orientations that were measured in each sector. When interpreting the significance of the relationships shown in these figures, it is instructive to be aware that the data for a rose diagram are based on recording only <u>one measurement of each particular fracture per outcrop</u>, and not on the <u>basis of recording the fracture frequency</u> as it relates to the number of fractures per unit area.

The closely-spaced nature of the cleavage fractures suggest that this direction probably coincides with the major transmissivity direction in the study area. As discussed previously in Section 3.1, Richard (1976) estimated that there are 30 to 40 times more cleavage/foliation partings than joints per volume of rock at High Head in Harpswell. Modeling by Gerber and Rand (1980) with field verification in the Cape Elizabeth Formation in Wiscasset indicated that aquifer transmissivity was 5 to 10 times greater along the direction of the rock cleavage/foliation than perpendicular to that direction in rock that was not heavily jointed. We have oriented the model coordinate axes to coincide approximately with rock cleavage and a direction at right angles to it, N50°W. In the model verification process, we had insufficient data to verify that the anisotropic transmissivity assumption is more valid than the isotropic assumption. In the sensitivity analysis, we found that one set of parameters using an isotropic assumption produced a water table match for Long Island that was about equally as good as the anisotropic case. We have selected the anisotropic case for all of the computer runs, based on our field observations on the islands and our experience with the rock formations in other locations where verifications were possible.

The statistics of the measured dips for each of the islands, separated by type of structural feature measured, are summarized below. These statistics justify in a general way the assumption that most of the fractures are steeply-dipping. This is an important assumption in considering how to construct a simulation model of a bedrock aquifer.

Bedrock Fracture Dips in Degrees Downward from the Horizontal

| Structural Feature | Peaks | Long | Cliff | Gr. Diamond | Lt. Diamond |
|---|---|---|---|---|---|
| Cleavage: | | | | | |
| Mean Dip | 79 | 82 | 77 | 66 | 46 |
| Stan. Dev. | 14 | 14 | 11 | 21 | 21 |
| Joints: | | | | | |
| Mean Dip | 67 | 66 | 64 | 68 | 71 |
| Stan. Dev. | 22 | 24 | 26 | 18 | 17 |
| Faults: | | | | | |
| Mean Dip | 37 | 90 | 80 | 85 | none noted |
| Stan. Dev. | 0 | 0 | 17 | 5 | " " |
| Intrusive Dikes: | | | | | |
| Mean Dip | 85 | 79 | 88 | 75 | none noted |
| Stan. Dev. | 5 | 7 | 4 | 0 | " " |

#### 5.3.2.4 Leakance

Leakage parameters were initially estimated from known or inferred soil thicknesses and characteristic soil permeabilities at each node. The elevations of ground water in the overlying soil aquifer were assumed to be as follows based mainly on the characteristic degree of soil drainage for each soil type: the ground surface (or water surface) for areas of exposed rock, soil less than 2' thick, swamp deposits and water bodies; 1' to 2' below ground surface for the areas covered by marine clay; 5' below the ground surface for areas covered by till or sand and gravel. Due to the inherent limitations regarding how this model deals with leakance from an overlying aquifer, as discussed above, some leakance adjustments were made throughout the model areas to reduce unrealistically high leakances to more reasonable values. Recharge to areas of shallow and exposed rock was not applied through leakage, but limited to maximum fixed recharge rate of 10% of average annual precipitation or to a lesser rate if earlier runs using soil leakance parameters indicated a lower recharge rate prevailed.

5.3.2.5 Precipitation Recharge

One of the direct benefits of the simulation modeling is the evaluation of the amount of precipitation recharge that would enter the bedrock aquifers. Our other bedrock aquifer studies in Maine have determined that crystalline rock aquifers receive recharge which averages between 5% and 15% of average annual precipitation. Through the summation of the leakage and recharge into the bedrock aquifer, which is the only source of water to the aquifer, we can determine the net recharge to the bedrock aquifer. This total leakance (plus fixed recharge) into the aquifer, divided by the total model area (not including the constant head boundaries out in the ocean) gives the recharge rates in Section 5.2.4.

5.3.2.6 High-Yield Zones

In Maine crystalline rock, high-yield bedrock aquifer zones are generally associated with highly fractured rock or individual continuous fractures with relatively large apertures. We chose a bedrock well yield of greater than 20 gpm as being indicative of high yield zones. Our well survey questionnaires for Cliff Island indicate that there are at least 4 wells (#101, #103, #114, and #121; Figure 14) in this category with yields ranging between 30-50 gpm. All 4 wells are situated on or adjacent to photolinears which we have identified on Figure 3. Wells #101, #103, and #114 are all associated with a single photolinear. This correlation of high bedrock yield to these photolinears suggests that these features are, in fact, surface expressions of fractures.

On Long Island, 3 wells (#218, #230, and #245) have yields in this category which range 20-30 gpm. None of these wells are directly over photolinears which we have identified. However, this does not preclude their association with fracture zones. Thick overburden may mask the detection of fractures from aerial photographs, or the fractures may be relatively horizontal. The lack of private well information for Peaks and Great and Little Diamond Islands precludes the evaluation of high yield bedrock aquifer zones on those islands. However, the intersections of multiple linears have often been found to produce high yield bedrock wells.

Therefore, we have suggested the presence of potential high yield zones on Figures 23-26.

5.3.3 Hydrogeologic Setting

Figures 15 through 26 and the statistics cited in this report all reveal important information about the aquifers on the islands. It is obvious first that only a few thick soil areas of high permeability exist on the islands and therefore surficial aquifers are not of major significance as potential public water supplies. The bedrock aquifer is therefore of most importance as a source of potable water and there do appear to be zones where high-yield bedrock wells have been or could be located on the islands. By developing the ground water flow and solute transport models, we have gained a further understanding of the overall bedrock aquifer. We have defined the general areas of recharge versus discharge, areas of potential high yield, areas of known or suspected contamination, and developed examples which illustrate the amount of time a contaminant will take to travel through the bedrock aquifer. Furthermore, we have defined the amount of average recharge available to the bedrock aquifer, and determined the general conditions under which salt water intrusion will occur.

Salt water intrusion occurs naturally under islands. A simplified model of salt water intrusion is called the "Ghyben-Herzberg principle". This states that the depth to the salt water interface below mean sea level is about 40 times the distance of the potentiometric surface above sea level at that point. Due to the small scale of the islands and the large tidal range in Casco Bay, there is a zone of dispersion on either side of the theoretical salt water "interface". Therefore, a well will encounter increasing chloride concentrations as it is drilled deeper, rather than abruptly passing from fresh to salt water. The thickness of this dispersion zone varies with position relative to the edge of the island, tidal range, thickness of the aquifer, the dispersivity of the aquifer, and the amount of freshwater flowing through the aquifer. The transition zone is probably on the order of tens of feet in thickness under the islands.

The Ghyben-Herzberg principle is still useful for evaluating steady-state problems in a general way. Much more complex analytical treatment of the salt water intrusion problem can be found in advanced textbooks on ground water hydraulics. We can approach the problem of salt water intrusion in two general ways for purposes of this report. The computer models could be used to evaluate specific problems that may arise in the future. Using our best estimate of the bedrock aquifer transmissivity and an assumption that a single-family living unit uses about 250 gallons per day of water, we calculate that a 5' average drawdown will occur in a 6" diameter drilled bedrock well. Using the Ghyben-Herzberg principle, this means that the static water elevation in a drilled well less than 200' from the shoreline should be at least 5' above Mean Sea Level, and preferably, 5' above Spring High Water if relatively salt-free water is desired on the islands. A well within 200' of the shoreline and meant to serve four families should be located in an area where the static water elevation is at least 21' above Mean Sea Level. Another way of looking at the problem is to base the allowable density of wells on the amount of precipitation recharge available to the islands. Wells should be as widely dispersed as possible and the density of wells should not exceed about 1 well per acre if salt water intrusion is to be prevented.

The travel time contours given on Figures 15-18 are meant to illustrate the general direction of ground water flow from certain points on the island (chosen arbitrarily) and also illustrate the time that it takes for a contaminant to move through a 300' thick aquifer with the specified transmissivities and porosity. Notice that typical rates of movement are 1 to 10 feet per day away from the hypothetical contaminant sources. Notice that ground water moves faster along the northeast-southwest directions than northwest-southeast (due to the assumptions on transmissivity put in the models). In some areas the direction of ground water flow seems to go contrary to the surface topography, which is entirely plausible, particularly on an island of little or no soil cover. In this case, ground water will mound in the center of the island, regardless of where the high points on the ground surface occur.

Our modeling process has allowed us to define the general areas of recharge and discharge on the islands. Notice that ground water discharge does not all have to occur beyond the shoreline of the island. Some bedrock aquifer discharge zones can be found within the interior of the islands. Some occur in large swampy areas; others occur in long flat areas at the foot of steep slopes. This discharge occurs into the overlying soils which, in the case of major discharge areas, will discharge in turn to a local stream or wet area. The locations of the recharge/discharge boundaries can be found on Figures 23-26.

#### 5.3.3.1 Peaks Island

The simulated potentiometric surface contours for the bedrock aquifer on Peaks Island are shown in Figure 19. The contour lines in this figure are "equipotential" lines connecting areas of equal hydraulic head simulated by the model as the elevation to which water would rise in a well placed at mid-height in the aquifer. Ground water flow is not perpendicular to the equipotential lines for anisotropic aquifers. Flow lines cut across the contours at an acute angle and the solute transport model takes this into account. The potentiometric surface on Peaks Island as simulated by the model generally mimics the ground surface topography.

Figure 23 shows that there are large interior portions of the island that may have upward vertical ground water gradients (i.e., are discharge areas). These areas should be favored for the location of landfills, transfer stations, fuel oil storage areas, and placement of other land uses that could cause potential contamination of ground water. Over discharge areas, there is much less chance of contaminating the aquifer.

There are only a few widely-scattered potential high yield bedrock aquifer sites on the island, based on the photolinear analysis.

### 5.3.3.2 Long Island

The simulated potentiometric surface contours of the bedrock aquifer on Long Island are shown on Figure 20. One major potentiometric surface peak occurs at each end of the island, approximately coinciding with ground surface topographic highs. A much smaller local peak occurs in the central portion of the island. These potentiometric surface peaks are the principal localized recharge zones. Notice on Figure 24 that there are a number of re-entrants in the recharge/discharge boundary that either coincide with topographic lows or areas of permeable soils that would not resist upward discharge from the bedrock aquifer.

There seems to be potential for high-yield bedrock wells just south of the high hill at the north end of the island. However, due to the proximity of the shorelines in this area there would be a practical limit to the rate at which any well could be pumped without inducing salt water intrusion.

### 5.3.3.3 Cliff Island

The simulated potentiometric surface contours for Cliff Island are shown in Figure 21. The irregular shape and unique geology of the island are responsible for the peculiar configuration of the potentiometric surface, i.e., the relative ground water isolation of the eastern peninsula from the remainder of the island. A potentiometric surface ridge occurs along the center of the northeast three-quarters of the island. A localized peak on the southwestern end of this ridge coincides with a similar ground surface topographic feature. Recharge in the bedrock aquifer occurs over most of the island. Discharge is near the shoreline and on the peninsula "neck" connecting the main island to the rocky peninsula.

There are a number of confirmed high yield bedrock aquifer zones in the central and southern portions of Cliff Island. However, due to the narrowness of the island and because of the relatively low potentiometric Levels on the island, a large sustained demand could not be taken from these high transmissivity zones without inducing salt water intrusion.

### 5.3.3.4 Great and Little Diamond Islands

The simulated potentiometric surface contour map for the bedrock aquifers on Great and Little Diamond Islands is shown in Figure 22. Similar to Peaks Island, the shape of the potentiometric surface on Great Diamond Island conforms closely to the ground surface. The potentiometric surface on Little Diamond Island has a high near the center of the island, however, whereas the topographic high is in the southwest corner of the island. On Great Diamond Island recharge (Figure 26) occurs on much of the southern, southeastern, and northeastern higher elevation interior regions. Discharge occurs close to the shoreline and along the lowland area adjacent to and southwest of the embayment on the northeastern shore. Some localized interior areas of the island which are relative lowlands are suggested by the computer simulations to be discharge areas, but we have no confirmation of this. There are numerous intersecting lineaments in the southeastern section of Great Diamond Island and it appears very likely that a high yield bedrock aquifer could be developed there. If a high yield aquifer exists there, the potentiometric contour map would probably change to indicate a lower potentiometric surface.

The potentiometric contours do not rise very high on Little Diamond Island because the small size of the island does not result in much ground water mounding. Except for two small lowland areas on the northwestern and northeastern shores of the island, most of the island is a recharge area. Numerous intersecting lineaments suggest the possibility of a high-yield bedrock aquifer under the northern half of the island, but because of limited recharge and a low potentiometric surface, not much demand could be placed on any high yield well without inducing salt water intrusion.

### 5.3.4 Potential Contaminant Sources

The well water quality data obtained from the study are discussed previously in Section 4.1.4 and the data are presented in Appendices B and C. Potential contaminant sources were located through reference to land use maps, field observations, and personal communications. Potential contamination of ground water by septic systems was interpreted from the Long Island well water quality survey.

#### 5.3.4.1 Peaks Island

Potential contaminant sources on Peaks Island are shown in Figure 23. We identified 3 areas near the western shore of the island where petroleum products are currently being stored. The site located east of the public ferry pier along Island Avenue is a gasoline service station. The site located directly north of the public ferry landing has several fuel tanks for gasoline and diesel storage. The more northerly site is the Peaks Island electric power plant facility where 5 above-ground fuel oil storage tanks are located.

Subsurface sewage disposal system effluent is another potential source of ground water contamination in areas not served by the Peaks Island public sewer. The sewer service area is shown in Figure 23 on the southwestern corner of the island. Along shoreline areas, overboard treated discharge is quite common, which minimizes some of the potential for ground water contamination by subsurface sewage disposal system effluent. Due to service by the Portland Water District, there are limited water quality data available for Peaks Island. The limited water quality data listed in Appendix C for Peaks Island indicates that there are at least 2 cases where domestic water wells have been impacted by subsurface sewage disposal system effluent. In addition, "Environmental Record Form" reports filed by the City of Portland Health Department, Environmental Health Division indicate that there were 3 incidences of subsurface sewage disposal system failure in 1984. We have no information to locate the associated dwellings on our map.

The sand/salt storage pile (approximately 300 cubic yards) used for road de-icing by the Department of Public Works is a potential threat to the local ground water quality on the island. Elevated levels of sodium and chloride leached into the ground water by precipitation infiltration into an uncovered sand/salt pile. However, the pile's location near a ground water discharge zone diminishes its potential adverse water quality impact since salty leachate would remain near-surface in the bedrock aquifer. People with dietary restrictions for sodium are especially sensitive to consumption of ground water contaminated by salt. In order to minimize any adverse impact to nearby ground water, the storage pile should be enclosed by a secure storage shed.

The Peaks Island landfill will be closed soon. It is located in the southeast quadrant of the island, just upgradient from a bedrock aquifer discharge zone. A solid waste transfer station will be constructed on the site of the landfill.

#### 5.3.4.2 Long Island

Due in part to the abundance of water quality data listed in Appendices A-C, we have identified several potential or existing ground water contaminant sources on Long Island as shown in Figure 24.

At least 50 cases of ground water contamination by subsurface sewage disposal system effluent occur throughout the island. This is 42% of the total number of wells for which water quality data are reported in Appendix B. This does not necessarily imply that the ground water is unsafe to drink, but it does mean that ground water contains physical and biological matter that is probably derived from subsurface sewage disposal systems. Should anyone using these septic systems have a disease that is readily transmitted in water, downgradient wells could pick up this virus or bacteria and transmit it to humans drinking the water. In addition, high nitrate concentrations in the ground water could cause young infants who drink the water to get "blue-baby" syndrome. High nitrate concentrations have also been linked to the potential to cause gastric cancer. The potential reasons for such a high incidence of contamination by subsurface sewage disposal systems are: a) poorly designed or maintained subsurface disposal systems; b) high localized concentrations of systems; and/or c) thin soil under the systems and fast contaminant travel times to the nearest well. Research has shown that viruses and bacteria can survive in ground water for up to 170 days.

The Long Island landfill located near the intersection of Beach and Fern Avenue (south-central portion of island at elevation 60') is currently being used only as a solid waste transfer station. Preliminary results for a study which we are conducting in order to evaluate an appropriate landfill closure design indicate that the landfill is having a minor deleterious impact on the water quality, mainly in elevated concentrations of manganese and iron, in both the surface and ground water immediately around the landfill. Since the landfill is positioned in a local recharge area for the southern portion of the island, any contaminants entering the bedrock aquifer in this region will probably be transmitted to deeper levels in the aquifer and not remain near-surface. An active debris disposal area is located approximately 800' east-northeast along Fern Avenue. The very permeable sand and gravel deposits overlying shallow bedrock in this bedrock aquifer recharge area makes this site particularly capable of polluting deep into the bedrock aquifer if any leachate generated from the fill reaches the bedrock.

Twelve large underground petroleum storages tanks are located in the west-central part of the island on property currently owned by Phoenix Resources. These are concrete-lined bedrock caverns which were constructed by the United States Navy during World War II for fuel oil storage. Although these are not currently active as storage tanks, some petroleum residue does remain. Petroleum leakage from the tanks has been detected in monitoring wells positioned around the tanks. The ground water in 12 monitoring wells around the general area of the tanks is being tested periodically. During reconnaissance bedrock mapping last summer in conjunction with the Long Island landfill closing study, strong "gasoline" odor was detected in the soil on the shoreline behind the general store adjacent to the Long Island Post Office, suggesting a potential petroleum tank leak in the general vicinity.

Approximately 100 cubic yards of sand/salt road de-icing mixture are stored on Long Island. The location of the storage pile on the western flank of a small hill places it in a localized ground water recharge zone. Wells located down-gradient (in a ground water sense) to the west could potentially be contaminated by salty leachate if precipitation is allowed to infiltrate the sand/salt mixture. One well directly east of the sand/salt pile reported relatively high levels of chloride which could be originating from the storage pile. In Figure 25, this well is represented by the symbol indicating contamination by subsurface sewage system since it also shows relatively high concentrations of coliform and bacteria. One case of well contamination by chlorides also occurs along the northwestern shore of the island, and one occurs along the east-central shore. These may be caused by either salt-water intrusion or road-salt contamination. More thorough chemical analyses would be required to distinguish between the two possibilities.

#### 5.3.4.3 Cliff Island

The limited ground water quality data for Cliff Island which were available from the Department of Human Services (Appendix C) show that in only 3 cases (2 coliform bacteria and 1 with high nitrate and coliform bacteria) of 17 tested were there any indications of subsurface sewage disposal system impact to the ground water quality. Potential contaminant sources on Cliff Island are shown in Figure 25.

The only commercial petroleum storage tank on the island is located on the eastern shore on Fisherman's Wharf. The numerous domestic heating oil fuel tanks located outside many of the homes on the island are also potential contaminant sources. Enhanced corrosion of the metal tanks due to sea-water aerosols could significantly decrease the life of exposed tanks relative to sheltered ones.

Approximately 30 cubic yards of sand/salt de-icing mixture are stored on Cliff Island. Due to the storage pile's location very close to a ground water discharge zone, it poses little threat to the good water quality of the island.

#### 5.3.4.4 Great and Little Diamond Islands

On Great and Little Diamond Islands, we identified 1 petroleum storage facility on each island as shown in Figure 26. A fuel storage building and a fuel tank is located on the west side of Great Diamond Island on the Fort McKinley property currently owned by Dictar Associates. It is not known whether petroleum currently is present in either the building or the tank. A gasoline or diesel storage tank is located on the northeast side of Little Diamond Island. This is storage for boat fuel and, presumably, it is currently in use. On both of these islands no data regarding well contamination by subsurface sewage disposal system effluent are available, since both are supplied with potable water by the Portland Water District. Approximately 2 cubic yards of sand/salt de-icing mixture are stored on Great Diamond Island near the ferry landing as shown in Figure 26. Due to its small volume and its location near a major discharge zone on the island, this sand/salt pile should not pose a threat to the ground water quality on the island.

## 6.0 GROUND WATER MANAGEMENT PLAN

### 6.1 RATIONALE FOR THE CITY PREPARING ITS OWN GROUND WATER MANAGEMENT PLAN

Why should the City of Portland develop its own ground water management plan when the State and Federal governments are placing so much emphasis on ground water protection? There several reasons why local governmental units should develop their own ground water protection strategy. It should be remembered that ground water issues have only received significant public attention in the last 10 years. Furthermore, ground water occurs in a diverse number of geologic settings and the technology to predict ground water movement has only become generally available in the last 10 years. Therefore, the regulatory process of developing appropriate ground water protection policy is still in a relatively early stage, particularly in the northeast United States, where ground water has always been relatively abundant and taken for granted. Since present day actions can inadvertently harm the ground water resource to the detriment of future generations, it is not wise to wait for State or federal policy to be implemented at the local level. By then it may be too late.

More specific reasons for the City acting on its own are listed below.

A. The federal government has essentially handed the job of developing ground water protection strategy over to the States. There is currently no coherent ground water management strategy for Maine, although work began on this about a year ago.

B. The State of Maine uses the common law "absolute ownership doctrine" in deciding civil matters involving ground water use conflicts. In other words, a landowner can take as much ground water from beneath his land as he wishes, regardless of the effects on his abutters. The only present legal mechanism that can overrule this doctrine is through statutory application of the Site Location of Development law by the Maine Dept. of Environmental Protection (DEP), or by appropriate application of the State Subdivision Statute at the City level. However, the actions of single landowners not coming under these statutes may not be controlled by any State statute.

C. The DEP only regulates large developments (generally over 20 acres in size) plus most forms of municipal or commercial waste disposal. Protection of ground water is specifically mandated in regulations pursuant to the governing statutes; however, bedrock aquifers are not given so much protection as sand and gravel aquifers. Work on the study of bedrock aquifers similar to that which has been done on sand and gravel aquifers for the last 5 years is just beginning this year at the state level. Furthermore, the regulations have allowed developers to pollute the ground water under their land right to the limit of the Safe Drinking Water Standards, thus leaving no "headspace" for the landowner downhill in a ground water sense from the developer. This amounts to a first-come, first-serve policy, which is not recommended for long-term land use planning.

D. State subdivision laws give the local governmental units an ability to control the impacts of laws coming under subdivision review in terms of their impact on ground water "quantity and quality". Unfortunately, the statute provides no guidance as to what standards should be used to determine whether a subdivision has no significant impact on ground water quantity or quality.

## 6.2 GOALS OF THE GROUND WATER MANAGEMENT PLAN

In developing goals for the ground water management plan, keep in mind that we are dealing with managing the amount of ground water that can be extracted from the ground in addition to managing the quality of that water. Ground water management cannot be done in a vacuum, without considerations of surface water interactions or other objectives of land and water use planning, such as economic growth, water rights, and coincidence with overall public policy. To be considered reasonable, a management policy must be fair to all, should preserve some options for future generations, and should recognize that any change in the land from the natural state will cause some ground water quality degradation. A goal of preventing any degradation is impossible to achieve. Finally, as with any plan, a system must be developed to measure the progress of the plan in achieving the goals and objectives of the plan. Thus some long-term monitoring of ground water quality and quantity will have to be undertaken and will require City resources in terms of time and money.

The following goals are proposed for the Portland Islands Ground Water Management Plan:

1. PRESERVE QUANTITY--Preserve the recharge rate to the island aquifers to the extent practical such that ground water tables are not significantly lowered and saltwater intrusion does not occur to either existing or future well sites.

2. PROTECT QUALITY--Protect ground water quality so that it will meet the State of Maine Primary Drinking Water Standards. Where the quality is presently inferior to those Standards, the goal is to restore the ground water to a quality equal to or better than the Safe Drinking Water Standards.

There are a number of management objectives that can be developed for each of these goals. The management plan will be a detailed plan of how the City should accomplish these objectives. We will describe objectives with respect to each of the above goals.

PRESERVE QUANTITY

A) Minimize reduction of recharge and augment recharge if feasible.

B) Coordinate storm water management with ground water management.

C) Reduce progressive lowering of the ground water table and thus avoid the need to drill deeper wells with associated higher pumping costs and potential for saltwater intrusion.

D) Do not exceed the safe yield of the bedrock aquifers.

E) Continue to develop a data base on ground water elevations and monitor long-term trends.

F) Provide education to the public on ways of preserving and enhancing recharge capability.

PRESERVE QUALITY

A) Prevent degradation of quality to the extent possible, since this is cheaper and more effective than cleaning up or treating ground water.

B) Assume that even where off-island water supplies and overboard discharges are presently available on the islands, that the islands may one day be forced to revert to self-sufficiency such that they will have to derive their water supply from the island and must dispose of their sewage on the island.

C) Control housing and commercial use densities commensurate with available recharge such that when an entire island is developed to its permitted density, the ground water quality will still meet Safe Drinking Water Standards.

D) Control the effects of residential subdivisions and other commercial developments that must undergo Site Plan Review such that any discharge to ground waters will not result in ground water quality leaving the property on which the development is located exceeding one-half of the difference between the quality of ground water entering the property and the Safe Drinking Water Limits for the applicable physical, chemical, and biological standards.

E) Control the disposal of any waste products on the island and define areas within which certain types of waste disposal should not occur.

F) Control saltwater intrusion by preventing wells from exceeding the aquifers' safe yields and by reducing ground water extraction to the extent practical.

G) Develop an emergency response plan for reacting to accidental chemical or petroleum spills.

H) Control non-point sources such as petroleum storage tanks, resource mining, material stockpiles, pipelines, agricultural practices, road de-icing chemicals, and abandoned wells.

I) Develop a remedial action plan for improving ground water quality where it is presently contaminated.

J) Develop a long-term ground water quality monitoring plan.

K) Provide public education on means of preserving ground water quality.

## 6.3 MANAGEMENT PLAN TO IMPLEMENT OBJECTIVES

### 6.3.1 Preserve Quantity

A) MINIMIZE LOSS OF RECHARGE AND ENHANCE IF POSSIBLE

This objective can be achieved by regulation of the amount of impervious area created by development, by encouraging return of sewage to the ground water system to the extent possible commensurate with preserving ground water quality, and by requiring development to take measures to enhance recharge to the extent possible. With respect to the objective of enhancing recharge, it will be difficult and basically unfeasible to do this with most typical artificial recharge techniques, since the islands in general have so little soil cover, and particularly not much thick sand and gravel soil cover. Therefore, it would not be practical to require each development to investigate means of onsite soil absorption of runoff or other means of enhancing recharge. We suggest that the Public Works Technical Supplement be amended to the effect that sites known by site exploration or shown on our maps to have over 10' of sand and gravel explore ways of enhancing soil recharge as part of the development scheme.

We recommend that the use of overboard sewage discharges be discouraged, not only for the impact on local shellfish resources, but for the fact that it represents a loss of recharge to the aquifers (assuming that the original water supply would come from wells on the island). To offset the loss of recharge for those lots using overboard discharges, we recommend that the minimum lot size for commercial and residential uses be changed in the zoning ordinance to 50% greater than the density otherwise allowed in that zone. Water metering should be required on any overboard discharge system.

The amount of impervious area created by development can be controlled either through the zoning ordinance or the site plan review ordinance. Leopold (1968) discusses the impact of development in increasing runoff and decreasing ground water recharge. The amount of fresh ground water that is available for use depends upon the amount of precipitation that can infiltrate the ground. If the infiltration capacity of the ground surface is reduced, fewer wells can be supplied with an adequate supply of water in a given area. Forested land supplies the most recharge, and is preferable to grassed land in terms of recharge potential.

Based upon results we have obtained from our literature search, and our own calculations and experience, we find that at a density of 2.5 acres per dwelling unit, there is effectively no reduction in ground water recharge rate. When densities exceed 0.5 acres per dwelling unit, recharge rates are drastically reduced. The most prominent effect of commercialization is reduction in recharge due to addition of impervious area. Gravel pit operations will not normally decrease the amount of recharge--in fact, they can increase it if the excavation does not go below the water table, and the site is graded to drain into a depressional area. However, borrow operations can decrease the recharge rate if access roads are paved, buildings or structures are placed in the area, washing operations create large areas of relatively impervious silt the area, washing operations create large areas of relatively impervious silt and clay in settling ponds, drainage ditches are created to lower the water table, or ground water ponds are created that increase the rate of evaporative water loss.

An adverse ground water impact on water quantity might be considered to be one which reduces the recharge capability of the land to less than one-half its capability in the undeveloped state. This could be accomplished by stating in the zoning ordinance that impervious cover not exceed a specified percentage (50% would be appropriate in the more intensely developed zones) of the lot unless a developer can show that he will enhance recharge to offset a greater percentage of impervious area cover.

B) COORDINATE STORM WATER MANAGEMENT WITH GROUND WATER MANAGEMENT

This objective can be attained by requiring in the Public Works Technical Supplement that the possibility of artificial recharge be investigated as part of the storm water management planning. Even where artificial recharge looks unfeasible, it would be beneficial to require standard detention basins that prevent the peak discharge in the 10-year (or 25-year) storm from exceeding that which would occur in the undeveloped state. The requirements would be waived if the developer can show that he is in a discharge area.

C) PREVENT LOWERING OF THE GROUND WATER TABLE

Progressive lowering of the ground water table increases the potential for saltwater intrusion. Lowering of the ground water table can be prevented by preventing loss of recharge (discussed above), reducing the water demand on the aquifer, by redistributing the demand so that it does not create excessive local drawdowns, and by preventing unnecessary lowering of the water table by projects associated with resource extraction or other uses where free ground water is considered a nuisance.

Reduction of demand on the aquifer can be accomplished by requiring water flow restrictions for all residences and commercial uses. This can be put into the subdivision ordinance or building code, requiring that all plumbing fixtures be of water conservation design; toilets shall have a low water volume standard and not use more than 4 gallons per flush; and other plumbing fixtures shall have flow restrictors with a maximum rated flow of 3 gallons per minute at 25 pounds per square inch pressure. Existing residences and commercial uses should be encouraged to install water conservation devices.

No single project should be allowed to create excessive drawdowns of the water table beyond its property boundary. In addition to providing a general encouragement to disperse well demand as broadly as possible around the island, there should also be performance standards for how much change in water table should be permitted. The Subdivision, Site Plan ordinance or performance standard in the Zoning ordinance should state that a development shall not cause more than a 10 foot lowering of the ground water table beyond the limits of the proposed development compared to the pre-development water table. Appropriate monitoring should be required to ensure compliance.

With respect to other alterations of the land that would cause ground water lowering, foundation drains, large cuts and fills, land drainage for agriculture, and resource mining are the major items that could create undesirable impact. Foundation drains are a necessary component for those buildings having basements and probably have an impact of relatively limited and insignificant effect. Agricultural drains that would normally only lower the ground water a few feet would be most effective in the spring and late fall, which is not a critical time for ground water recharge. The Site Plan Ordinance should require a permit for large cuts and fills. These could be subjected to the performance standard for offsite drawdown.

Borrow pits and quarries are presently forbidden on the islands under the zoning ordinance. Should quarries or borrow pits eventually be permitted, a detailed hydrogeologic study will have to be done to determine the extent that the borrow pit or quarry will lower the ground water table. It should not lower the ground water table in adjacent properties more than 10 feet below the position prior to starting the quarry or borrow pit. As part of reclamation, the bottom of any rock quarry should be graded to drain (through a permeable gravel deposit set over rock, if necessary) and at least 2 feet of loamy soil should be placed and seeded over the drainage blanket material.

D) DO NOT EXCEED THE SAFE YIELD OF THE BEDROCK AQUIFERS

As we recommended in the earlier section of this report, the averaged annual safe yield evaluation of the island aquifers indicates that the average overall residential lot density should not exceed 1 dwelling per square acre if the island has to rely upon drilled wells on the island for its water supplies. This concept is generally met in the existing zoning system. The 60,000 square foot lot size requirement in the IR-1 Zone for the more rural areas of the island offsets the 20,000 square foot requirement for the developed village areas of the IR-2 Zone. As the IR-1 Zone typically is the largest zone in terms of total area on the islands, this provides a large potential recharge area. However, the City may want to evaluate the grandfathered lot size provisions and the residential density of the island business zones since these regulations allow for a higher residential density than the normal density of the IR-1 and IR-2 zones. A third density adjustment that might be considered would be the residential density of the IR-3 Zone. The IR-3 Zone has a base density of 32,000 square feet per dwelling. If a development met certain standards, the density could be increased under certain circumstances to 25,000 square feet even without the presence of public water. On islands lacking public water, a development density in this range could be counterproductive to an island density goal of 1 dwelling per acre. The City may want to adjust the residential density requirements of the IR-3 Zone to 40,000 square feet in cases where a development could not be served by public water.

With respect to commercial developments that use more than the proportionate share of water (more than 250 gallons per day per acre), either the offsite 10' drawdown performance standard could be used, or the minimum lot size could be directly tied to projected water use. The latter standard would make many commercial uses such as restaurants nonconforming. We suggest that the performance standard be used in evaluating new or expanding uses.

E) DEVELOP A LONG-TERM DATA BASE

The major sources of data on the bedrock aquifer are individual well records.

This study has begun the collection of these types of data. Information is stored in computer spreadsheet format on "Lotus 1-2-3". Many more data points are needed to create a solid data base for model calibration. We suggest that the City continue to collect well data. The best way in which this could be done successfully is to require that a record of each new well drilled on the islands be submitted to the Building Inspector prior to the Building Inspector issuing an occupancy permit. Therefore, we recommend that the Building Code require that any drilled well in the City of Portland obtain a well drilling permit. A nominal fee would be charged and the well driller and homeowner would be required to complete a form similar to the "Well Questionnaire" form (Appendix A) for data collection. The information would be placed on file with the Building Permit. As time and funding permit, Planning Dept. staff could add the well data to the "Lotus" compilation that we have already begun.

The ground water management plan must include long-term monitoring of ground water elevation trends under the islands in order to measure the effectiveness of the plan and improve the data base for later decision making. To monitor the plan's impact on water quantity, we would measure this indirectly by monitoring ground water elevation trends in different parts of the island. This will require a network of about 5 drilled bedrock wells on each island that are easily accessible for monitoring. Preferably these would be the same wells in which water quality monitoring would be done. If agreements could not be made with private landowners concerning the monitoring of their wells, some monitoring well installation would be necessary. A consultant should be retained to recommend appropriate locations and measurement protocol, once sites with potential free access are defined and legal arrangements and funding are provided.

Ideally, ground water level measurements should be made monthly; however, quarterly measurements would be the minimum acceptable frequency. It may be possible to get interested local citizens to take the water level measurements and transmit the raw data to the responsible City staff. Otherwise, the data collection work would need to be done by City staff. A permanent file should be established for each well into which the raw data would be placed. At intervals as personnel time and funding permit, the data should be organized on a computer spreadsheet such as "Lotus", and trends could be plotted using the "Lotus" plotting capabilities.

As funds become available or specific development proposals create the demand, the computer models generated for this study could be updated and calibrated to the data that would be collected. Calibrations for seasonal variations could eventually be made.

F) PROMOTE PUBLIC EDUCATION

This objective recognizes that if each island property owner understood how his actions affected the ground water table and the potential for salt water intrusion, then the islanders would do much of the work themselves in protecting ground water quantity. The objective, then, is to inform the islanders of the facts concerning their ground water resource and to tell them how their actions can affect the resource.

The science of ground water hydraulics is a difficult one for lay people to understand. Although we hope that this report will help to educate the public, we realize that its shear size and scope will prevent it from being read by most people. We recommend that a separate brochure be prepared for the islands that can be distributed to each property owner that will summarize the pertinent facts using simple graphic illustrations.

### 6.3.2 PRESERVE QUALITY

#### A) PREVENT QUALITY DEGRADATION

Different types of land use create different types and intensities of water quality impacts. The primary forms of impact that are created by the major land use types are discussed below.

Impacts of Residential Use and Development

Reduction in recharge rate is not the limiting factor to permissible residential densities, particularly in areas served by subsurface sewage disposal systems. The primary impact from residential housing with septic tanks is on ground water quality. This impact comes from two main sources: bacterial and virus contamination; and nitrate-nitrogen contamination of the ground water caused by subsurface sewage disposal systems.

Nitrate-nitrogen is generally considered to be the most limiting contaminant in residential sewage and is discharged into the leachfield from the septic tank in concentrations that range from 30 to 70 mg/l on the average. About one-half the nitrate-nitrogen is denitrified in the soil above the water table, but once nitrate reaches the water table, it is usually only attenuated by dilution with other ground water. Nitrate-nitrogen is dangerous to young children and can cause death in concentrations as low as 20 mg/l. It causes methemoglobinemia, or "blue-baby syndrome". The federal and State Safe Drinking Water Limit for nitrate-nitrogen in potable water is 10 mg/l. Using a simple mass balance model to calculate the concentration of nitrate-nitrogen in the ground water as a function of residential density, one can calculate that there is enough rainfall dilution in a sand and gravel aquifer to allow 2 dwelling units per acre. However on areas of thick till, where runoff is greater and rainfall recharge is less, only 0.5 dwelling units per acre can be put on the land. Table 2 summarizes some approximate "rules of thumb" for permissible residential density as a function of soil type for developments using subsurface sewage disposal. Although this table may be suitable for initial evaluations, it is not a substitute for a site-specific evaluation (which may require computerized ground water models) of large developments.

RGGI has evaluated the effects of subsurface sewage disposal on the water quality of the bedrock aquifers under the islands for the theoretical scenario that each island would be developed with onsite subsurface sewage disposal systems to its maximum permitted residential density as currently zoned (this included the new IR-3 zone on Great Diamond Island). This did not include consideration of grandfathered lots, some of which are smaller than presently permitted lot sizes. Using the computerized solute transport models that were developed for this study, we distributed the sewage load in the soil (overlying aquifer) as if it were a "conservative" contaminant (one not removed by adsorption, chemical reaction, volatilization, etc.), which would be the case for chloride and nitrate-nitrogen. Figures 27 through 30 show the results of the simulations where the contaminant concentrations have reached table. Therefore, for nitrate-nitrogen which enters the ground water under a subsurface sewage disposal system serving a single-family dwelling at an average concentration of 30 mg/l, the 30% isocon represents 30% of 30 mg/l, or 9 mg/l. If background nitrate-nitrogen is 1 mg/l in uncontaminated ground water, at the 30% isocon the Safe Drinking Water Standard of 10 mg/l would be exceeded. The Diamond Islands and almost all of Cliff Island would appear not to have problems if proper septic systems were widely dispersed under the presently allowed densities. However, several areas on the northwest shore of Long Island are suggested by the modeling to have permitted densities that would create ground water contamination from septic systems, preventing those areas from being used as ground water well supplies unless treatment were provided. We recommend a review of the permitted densities on Peaks and Long Islands.

New information on the dangers of virus and bacterial contamination from septic systems has begun to emerge. According to Yates (1985), the U.S. Environmental Protection Agency has designated areas with a septic tank density of greater than 1 per 16 acres as regions of potential contamination problems. Based on the discussion in Yates (1985) and Canter and Knox (1985), which is the most recent literature available on the subject, it appears that definite problems have been shown to occur when densities exceed 0.33 units per acre and travel times to the nearest well are less than 170 days. In the bedrock aquifers on the islands, in this time period, a particle of ground water would typically move 300 to 500 feet.

Although bedrock aquifers may have a somewhat lower permeability than sand and gravel aquifers, the porosity is usually much lower by as much as 2 to 3 orders of magnitude and bedrock aquifer ground water slopes are steeper than the slopes for sand and gravel aquifers. Therefore, contaminants may travel much farther in a bedrock aquifer in the same time period than would occur in a sand and gravel aquifer. The primary protection for a bedrock aquifer must therefore rely on the soil thickness and permeability overlying the recharge area. It may be difficult to provide an adequate protection radius around bedrock wells that would insure a minimum of 170 days travel time to the nearest bacteria or virus source (such as a septic system), particularly in a high yield bedrock aquifer. It is therefore important to insure that subsurface sewage disposal systems are built properly and are operating properly and that maximum separation distances are maintained between wells and subsurface sewage disposal systems.

Although there are advantages to cluster housing development, large centralized subsurface sewage disposal systems can cause localized excessive contamination of ground water. A full hydrogeologic study should be done as part of the design of any large centralized subsurface sewage disposal system. To minimize the impact of sewage disposal systems, it is desirable to disperse the systems as much as possible.

## Agricultural Impacts

The most common ground water impacts from agricultural land use are water quality degradation from bacteria in manure and from nitrate-nitrogen in both fertilizer and manure. These effects can be particularly noticeable in areas of thin soil cover.

quality degradation from bacteria in manure and from nitrate-nitrogen in both fertilizer and manure. These effects can be particularly noticeable in areas of thin soil cover.

A problem more recently recognized is ground water contamination resulting from the use of herbicides and pesticides. Not much is known about the persistence of the many chemicals that are in use, but the Maine Board of Pesticides Control has taken a conservative approach in the use of these chemicals. Risk assessments on many commonly applied pesticides and herbicides are available through the Board of Pesticides Control. We can make no blanket recommendation with respect to the use of these chemicals in recharge areas other than to use extreme caution and refer potential problems to the appropriate Maine state agency.

Commercial and Industrial Impacts

The most prominent effect of commercialization is reduction in recharge due to creation of impervious area. The types of waste produced and the methods of waste disposal should be carefully controlled. This is probably best accomplished with the Site Plan Review ordinance. These types of uses are the ones most commonly associated with storage and use of hazardous materials and petroleum products. Based on a few articles that we have read (such as Johnson and Dendrou, 1984) and our experience working with petroleum spills in Maine, we recommend that extreme caution be used in siting and containing petroleum storage, since any leak could contaminate a large portion of an island aquifer for a number of years. For commercial facilities, we recommend double containment, ground water monitoring and/or other protective measures as given in the Maine (DEP) Standards for Permitting Underground Oil Storage Facilities in areas situated over sand and gravel aquifers for <u>all areas of the islands</u>.

Resource Extraction

There is a large demand for sand and gravel and the need for random fill could provide an incentive to develop borrow pits in other soil types. Similarly, the demand for topsoil is great and could result in stripping of large land areas. Opening of new borrow pits is presently prohibited under the zoning ordinance. Due to the cost of transporting fill and gravel, there may be pressure to relax this prohibition, or to expand existing grandfathered uses. The impacts of mining include: a) the removal of the topsoil filtering medium; b) increased evaporative loss of water when excavations go below the water table; c) increase of ground water temperatures when excavations go below the water table; and d) reduction in ground water recharge in winter and spring months where the stripped areas do not drain into a central depression.

Bedrock quarries may also be opened to provide erosion protection riprap, concrete and other aggregates, and random fill. The same impacts that occur with sand and gravel pits can occur with rock quarries.

Finally, there is the need to reclaim land that has been mined, and too often in the past, if reclamation has been done at all, it has been done with undesirable refuse. Land filling is now tightly controlled by the Maine Dept. of Environmental Protection.

Transportation Effects

Other than the impervious cover created by roads, the major ground water impact from roadways is chloride and sodium contamination caused by highway deicing salts. These salts leach from sand and salt stockpiles, as well as washing off roads on which salt has been spread for ice control. Several wells on Long Island appear to be affected more by road salt contamination than by salt water intrusion. Hutchinson (1970) found that salt contamination of wells and farm ponds adjacent to highways was common and inversely proportional to distance from the road. As the price of salt and the cost of spreading it rises, there will be less contamination of ground water from road salt over time. Salt and salt-sand stockpiles should be banned from the bedrock aquifer recharge areas or the stockpiles should be put under cover and on an impermeable base so no salt will leach into the ground.

Land Use Controls

A fundamental tool in controlling land use control is the zoning ordinance. The major variable in establishing the aquifer protection zone criteria is how conservative the City wants to be in protecting its resource. If the City wishes to maintain a high quality ground water resource with essentially no degradation in quality or recharge potential, then the controls must be quite strict. However, if there are economic or other pressures to allow some development, the City may wish to trade off some land use protection against a higher cost of water treatment and a greater risk of some catastrophic contamination occurring to the aquifer.

An important zoning mechanism on the islands is the IR-3 zone. The IR-3 zone could provide needed flexibility to site development in order to preserve sensitive recharge areas in their natural condition. Any IR-3 proposal should be analyzed carefully and the City should consider density restrictions to maintain the 1 dwelling per acre density average. The information provided in this report can assist the City in reviewing development proposals for an IR-3 zone or any other development proposal. However, the City should require that an applicant prepare a ground water impact study for a larger scale development on a particular site.

B) ASSUME ISLANDS MUST BE SELF-SUFFICIENT IN WATER SUPPLY & SEWAGE DISPOSAL

This is a simple policy concept that we recommend. We recognize that Peaks Island and the Diamond Islands have water supplied by the Portland Water District and that portions of Peaks Island have a sewage collection system. However, we believe that islands should be islands of self-sufficiency as well as physical islands. The densities of islands should not be dictated by certain urban amenities that may exist today, but should be regulated by the ability to suffice from what the island itself can supply in the way of water supply and sewage disposal. This is simply a policy with which the City Council can either agree or disagree.

C) LIMIT HOUSING AND COMMERCIAL DENSITIES TO THOSE DICTATED BY WATER QUALITY IMPACTS

This objective assumes that in addition to concerns about loss of recharge and the need to limit densities to well water demand, there is also a need to limit the degradation of the water quality such that the cumulative impacts of all present and future permitted development do not cause the water quality to fail to meet the Maine Primary Drinking Water Standards. We urge this standard because we believe it is cheaper to preserve water quality in a potable state than take polluted water out of the ground and treat it either at individual points of use or at a central treatment station. This is a tradeoff, or course, which must be weighed, but we believe that adoption of this important policy standard will be in the best long-term interest of the inhabitants and visitors to the islands. We also point out that at present, on a State level, all ground water in Maine is in only one Classification--it must be potable. To adopt a policy allowing degradation below Safe Drinking Water Standards would go against present State policy.

D) SET WATER QUALITY PERFORMANCE STANDARDS FOR DEVELOPMENTS

This objective specifies a performance standard for all developments that must come under Site Plan or Subdivision review. This performance standard would be adopted as a regulation in the ordinances and would represent an interpretation of the State Subdivision Statute criterion that a subdivision "will not, alone or in conjunction with existing activities, adversely affect the quality or quantity of ground water". The regulation would state: <u>"No development shall create an adverse impact on ground water quality. An adverse impact would result if a development would increase any contaminant concentration in the ground water more than one half of the difference between the background concentration before development, and the Primary Drinking Water Standard for that particular contaminant</u>". This standard leaves room for other down-gradient development which might otherwise be pre-empted if all of the allowable water quality increment is used by one development. It removes the 'first come, first serve' policy that presently exists in the Maine Dept. of Environmental Protection Site Location Law regulation that allows a developer to use all of the available increment to the Safe Drinking Water limit. We do not feel that this is appropriate long-term planning policy. Another advantage of our proposed policy is that it allows some room for error in evaluating impact. It is important to understand that prediction of ground water impact is a difficult science and requires much expensive data collection. There are many sources of error in the prediction process. Leaving some room for error is important in any long-term policy.

We have discussed only the Primary Drinking Water Standards up to this point. There are "Secondary" standards which deal with esthetic quality for contaminants (such as iron, manganese, and chloride) or chemicals having a health effect on only a limited portion of the population (such as sodium which affects some people with heart conditions). In some cases, such as on Cliff Island, the secondary standard for manganese and/or iron is naturally exceeded in the bedrock ground water due to the dissolution of naturally occurring minerals in the rock. However, certain types of development impacts can exacerbate existing problems or create new problems with parameters covered under the "secondary" drinking water standards. These should also be evaluated by the developer, but the Planning Board would have to determine whether the impact is excessive on a case-by-case basis. An alternative would be to set a standard such that no development would cause the secondary standards to be exceeded, except in the case where the background quality already exceeds the standards, in which case the development would not cause the concentration of the parameter in question to exceed 150% of the ambient concentration. This should be particularly observed in the case of sodium, which has health-related effects. Discharge of the salt brine from home water softeners into subsurface waste water treatment systems can result in high concentrations of sodium in ground water.

The subdivider should be required to map basic soil, water table, and drainage conditions and provide an analysis and evaluation of the subdivision's impact on the ground water resources. The developer should be required to lay out subsurface sewage disposal areas and wells in a manner that will minimize off-site ground water contamination. These locations should not be changed without the approval of the Planning Board. The ground water quality impacts of large developments with subsurface sewage disposal areas should be evaluated to determine the concentration of nitrate-nitrogen at the project boundary. The ground water impacts of commercial developments would have to be investigated by appropriate techniques so that the burden of proof on the part of the developer is sustained.

An important policy decision to be made is where pollutant levels should be measured to determine compliance with the ordinance. The Maine Dept. of Environmental Protection has adopted the convention of measuring the impact at the project down-gradient property boundary. We suggest that this be modified somewhat so that a large piece of property will not be used to dilute a high intensity contaminant source, by stating that the project impact should be determined no farther than 500' away from potential sources, or the property boundary, whichever is closer. Any plan or demonstration purporting to show compliance with the applicable Performance Standards must be prepared by a State Certified Geologist or Registered Professional Engineer with experience in hydrogeology.

Finally, the issue of long-term ground water monitoring needs some consideration. It is imperative that the "background" quality be determined before the development is approved, so that the available increment of degradation will be known by the hydrogeologist performing the impact analysis. This requires the installation of a <u>minimum</u> of 3 ground water monitoring wells. Occasionally, but not always, this arrangement would also suffice for long-term monitoring purposes. Based on the hydrogeologist's determination of the time it would take for any potential contaminant to reach a steady-state chemical distribution in the ground water, it may be possible to terminate the monitoring program after several years of measurements from the time the development is completed. However, in the case of monitoring for potential petroleum tank leaks, of course the monitoring must continue as long as the tank is in service.

E) CONTROL DISPOSAL AND STORAGE OF HAZARDOUS AND SOLID AND LIQUID WASTE MATERIALS

Since hazardous materials and solid and liquid wastes have the potential to cause catastrophic contamination of the island water supplies for tens of years, it is imperative that these substances be handled very carefully. The types of waste materials that are commonly associated with large populations include landfills handling domestic waste and garbage, septic sludge disposal areas, stump dumps and demolition debris disposal areas, ash disposal areas, solid waste transfer stations, and manure disposal.

We suggest that all hazardous material storage (or disposal) and all solid and liquid waste disposal (except common sewage) be generally prohibited, or at a minimum, where such materials are essential to the needs of islanders, be restricted to those portions of the islands that are bedrock discharge areas. In these areas, if a leak, spill, or leaching did occur, it would not affect the basic bedrock aquifer resource. An experienced hydrogeologist can determine whether a particular point is a recharge or discharge area, although certain areas may reverse from one season to the next. Our Special Features maps designate the bedrock discharge areas as we presently believe them to be and can be used for general planning purposes. To implement this guideline, the Zoning Ordinance would state that disposal of solid waste, liquid waste not including domestic sewage, and storage and/or disposal of hazardous materials shall not be done in bedrock aquifer recharge areas.

Manure and manure sludge disposal can be controlled by inserting regulations in the Health Ordinance that all storage and land disposal of manure shall be done in conformance with the procedures prescribed by the Cumberland County Soil and Water Conservation District Technical Guide, Standard and Specification Number 313 and the Maine Guidelines for Manure and Manure Sludge Disposal on Land. Land disposal requires a knowledge of USDA soil series occurring on the land. A high intensity soil survey must be performed by a Maine Certified Soil Scientist as part of the manure disposal planning process.

Whenever a commercial development proposes to make, store, or dispose of materials potentially deleterious to ground water quality, the following should be required from the developer:

a) detailed chemical and physical analysis of the material
b) written monitoring plan and inspection schedules
c) personnel training program details
d) contingency plans for handling accidents
e) manifest system for accounting for material quantities and transport
f) ground water monitoring program
g) closure plan covering post-closure care
h) description of how financial responsibility is established for handling spills and post-closure care

Common types of commercial establishments which generally have hazardous substances on their property include:

| | |
|---|---|
| boat yards | gas stations |
| dry cleaners | marinas |
| machine shops | gardening stores |
| paint and hardware stores | refrigeration service shops |
| earth work contractors | building contractors |

F) CONTROL SALT WATER INTRUSION

Salt water intrusion into island wells will not only render the water not fit to drink; it will also corrode plumbing fixtures and can cause health effects on people who should be on a salt-free diet. Desalinization is an expensive process both in terms of capital investment and operating expense. The need for desalinization should be avoided if at all possible.

The types of controls necessary to prevent saltwater intrusion were already discussed under the Objectives A, C, and D of the "Preserve Quantity" goal. In general, well demand should be as dispersed as possible, well drawdowns should be limited, recharge capability should be preserved or enhanced, and developers should document their impacts. In this case, a well pumping test, combined with an analytical or computerized ground water model should be able to predict whether salt water intrusion might occur due to a new well demand.

G) DEVELOP AN EMERGENCY RESPONSE PLAN

Accidental release of materials harmful to ground water quality will inevitably occur no matter how much care is taken in planning for prevention. One of the most common occurrences is a petroleum tank leak, or traffic accident involving a petroleum transporting vehicle. It is imperative to act swiftly and correctly when accidents like this occur. Although the Portland Dept of Public Works has emergency response plans and the Maine DEP has emergency response plans that can be put into action swiftly on the mainland, these trained and well-equipped teams can not respond quickly to accidents on the islands. It is necessary to assume that the initial response to these types of emergencies must come from people living on the islands. A team of island people must be trained and equipped to react as the "first response" team to the various types of emergencies that might occur--particularly as to the proper responses to protect ground water in addition to immediate protection of life and property.

The Maine Dept. of Environmental Protection may be able to provide training courses or at least appropriate training literature to the island response teams. These Public Works Dept should organize and equip these teams with appropriate knowledge and equipment to react to typical emergency situations such as petroleum spills that could endanger ground water.

H) CONTROL "NON-POINT" POLLUTION SOURCES

The federal Environmental Protection Agency (EPA) draws a distinction between an identifiable liquid discharge from a pipe (a "point" source) and all other sources of pollution. Therefore, many things which many people might think of as point sources, are classified as non-point sources by the EPA. The following is a list of potential "non-point" sources: subsurface sewage disposal systems; petroleum storage tanks; resource mining; material stockpiles; sand/salt or salt piles; pipelines; agricultural practices; roadway application of salt; heat pumps using ground water; and abandoned wells.

a) Sewage Disposal Systems

With respect to subsurface sewage disposal systems, we have already discussed the control of these systems in terms of the allowable densities and evaluation of impact. We suggest that the City also adopt an ordinance that would extend Part II of the State Plumbing Code to require that single family garbage disposal units only be permitted when septic tank capacity is increased 250 gallons in size beyond that required for the design flow. In addition, we believe that the following would be important to the ground water quality of the islands:

1) Institute a periodic inspection program of all subsurface sewage disposal systems on the islands (every three to five years) by a properly trained City employee. The inspection would involve looking for signs of malfunctioning which is quite evident as wet spots, septic odor, and certain types of vegetation. If malfunctions are found, the City should order the systems to be repaired.

2) Require that whenever an island property which includes a subsurface sewage disposal system is sold, that the sewage system must be inspected by a Licensed Site Evaluator and either certified to be working properly, or re-designed and re-built to the present Plumbing Code Standards (replacement system variances are permissible) in the case where the Licensed Site Evaluator feels that the system is not or will not function properly for the proposed use of the new owner.

b) Petroleum Storage Tanks

Petroleum storage tanks--both above ground and buried--represent a great threat to ground water quality. Tough new regulations adopted by the Maine Dept. of Environmental Protection control the installation of new tanks and abandonment of tanks. However, existing tanks--particularly those serving single family homes or small businesses--may be leaking without anyone's knowledge. Most existing tanks are steel tanks but steel tanks have a limited life span, which is particularly short in the corrosive environment of the Maine islands. We recommend that the Mechanical Section of the Building Code be amended to require that all commercial petroleum storage tanks that are located in bedrock aquifer recharge areas as shown on our "Special Features" maps (or as proven by the applicant) have double containment, ground water monitoring and/or other protective measures as given in the Maine (DEP) Standards for Permitting Underground Oil Storage Facilities in areas situated over sand and gravel aquifers. Furthermore, we suggest that a regular house-to-house inspection schedule of petroleum tanks be set up on a 3 to 5 year periodic basis (perhaps at the same time as the subsurface sewage disposal system inspections recommended above) to check the condition of tanks. If a tank is found to be dangerously corroded or leaking, a repair would be ordered. In the educational brochure prepared for the island residents, the importance of preventing petroleum products and other hazardous materials from leaking should be emphasized.

c) Resource Mining

We have already discussed resource mining, and it is our understanding that non-grandfathered pits and mines are not permitted under the present zoning ordinance. We understand that there are some grandfathered pits on the islands. We suggest that the Zoning Ordinance be amended to cover operation of all pits and mines within the City limits to include the following standards:

i) all petroleum products should be kept out of the pit and if refueling and oil changes must be conducted in the pit, a special area must be constructed that would prevent even the maximum possible spill from entering the ground. Absorbent pads should be kept onsite to be used immediately, should any petroleum products be spilled on the soil.

ii) there shall be no storage or dumping in the excavation of any substances that could produce a harmful leachate, unless such substances are placed under cover and on an impermeable, spill-proof base. Such potentially deleterious substances include, but are not limited to salt, rubbish, creosoted timber, and petroleum products.

iii) any washing or crushing operations should be conducted in a manner that will minimize runoff and evaporation.

iv) no paving, salting, or oiling of access and haul roads will be permitted.

v) no ditches, trenches, pumping or other methods shall be used to lower the water table in a gravel pit to permit more gravel extraction than could occur under natural conditions.

vi) access to the pit shall be strictly controlled at all times with locking gates and when the operations are finished, all vehicular entrances shall be made impassable.

We suggest the following plan submission requirements for resource mining:

a) The applicant shall provide a map of the seasonally high ground water contours (contours on the permanent--not perched--water table) in the proposed area of mining. The plan should indicate the location of borings that were made to determine the position of the water table, and logs of the borings should be provided to the Planning Board. The ground water contours should be referenced to a local benchmark that can be used in the future by the Code Enforcement Officer to determine compliance of the pit operator with the performance criteria relating to the permissible depth to which mining may proceed relative to the water table position.

b) The applicant shall provide any plans for washing operations, including plans for ground water extraction to provide water for washing. The temporary and long-term management plans for siltation basins shall be defined. The ground water extraction wells should not lower the ground water on the project boundaries by more than 10 feet.

c) The applicant shall provide plans for storage of salt, petroleum products, and other potentially deleterious substances; shall show compliance with our suggested performance criteria in that regard; and shall develop contingency plans for handling any unintended ground water contamination or accidental spills of contaminants.

d) Material Stockpiles

Other non-point source impacts can come from material stockpiles. (Sand/salt piles are discussed in the next paragraph.) Typical stockpiles that might be expected on the islands include wood products and materials that would be part of a general contractor's operation such as steel reinforcing bar, creosoted timbers and equipment of various types. Paint thinners, degreasers and other similar chemicals can usually be found in the ground near general contractor-type garages and storage areas. It is obviously important to require operations of this type to control tightly the storage, use and disposal of these materials.

Sand/salt piles for winter road deicing are located on Peaks, Long, and Great Diamond Islands. The salt, in the form of sodium chloride, is added to the stockpile to keep the sand from freezing during the winter (in which case it would not be able to be loaded into trucks). However, sand/salt piles can have a serious deleterious effect on ground water quality. The Town of York paid a judgment of over $300,000 to a group of homeowners who sued the Town for damage to their wells and concomitant reduction in property values because the Town sand/salt pile was proven to have contaminated the wells. Sand/salt piles and salt piles should not be located in aquifer recharge areas unless they are covered and located on an impermeable base.

Roadway application of salt or sand/salt has decreased in recent years due to the high cost (see discussion of transportation effects on ground water quality). We understand that the islands do not use straight salt and we expect that sand/salt use is very sparse in any event. We expect that there will only be a few isolated instances of road salt contamination.

e) Pipelines

Other than standard sanitary sewer pipe, the only pipeline that could have a major ground water impact would be the petroleum pipeline on Long Island. Although this is currently not in use, we understand that it could be reactivated at some time in the future. Since this is a pre-existing use, it is more difficult to control than a new pipeline would be. Periodic inspection and testing, coupled with ground water monitoring is the only way to detect problems.

f) Agriculture

Agricultural practices were discussed in previous sections. Control of agricultural practices is perhaps the most difficult of all land uses, since it has been very difficult to pass enabling legislation to gain control over agricultural operations. A combination of public education effort and funding for projects such as concrete-lined manure storage pits has been moderately successful in the lakes regions of Maine in limiting surface water impacts. The State Board of Pesticide Control has tightly regulated the use of pesticides and herbicides. Other measures that can control agricultural impacts are discussed elsewhere in this report.

g) Heat Pumps

Heat pumps using ground water for the heat exchange medium are becoming more common, particularly in the mid-West. We expect these types of applications will become more common in Maine, particularly if energy prices rise again. Heat pumps will definitely change ground water temperatures and consequently will affect water viscosity and therefore aquifer transmissivity. In addition, anti-fouling chemicals added to heat pump systems may get introduced into the aquifer. Until more demand for heat pumps appears and more is known about their effects, we suggest the City ban the use of ground water as a heat exchange medium on the islands.

h) Abandoned Wells and Building Demolition

Abandoned wells and building demolition in general can cause ground water quality degradation. We have had the opportunity to monitor the effects of burning buildings on ground water quality next to the building. Burning should not be allowed on the islands as a means of demolition because ground water quality can be degraded for a period of several years. Typical water quality effects include high iron and manganese concentrations and increases in the concentrations of other heavy metals and Chemical Oxygen Demand. Abandoned wells should be properly sealed to prevent entrance of contaminated surface water into the aquifer, or perhaps allowing saltwater intrusion to move from one aquifer to another. Appendix F includes a typical specification for properly abandoning a drilled well. When a demolition permit is issued by the City, the Building Inspector should determine whether there is a well on the property and require that these specifications be followed as part of the demolition process.

I) DEVELOP A REMEDIAL ACTION PLAN FOR CONTAMINATED GROUND WATER

Remedial measures can include removing the sources of contamination and/or treating the contamination inplace and/or pumping out or purging the aquifer and/or blocking or relocating a contaminant plume.

The only instances of widespread ground water contamination that we know of on the islands occur in scattered locations on Long Island and are due to subsurface sewage disposal systems. These could be due to malfunctioning systems, excessive local densities of systems, or improperly sited systems. Other than doing a periodic survey of all systems and requiring malfunctioning systems to be reconstructed, the only other near-term program of which we are aware that could provide assistance in solving what is a very expensive problem is a Maine Dept. of Environmental Protection program that provides up to $100,000 to an individual city or town in Maine to study sewage disposal problems and fund solutions which may include rebuilding of individual systems. We suggest that the City staff apply for this grant to study and solve Long Island subsurface sewage disposal problems.

If salt water intrusion becomes prevalent, there are ways of reversing or inhibiting salt water intrusion. However, in bedrock aquifers which are non-isotropic and non-homogeneous, this can be a difficult problem. Nonetheless, given enough money and field data, appropriate technologies can be applied to the problem. Suffice it to say that avoiding saltwater intrusion is far easier than reversing it or treating salt water.

In terms of aquifer cleanup, natural flushing can be effective, given enough time, if the source of the contamination can be removed. For example, a good rule of thumb for the island bedrock aquifers is that a step change in aquifer contaminant concentration will take about 1 year to change concentration to about 63% of the step change. Therefore, if a source is terminated, natural flushing will reduce contaminant distributions (assume a steady-state had been obtained) to 63% in the first year; 63% of 63% in the second year, etc. These rules do not hold for chlorinated hydrocarbons which may persist for many more years than a dissolved contaminant such as chloride.

J) DEVELOP A LONG-TERM GROUND WATER QUALITY MONITORING NETWORK

As discussed under the similar item for the "PRESERVE QUANTITY" goal, a long-term monitoring plan is a necessary part of any ground water management plan. It will be particularly important on Peaks and the Diamond Islands where we presently have almost no data on ground water quality.

The objectives of a water quality monitoring program would be to establish a baseline water quality as soon as possible, then monitor certain key parameters (that are relatively cheap to test) on a quarterly basis with a more complete test on an annual basis. On Cliff Island and Long Island, existing domestic wells can probably be used if permission can be granted from the landowners. On Peaks and the Diamond Islands, monitoring wells will probably have to be drilled. This will involve interfacing with private landowners and obtaining long-term permission to get access to the property. As we suggested with respect to the "Preserve Quantity" monitoring objective, the City should hire a consultant to set up the monitoring program and inspect the installation of the monitoring wells.

K) PROMOTE PUBLIC EDUCATION

As with the "Preserve Quantity" public education objective, it is quite important to help people learn about how their life styles can influence ground water quality. They need to learn about the impacts of septic systems, about the effects of lawn fertilizers and herbicides, about pouring left-over gasoline or paint thinner on the ground, about the need to inspect fuel tanks, and about the basic ground water hydrogeology of their island. Although this report should begin the process, we believe that a special pamphlet prepared specifically for the islands and distributed to each property owner (e.g., with a tax bill) would be an important educational tool. The City, in adopting appropriate zoning and other land use regulations to protect ground water, will also provide an education process since many public hearings will be held and there will be much publicity.

## 7.0 SUMMARY

The summary is included in the letter of transmittal at the front of this report.

## BIBLIOGRAPHY


American Society of Civil Engineers, 1972, Ground Water Management, 216 pp. ASCE--Manuals and Reports on Engineering Practice--No. 40.

Bureau of Health, Health Engineering Division, Maine Department of Human Services--records of the water quality of individual water supplies on Peaks, Long, and Cliff Islands from 1962 to 1985.

Canter, L.W., and Knox, R.C., 1985, Septic tank system effects on ground water quality. Lewis Publishers, Inc., 121 S. Main St., Chelsea, Michigan 48118, 336 p.

Caswell, W.B., 1978, Ground-Water Handbook for the State of Conservation, Geological Survey, Division of Hydrogeology.

Caswell, W.B., and Lanctot, E.M., 1978, Ground water resource maps of Cumberland Co. Maine Geological Survey, Augusta, Maine 04333, maps at scale 1:250,000.

City of Portland, 1979, Peaks Island Sewerage System--Application for a modification of the NPDES permit no. ME 0101435 discharge serial no. 057 & 058.

Department of Planning and Urban Development, City of Portland, 1985, Islands Land Use and Zoning Study, 50 pp.

Department of Planning and Urban Development, City of Portland, 1985, Island Zoning Amendments, 45 pp.

Department of Public Works, City of Portland, 1984, (Draft Copy) Portland Islands Solid Waste Management Alternatives, 20 pp.

Dictar Associates, 1985, Request for re-zoning of a parcel of land on Great Diamond Island, includes supporting consultants reports and plates.

Eco-Analysts, 1985, Ecological assessment report--Great Diamond Island, a consultant's report for Dictar Associates, 29 pp and plates.

Freeze, R.A., and Cherry, J.A., 1979, Groundwater: Prentiss-Hall, Inc., Englewood Cliffs, NJ, 604 p.

Gerber, R.G. and Rand, J.R., 1980, Geology and Hydrology of Mason Station Ash Disposal Facility, Wiscasset, Maine. A consultants' report for the Central Maine Power Company.

Gerber, R.G. and Rand, J.R., 1982, Ground Water Resource Analysis for Harpswell, Maine. A consultants' report for the Town of Harpswell, Maine.

Gerber, R.G., Inc., 1986, Water supply questionnaires from the residents of Long and Cliff Islands. A survey for the City of Portland, Island Ground Water Management Study.

Gerber, R.G., Inc., (in progress), Hydrogeological Study of the Long Island Landfill Area, a consultant's report for Woodard & Curran, Inc.

Gordon, W., 1984, Citizen's Handbook on Groundwater Protection, 208 pp. Natural Resources Defense Council.

GPCOG, 1984, Assorted Land Use Maps of Peaks, Long, Cliff, Great Diamond and Little Diamond Islands.

Haskell, O.W., Inc., 1984, Subdivision plan of land on Little Diamond Island, Portland, Maine and soil test pit logs. A consultant's report for Saint Joseph's Convent and Hospital.

Hussey, A.M. II, 1981, Reconnaissance Bedrock Geology of the Casco Bay Quadrangle, Maine. Open File Map No. 81-31, at scale 1:62,500.

Hutchinson, F.E., 1970, Environmental pollution from highway de-icing compounds. Journal of Soil and Water Conservation, July-August 1970, pp 144-146.

Huyakorn, P.S. and Pinder, G.F., 1983, Computational Methods in Subsurface Flow, 473 pp. Academic Press, Inc., New York, N.Y.

Javandel, I.; Doughty, C.; Tsang, C.F.; 1984, Ground Water Transport: Handbook of Mathematical Models, 228 pp. American Geophysical Union, Water Resources Monagraph Series 10.

Johnson Division, UOP Inc., 1975, Ground water and wells; a reference book for the water-well industry: Johnson Division, UOP Inc., St. Paul, MN, 440 p.

Johnson, R.C., and Dendrou, S.A., 1984, Evaluation of the potential water supply impacts posed by the Transgulf Pipeline, Broward County, Florida, In Practical Applications of Ground Water Models, NWWA conference proceedings, August 15-17, 1984, pp. 584-602.

Jordan, E.C., 1977, The GPCOG Areawide Water Quality Management Plan: 201 Facilities Plan for the Islands of Portland Harbor.

Konikow, L.F. and Bredehoeft, J.D., 1978, Computer Model of Two-Dimensional Solute Transport and Dispersion in Ground Water. Techniques of Water-Resources Investigations of United States Geological Survey, U.S. Government Printing Office, Washington, D.C.

Land Use Consultants, 1986, Subdivision lot plan map and soil test pit logs for Jerry Point, Long Island, Maine. A consultant's report for Northland Properties, Inc.

Leavitt, H.W., and Perkins, E.H., 1934, A survey of road materials and glacial glacial geology of Maine. Bul. 30, Maine Technology Experiment Station, Univ. of Maine, Orono, Vol. I, Parts I and II, and map at scale of 1:453,168.

Leopold, L.B., 1968, Hydrology for urban planning--a guidebook on the hydrologic effects of urban land use. U.S. Geol. Survey Circular 554, Washington, D.C., 18 pp.

Lohman, S.W., 1979, Ground water hydraulics: U.S. Geol. Survey Professional Paper 708, 70 p.

Long Island Residents, 1985, Water quality data from private wells.

Office of Technology Assessment, 1984. Protecting the Nations Groundwater from Contamination, 244 pp. U.S. Congress, Office of Technology Assessment, OTA-O-233.

Pye, V.I.; Patrick, R.; and Quarles, J.; 1983, Groundwater Contamination in the United States, 315 pp. University of Pennsylvania Press, Philadelphia.

Richard, J.K., 1976, Characterization of a bedrock aquifer in Harpswell, Maine. Unpublished Master Thesis, Ohio State University, 141 pp and plates.

Soil Conservation Service, 1974, Soil survey, Cumberland Co., Maine. U.S. Department of Agriculture, Washington, D.C., maps at scale 1:20,000.

Smith, G.W., 1977, Surficial Geologic Map of the Casco Bay Quadrangle, Maine. Open File Map No. 77-11, at scale of 1:24,000

U.S. Environmental Protection Agency, 1980, Proposed Ground Water Protection Strategy. U.S. EPA, Office of Drinking Water, Washington, D.C.

Walton, W.C., 1984, Practical aspects of ground water modeling: National Water Well Assoc., Columbus, OH, 566p.

Well Survey Questionnaires, 1986, Residents of Long and Cliff Islands.

Yates, M.V., 1985, Septic tank density and ground-water contamination. Vol. 23, No. 5 Ground Water Journal of the NWWA, pp. 586-591.

# TABLE 1--LEGEND FOR WELL TYPE AND GEOLOGIC UNIT CODE

## Well Type Legend

| | |
|---|---|
| 1 | drilled (artesian) well in bedrock |
| 2 | dug well in soil in which the ground water seldom or never overflows |
| 3 | spring developed in soil in which the ground water overflows the ground at least part of the year |
| 4 | spring developed in bedrock where the ground water flows out of the bedrock and overflows the ground surface during at least part of the year |
| 5 | well point (in soil) |

## Geologic Unit Code

| | |
|---|---|
| 1 | diabase dike |
| 2 | Jewell Island Formation, sulfidic and non-sulfidic phyllite |
| 3 | Spurwink Formation, limestone |
| 4 | Scarboro Formation, sulfidic and non-sulfidic phyllite |
| 5 | Scarboro Formation, limestone |
| 6 | Diamond Island Formation, black sulfidic phyllite |
| 7 | Spring Point Formation, quartz-feldspar gneiss |
| 8 | Spring Point Formation, quartz-feldspar granofels |
| 9 | Cape Elizabeth Formation, sulfidic and non-sulfidic phyllite |
| 10 | Cushing Formation, quartz-feldspar gneiss |
| 11 | Cushing Formation, sulfidic schist |
| 12 | thick (>5') glacial till |
| 13 | thin (<5') glacial till |
| 14 | glaciomarine clay-silt |
| 15 | glaciofluvial sand and gravel, glaciomarine sand, and recent marine sand |
| 16 | glaciomarine silt and fine sand |
| 17 | swamp deposits |
| 18 | exposed bedrock and thin (<2') soils |

## TABLE 2--ALLOWABLE RESIDENTIAL DENSITIES AS LIMITED BY WATER QUALITY IMPACTS

| Geologic Unit Code | Soil Type | Natural Recharge Rate | Allowable Dwellings Per Acre | Allowable Acres per Dwelling |
|---|---|---|---|---|
| 12 | thick silty till | 0.23 gpm/acre | 0.5 | 2.0 |
| 13 | thin sandy glacial till | 0.57 gpm/acre | 1.3 | 0.8 |
| 14 | glaciomarine clay-silt | 0.11 gpm/acre | 0.2 | 4.2 |
| 15 | sand and gravel | 1.14 gpm/acre | 2.5 | 0.4 |
| 16 | glaciomarine fine sand and silt | 0.68 gpm/acre | 1.5 | 0.7 |
| 18 | thin soil over rock | 0.34 gpm/acre | 0.7 | 1.3 |

FORMULA FOR CALCULATING ALLOWABLE DENSITIES:

$$C_{nitrate} = C_b + \frac{(C_s \times q_s \times d)}{q}$$

$C_{nitrate}$ is the resultant concentration of nitrate-nitrogen in ground water as a result of subsurface sewage disposal systems

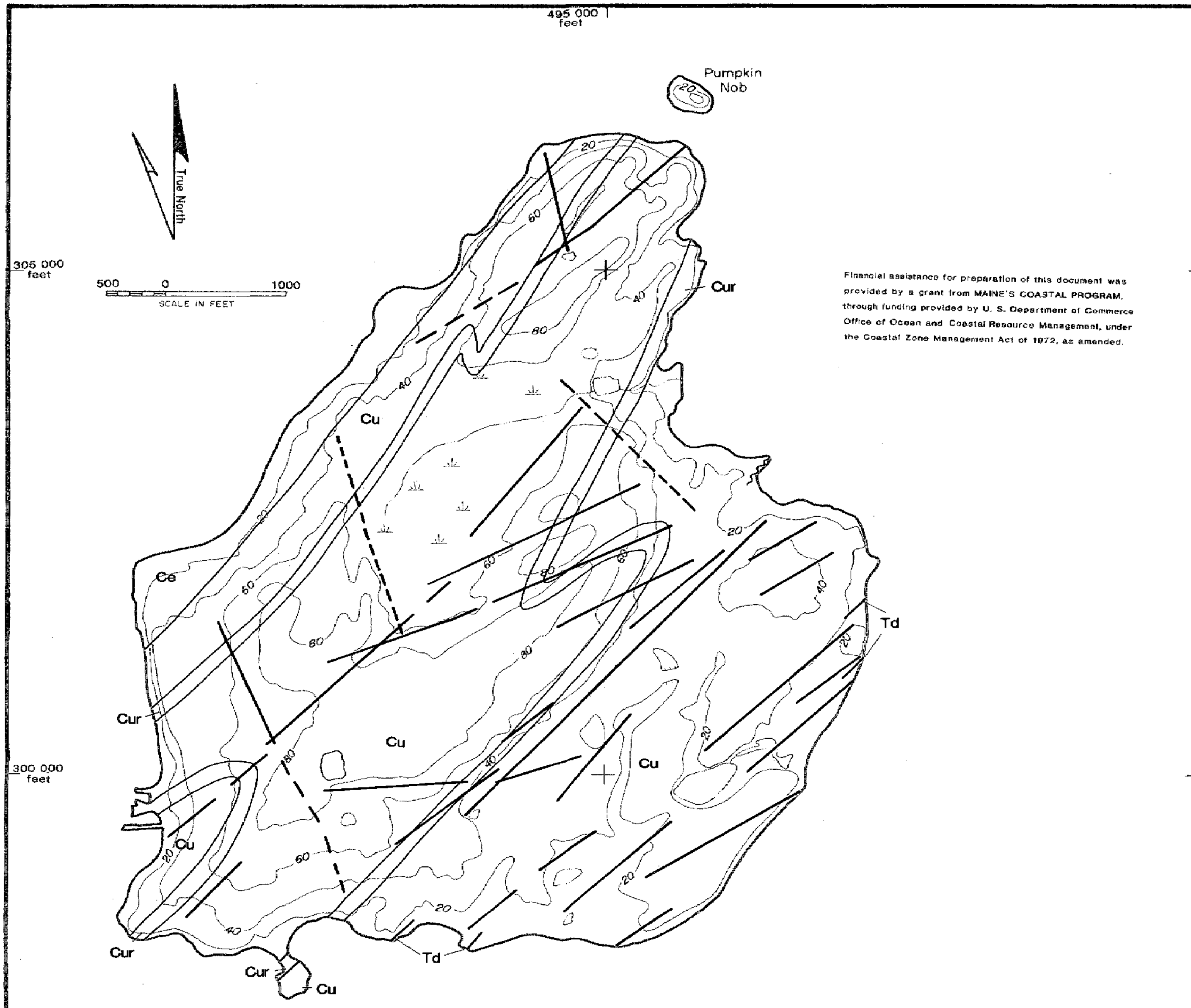
$C_b$ is the background concentration of nitrate-nitrogen in ground water, which is equal to about 0.25 mg/l (parts per million)

$q_s$ is the average leachfield discharge rate per dwelling, which is equal to 70% of 300 gallons per day or 0.15 gallons per minute

$q$ is the rate of natural ground water recharge, averaged over the year

$d$ is the allowable housing density in dwellings per acre which is derived algebraically

$C_s$ is the concentration of nitrate-nitrogen in septic tank discharges = 30 mg/l




Financial assistance for preparation of this document was provided by a grant from MAINE'S COASTAL PROGRAM, through funding provided by U. S. Department of Commerce Office of Ocean and Coastal Resource Management, under the Coastal Zone Management Act of 1972, as amended.

## LEGEND

| GEOLOGIC UNIT CODE | | Bedrock Formation | Rock Type |
|---|---|---|---|
| | | **IGNEOUS ROCKS** | |
| 1 | Td | Tabular Diabase Dikes | |
| | | **LAYERED METAMORPHIC ROCKS** | |
| 2 | Je | Jewell | Sulfidic and Non-sulfidic Phyllite |
| 3 | Sk | Spurwink | Limestone |
| 4 | Sc | Scarboro | Sulfidic and Non-sulfidic Phyllite |
| 5 | Scl | Scarboro | Limestone |
| 6 | Di | Diamond Island | Black, Sulfidic Phyllite |
| 7 | Sp | Spring Point | Quartz-Feldspar Gneiss |
| 8 | Sf | Spring Point | Quartz-Feldspar Granofels |
| 9 | Ce | Cape Elizabeth | Sulfidic and Non-sulfidic Phyllite |
| 10 | Cu | Cushing | Quartz-Feldspar Gneiss |
| 11 | Cur | Cushing | Sulfidic Schist |

SYMBOLS

Contact Between Formations (modified after Hussey, 1981)

High-angle Bedrock Faults

Photolinears

# BEDROCK GEOLOGY

FOR

CITY OF PORTLAND

ISLAND GROUND WATER MANAGEMENT STUDY

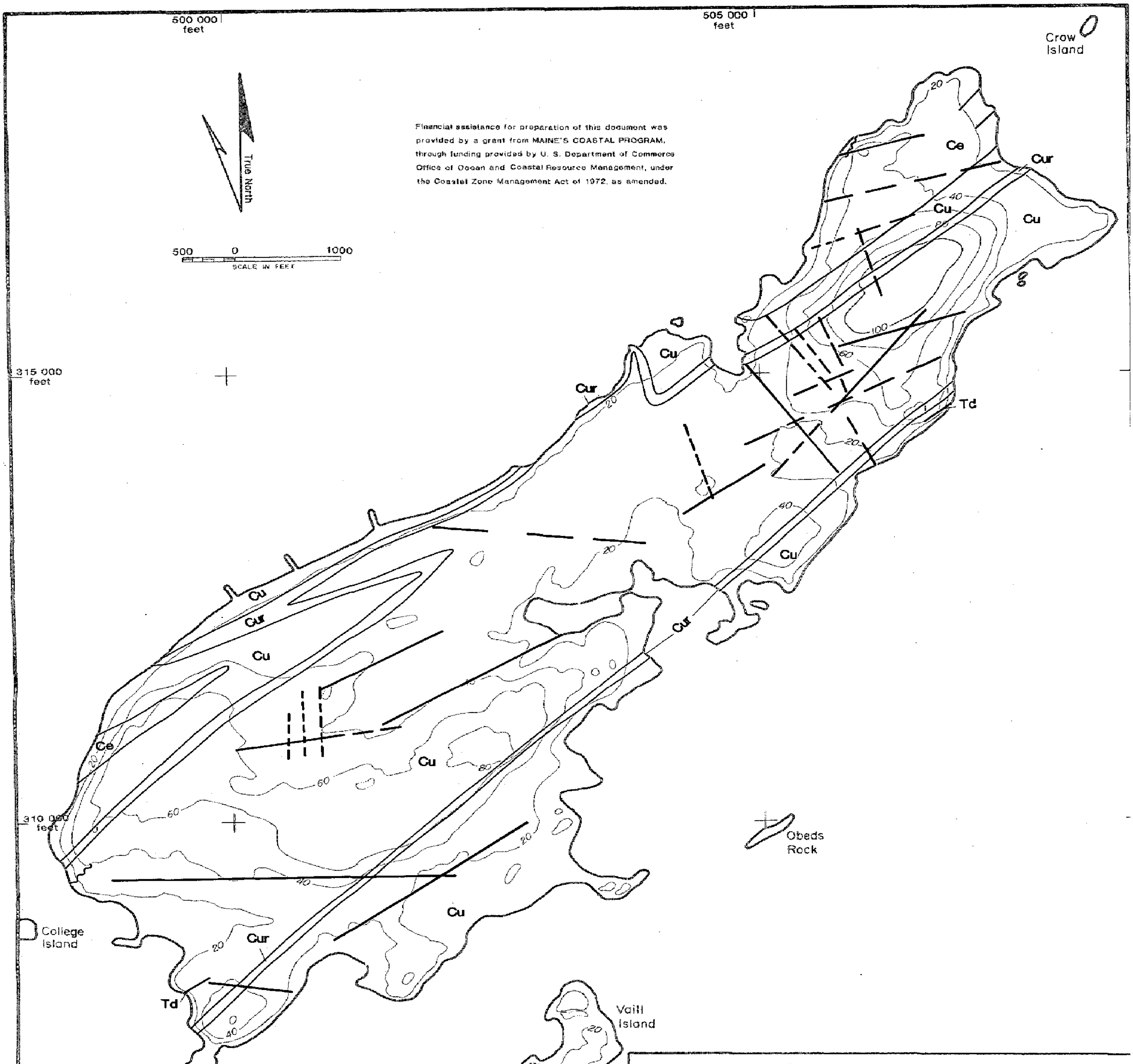
*BY*

*ROBERT G. GERBER, INC.*

*CONSULTING CIVIL ENGINEERS AND GEOLOGISTS*
*FREEPORT, MAINE*

## PEAKS ISLAND

DATE **JUNE 1986** | FIGURE **1**




Financial assistance for preparation of this document was provided by a grant from MAINE'S COASTAL PROGRAM, through funding provided by U. S. Department of Commerce Office of Ocean and Coastal Resource Management, under the Coastal Zone Management Act of 1972, as amended.

## LEGEND

| GEOLOGIC UNIT CODE | | IGNEOUS ROCKS | |
|---|---|---|---|
| 1 | Td | Tabular Diabase Dikes | |
| | | **LAYERED METAMORPHIC ROCKS** | |
| | | Bedrock Formation | Rock Type |
| 2 | Je | Jewell | Sulfidic and Non-sulfidic Phyllite |
| 3 | Sk | Spurwink | Limestone |
| 4 | Sc | Scarboro | Sulfidic and Non-sulfidic Phyllite |
| 5 | Scl | Scarboro | Limestone |
| 6 | Di | Diamond Island | Black, Sulfidic Phyllite |
| 7 | Sp | Spring Point | Quartz-Feldspar Gneiss |
| 8 | Sf | Spring Point | Quartz-Feldspar Granofels |
| 9 | Ce | Cape Elizabeth | Sulfidic and Non-sulfidic Phyllite |
| 10 | Cu | Cushing | Quartz-Feldspar Gneiss |
| 11 | Cur | Cushing | Sulfidic Schist |

**SYMBOLS**

Contact Between Formations (modified after Hussey, 1961)
High-angle Bedrock Faults
Photolinears

# BEDROCK GEOLOGY

FOR

CITY OF PORTLAND

ISLAND GROUND WATER MANAGEMENT STUDY

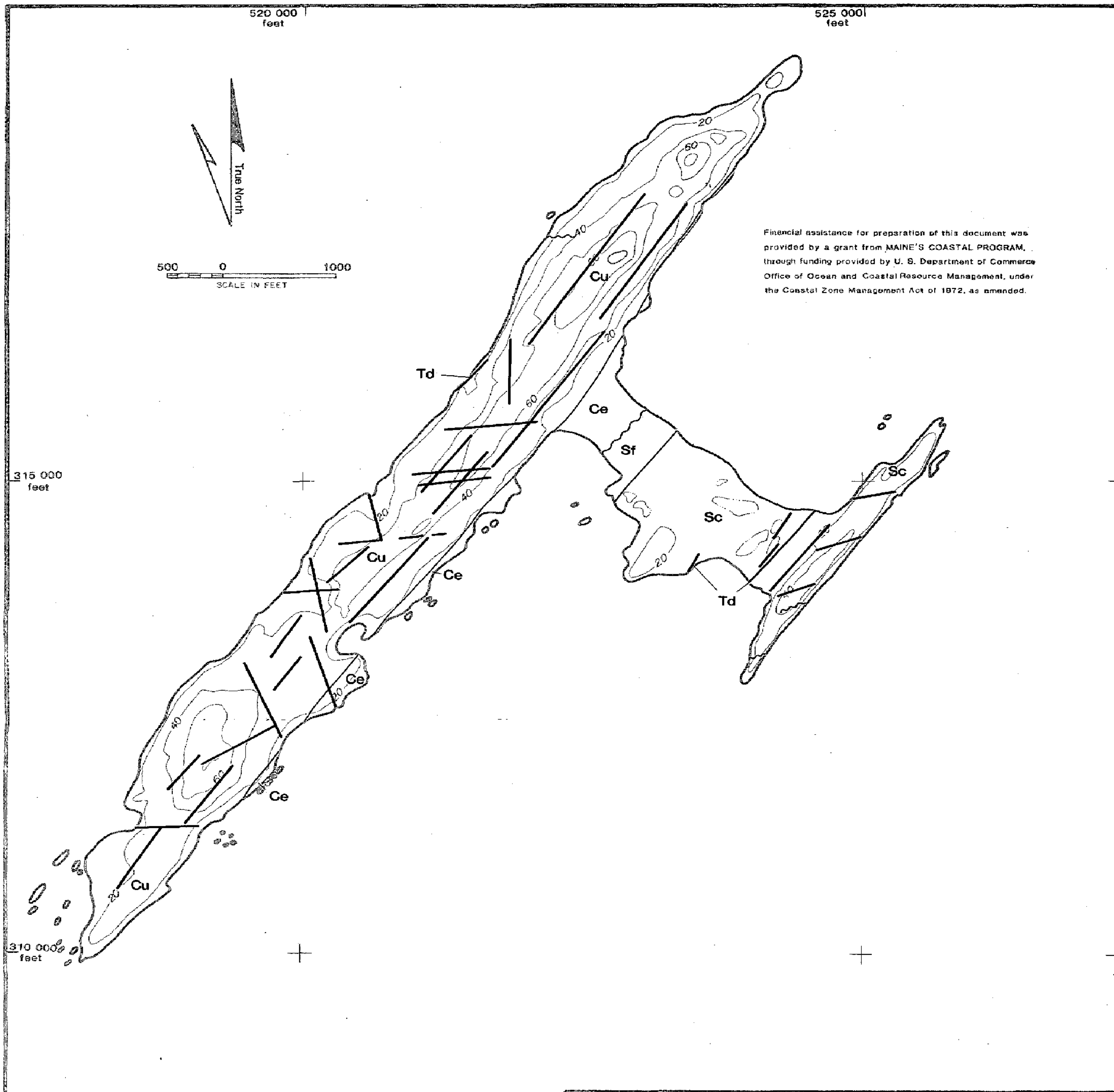
*BY*

*ROBERT G. GERBER, INC.*

*CONSULTING CIVIL ENGINEERS AND GEOLOGISTS*
*FREEPORT, MAINE*

## LONG ISLAND

DATE **JUNE 1986** | FIGURE **2**




Financial assistance for preparation of this document was provided by a grant from MAINE'S COASTAL PROGRAM, through funding provided by U. S. Department of Commerce Office of Ocean and Coastal Resource Management, under the Coastal Zone Management Act of 1972, as amended.

## LEGEND

| GEOLOGIC UNIT CODE | | | |
|---|---|---|---|
| | | **IGNEOUS ROCKS** | |
| 1 | Td | Tabular Diabase Dikes | |
| | | **LAYERED METAMORPHIC ROCKS** | |
| | | Bedrock Formation | Rock Type |
| 2 | Je | Jewell | Sulfidic and Non-sulfidic Phyllite |
| 3 | Sk | Spurwink | Limestone |
| 4 | Sc | Scarboro | Sulfidic and Non-sulfidic Phyllite |
| 5 | Scl | Scarboro | Limestone |
| 6 | Di | Diamond Island | Black, Sulfidic Phyllite |
| 7 | Sp | Spring Point | Quartz-Feldspar Gneiss |
| 8 | Sf | Spring Point | Quartz-Feldspar Granofels |
| 9 | Ce | Cape Elizabeth | Sulfidic and Non-sulfidic Phyllite |
| 10 | Cu | Cushing | Quartz-Feldspar Gneiss |
| 11 | Cur | Cushing | Sulfidic Schist |

**SYMBOLS**

- Contact Between Formations (modified after Hussey, 1981)
- High-angle Bedrock Faults
- Photolinears

# BEDROCK GEOLOGY

FOR

CITY OF PORTLAND

ISLAND GROUND WATER MANAGEMENT STUDY

*BY*

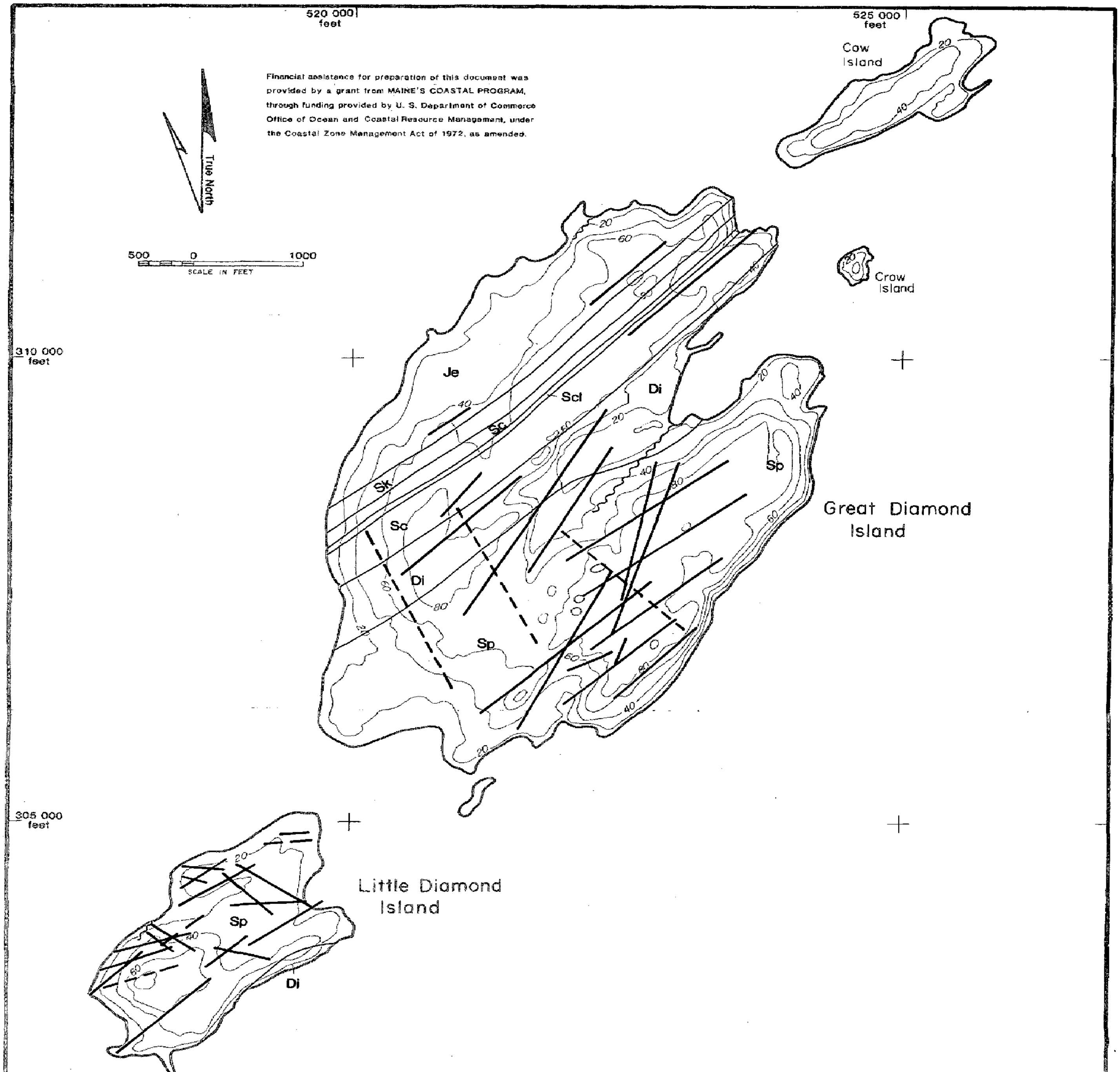
*ROBERT G. GERBER, INC.*

*CONSULTING CIVIL ENGINEERS AND GEOLOGISTS*
*FREEPORT, MAINE*

## CLIFF ISLAND

DATE **JUNE 1986** FIGURE **3**

Financial assistance for preparation of this document was provided by a grant from MAINE'S COASTAL PROGRAM, through funding provided by U. S. Department of Commerce Office of Ocean and Coastal Resource Management, under the Coastal Zone Management Act of 1972, as amended.




## LEGEND

| GEOLOGIC UNIT CODE | | |
|---|---|---|
| | | **IGNEOUS ROCKS** |
| 1 | Td | Tabular Diabase Dikes |

**LAYERED METAMORPHIC ROCKS**

| | | Bedrock Formation | Rock Type |
|---|---|---|---|
| 2 | Je | Jewell | Sulfidic and Non-sulfidic Phyllite |
| 3 | Sk | Spurwink | Limestone |
| 4 | Sc | Scarboro | Sulfidic and Non-sulfidic Phyllite |
| 5 | Scl | Scarboro | Limestone |
| 6 | Di | Diamond Island | Black, Sulfidic Phyllite |
| 7 | Sp | Spring Point | Quartz-Feldspar Gneiss |
| 8 | Sf | Spring Point | Quartz-Feldspar Granofels |
| 9 | Ce | Cape Elizabeth | Sulfidic and Non-sulfidic Phyllite |
| 10 | Cu | Cushing | Quartz-Feldspar Gneiss |
| 11 | Cur | Cushing | Sulfidic Schist |

**SYMBOLS**

Contact Between Formations (modified after Hussey, 1961)
High-angle Bedrock Faults
Photolineers

# BEDROCK GEOLOGY

FOR

CITY OF PORTLAND

ISLAND GROUND WATER MANAGEMENT STUDY

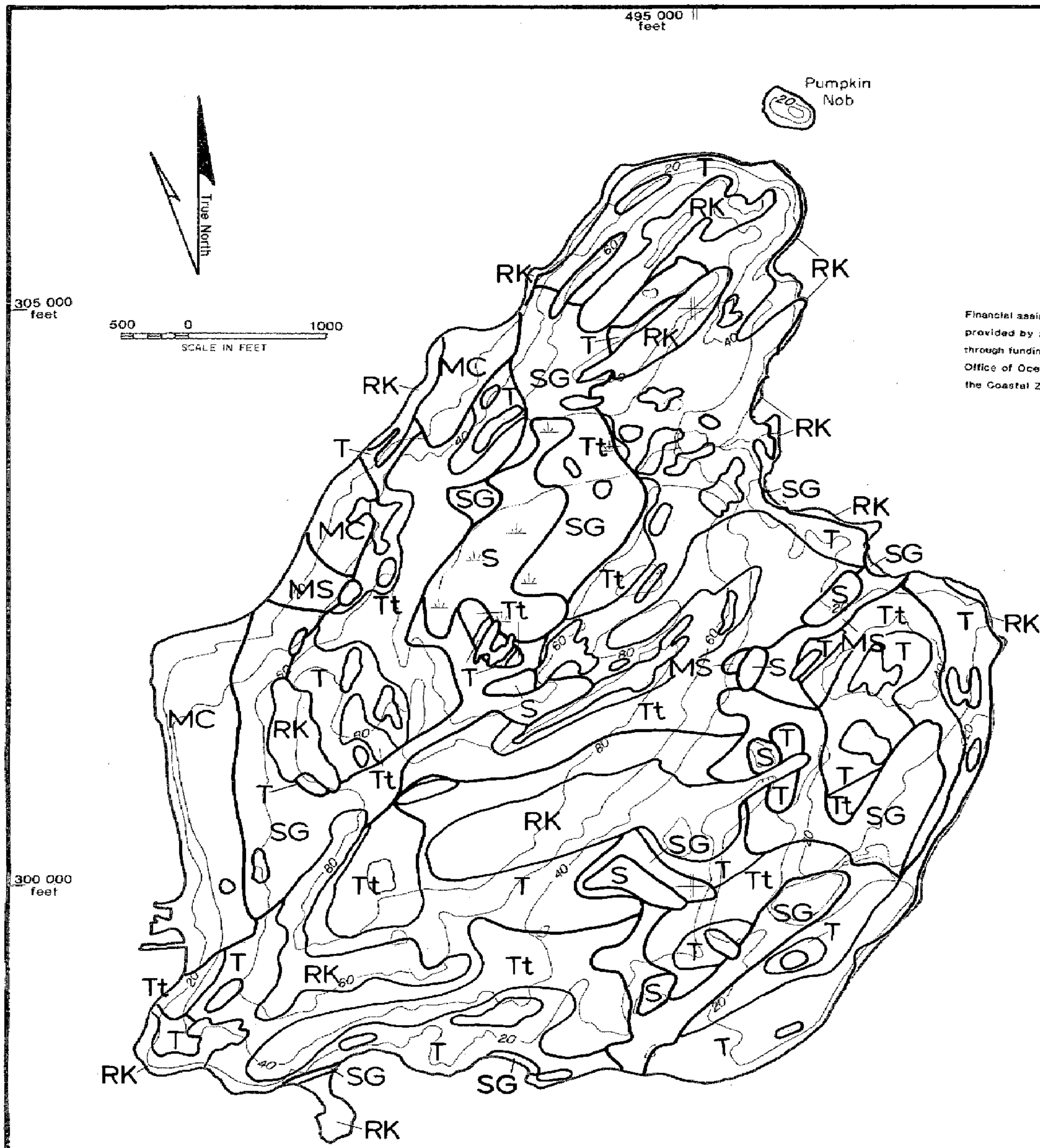
*BY*

*ROBERT G. GERBER, INC.*

*CONSULTING CIVIL ENGINEERS AND GEOLOGISTS*
*FREEPORT, MAINE*

## DIAMOND ISLANDS

| DATE | **JUNE 1986** | FIGURE | **4** |
|---|---|---|---|




Financial assistance for preparation of this document was provided by a grant from MAINE'S COASTAL PROGRAM, through funding provided by U. S. Department of Commerce Office of Ocean and Coastal Resource Management, under the Coastal Zone Management Act of 1972, as amended.

## SURFICIAL GEOLOGY

| GEOLOGIC UNIT CODE | | DESCRIPTIONS OF SURFICIAL (SOIL) UNITS | AVERAGE RECHARGE RATES INTO BEDROCK |
|---|---|---|---|
| 12 | Tt | Relatively thick (>5') glacial till, including both fine grained and sandy varieties | 0.23 GPM per acre |
| 13 | T | Glacial till, less than 5' thick | 0.57 GPM per acre |
| 14 | MC | Glaciomarine clay-silt, usually overlying till | 0.11 GPM per acre |
| 15 | SG | Glaciofluvial sand and gravel, glaciomarine sand, and recent marine sand | 1.14 GPM per acre |
| 16 | MS | Glaciomarine silt and fine sand | 0.68 GPM per acre |
| 17 | S | Swamp deposits | NA |
| 18 | RK | Exposed bedrock and thin (<2') soils | 0.34 GPM per acre |

# SURFICIAL GEOLOGY

FOR

CITY OF PORTLAND

ISLAND GROUND WATER MANAGEMENT STUDY

*BY*

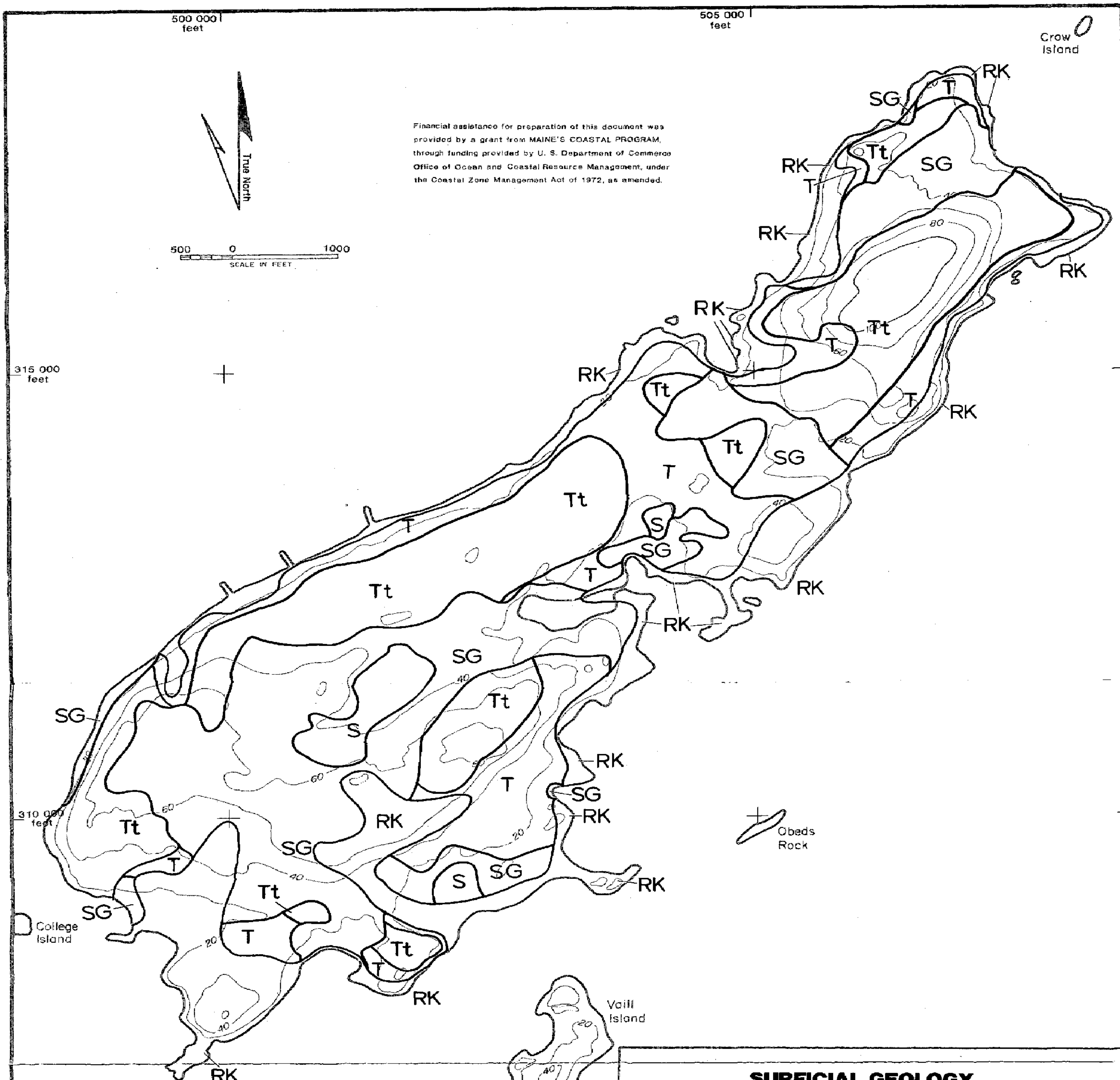
*ROBERT G. GERBER, INC.*

*CONSULTING CIVIL ENGINEERS AND GEOLOGISTS*

*FREEPORT, MAINE*

# PEAKS ISLAND

DATE **JUNE 1986** | FIGURE **5**




Financial assistance for preparation of this document was provided by a grant from MAINE'S COASTAL PROGRAM, through funding provided by U. S. Department of Commerce Office of Ocean and Coastal Resource Management, under the Coastal Zone Management Act of 1972, as amended.

## SURFICIAL GEOLOGY

| GEOLOGIC UNIT CODE | | DESCRIPTIONS OF SURFICIAL (SOIL) UNITS | AVERAGE RECHARGE RATES INTO BEDROCK |
|---|---|---|---|
| 12 | Tt | Relatively thick (>5') glacial till, including both fine grained and sandy varieties | 0.23 GPM per acre |
| 13 | T | Glacial till, less than 5' thick | 0.57 GPM per acre |
| 14 | MC | Glaciomarine clay-silt, usually overlying till | 0.11 GPM per acre |
| 15 | SG | Glaciofluvial sand and gravel, glaciomarine sand, and recent marine sand | 1.14 GPM per acre |
| 16 | MS | Glaciomarine silt and fine sand | 0.68 GPM per acre |
| 17 | S | Swamp deposits | NA |
| 18 | RK | Exposed bedrock and thin (<2') soils | 0.34 GPM per acre |

# SURFICIAL GEOLOGY

FOR

CITY OF PORTLAND

ISLAND GROUND WATER MANAGEMENT STUDY

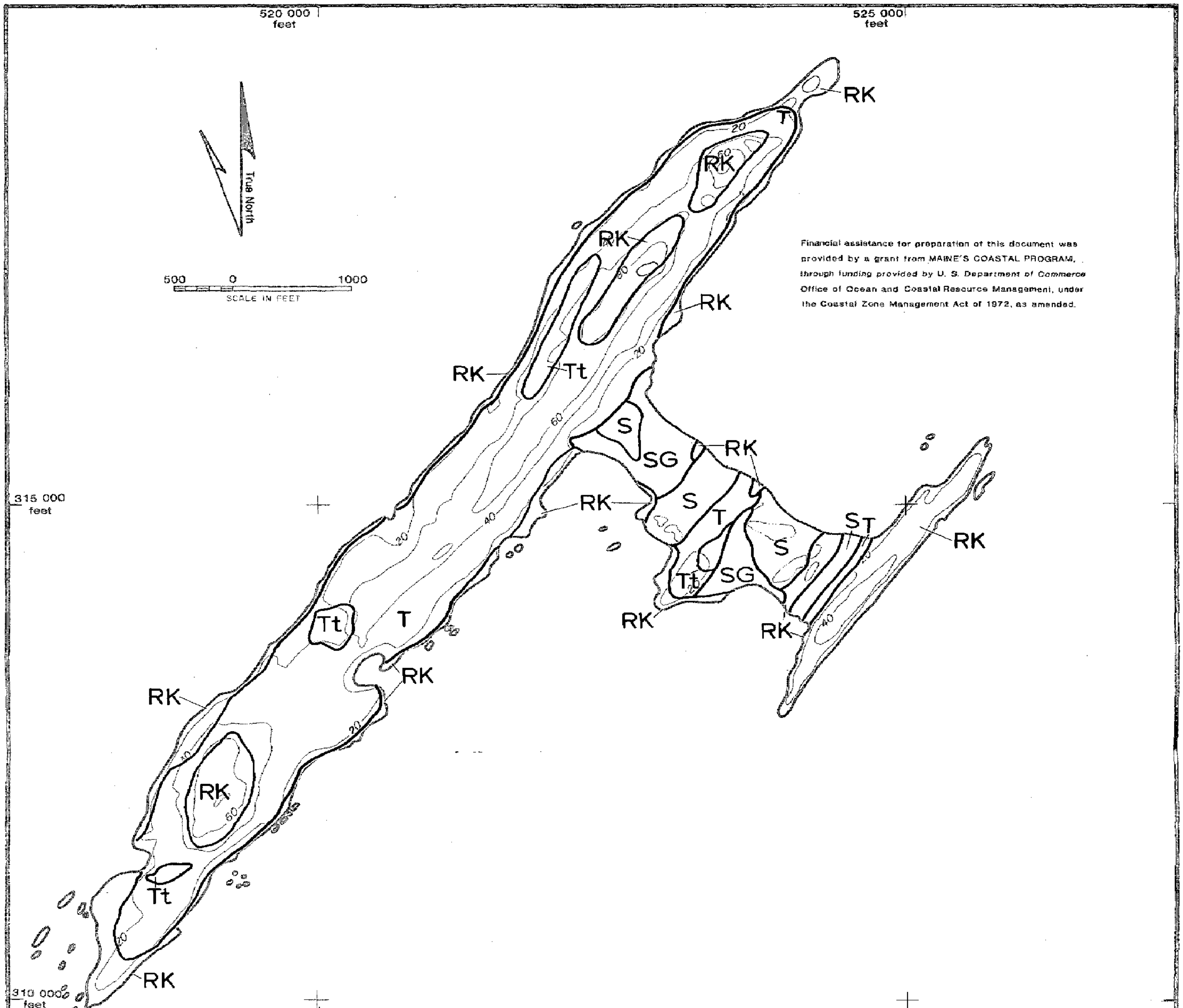
*BY*

*ROBERT G. GERBER, INC.*

*CONSULTING CIVIL ENGINEERS AND GEOLOGISTS*
*FREEPORT, MAINE*

## LONG ISLAND

DATE **JUNE 1986** | FIGURE **6**




Financial assistance for preparation of this document was provided by a grant from MAINE'S COASTAL PROGRAM, through funding provided by U. S. Department of Commerce Office of Ocean and Coastal Resource Management, under the Coastal Zone Management Act of 1972, as amended.

## SURFICIAL GEOLOGY

| GEOLOGIC UNIT CODE | | DESCRIPTIONS OF SURFICIAL (SOIL) UNITS | AVERAGE RECHARGE RATES INTO BEDROCK |
|---|---|---|---|
| 12 | Tt | Relatively thick (>5') glacial till, including both fine grained and sandy varieties | 0.23 GPM per acre |
| 13 | T | Glacial till, less than 5' thick | 0.57 GPM per acre |
| 14 | MC | Glaciomarine clay-silt, usually overlying till | 0.11 GPM per acre |
| 15 | SG | Glaciofluvial sand and gravel, glaciomarine sand, and recent marine sand | 1.14 GPM per acre |
| 16 | MS | Glaciomarine silt and fine sand | 0.68 GPM per acre |
| 17 | S | Swamp deposits | NA |
| 18 | RK | Exposed bedrock and thin (<2') soils | 0.34 GPM per acre |

# SURFICIAL GEOLOGY

FOR

CITY OF PORTLAND

ISLAND GROUND WATER MANAGEMENT STUDY

*BY*

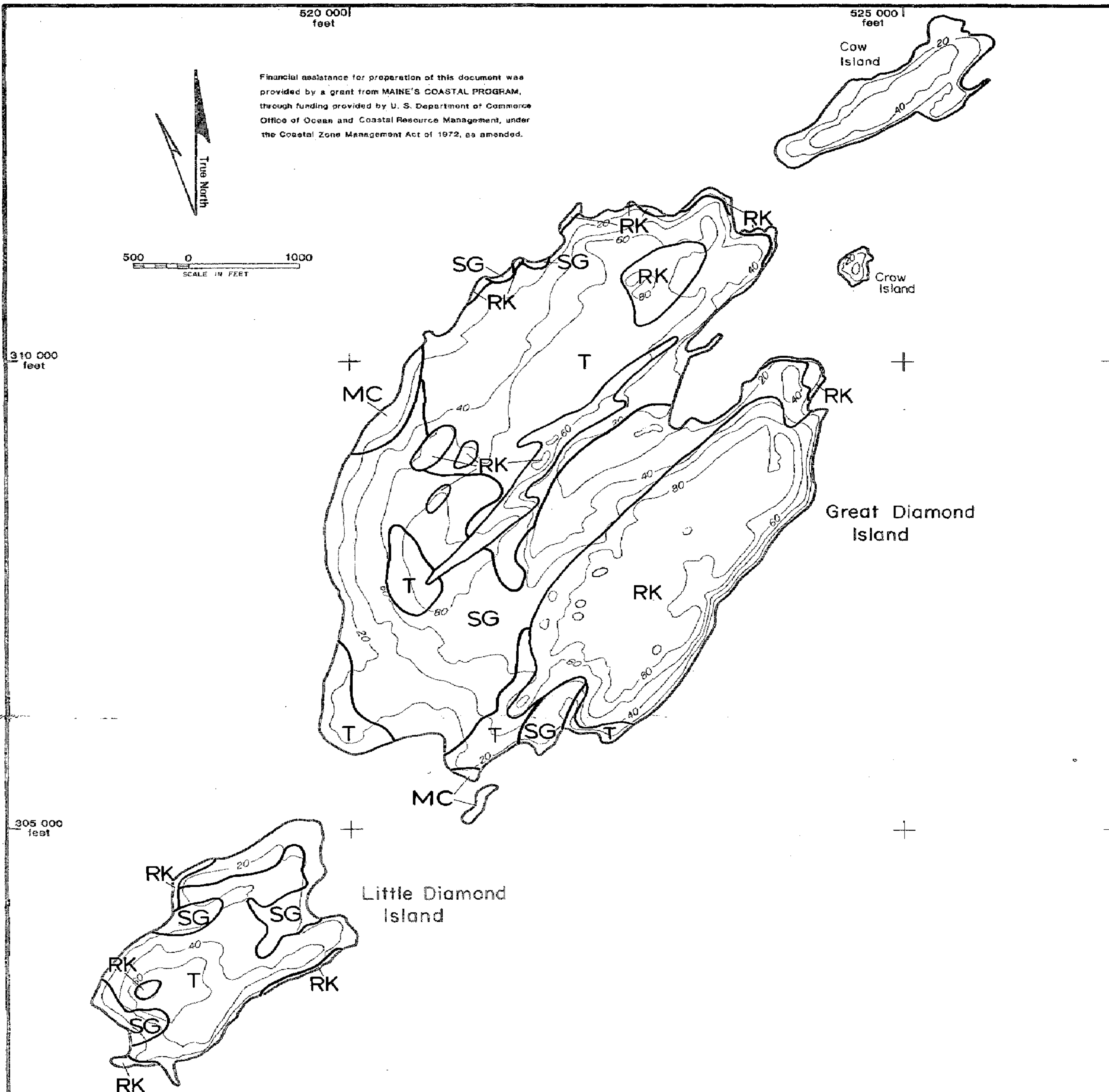
*ROBERT G. GERBER, INC.*

*CONSULTING CIVIL ENGINEERS AND GEOLOGISTS*

*FREEPORT, MAINE*

# CLIFF ISLAND

DATE **JUNE 1986** FIGURE **7**




Financial assistance for preparation of this document was provided by a grant from MAINE'S COASTAL PROGRAM, through funding provided by U. S. Department of Commerce Office of Ocean and Coastal Resource Management, under the Coastal Zone Management Act of 1972, as amended.

## SURFICIAL GEOLOGY

| GEOLOGIC UNIT CODE | | DESCRIPTIONS OF SURFICIAL (SOIL) UNITS | AVERAGE RECHARGE RATES INTO BEDROCK |
|---|---|---|---|
| 12 | Tt | Relatively thick (>5') glacial till, including both fine grained and sandy varieties | 0.23 GPM per acre |
| 13 | T | Glacial till, less than 5' thick | 0.57 GPM per acre |
| 14 | MC | Glaciomarine clay-silt, usually overlying till | 0.11 GPM per acre |
| 15 | SG | Glaciofluvial sand and gravel, glaciomarine sand, and recent marine sand | 1.14 GPM per acre |
| 16 | MS | Glaciomarine silt and fine sand | 0.88 GPM per acre |
| 17 | S | Swamp deposits | NA |
| 18 | RK | Exposed bedrock and thin (<2') soils | 0.34 GPM per acre |

# SURFICIAL GEOLOGY

FOR

CITY OF PORTLAND

ISLAND GROUND WATER MANAGEMENT STUDY

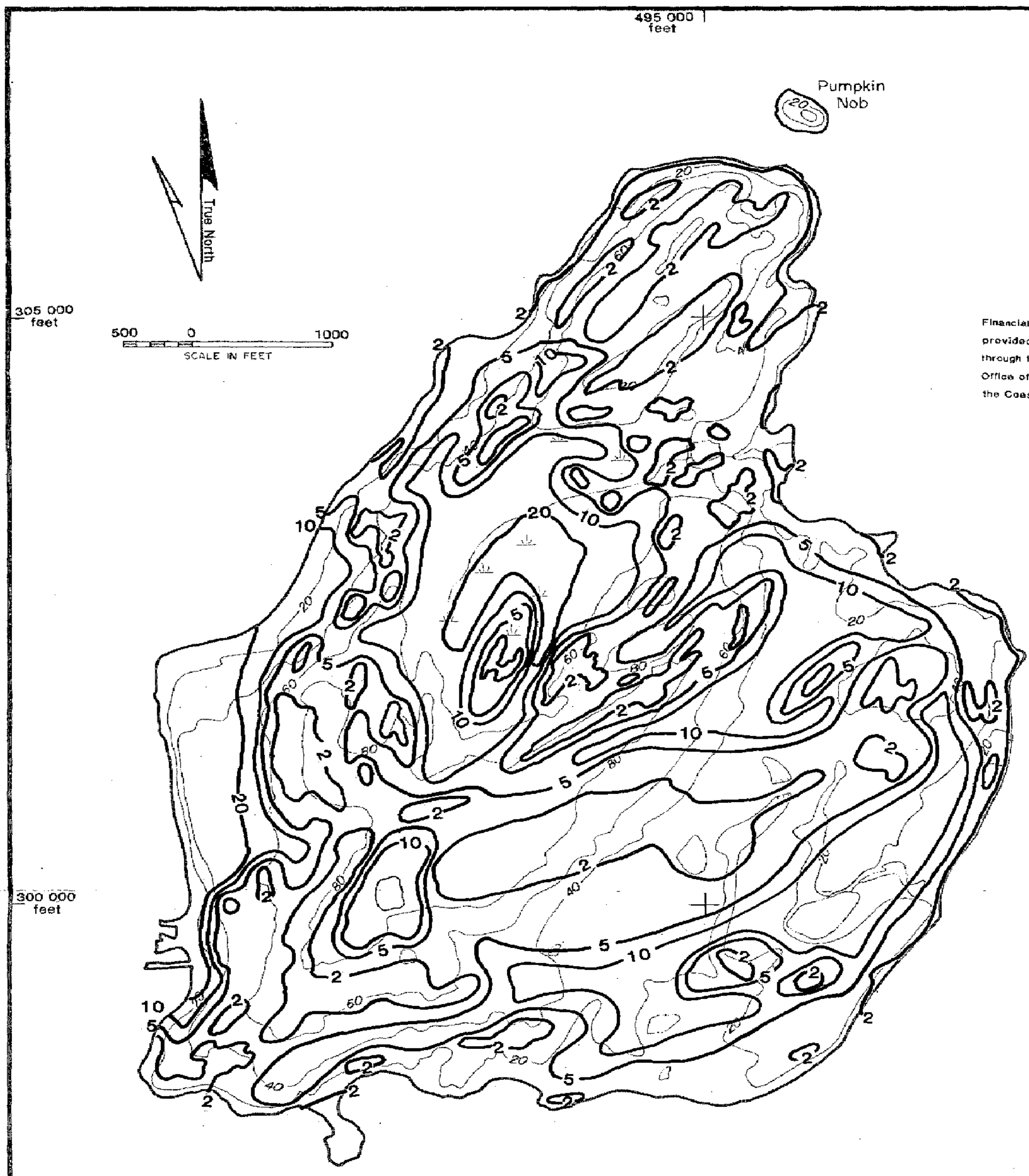
*BY*

*ROBERT G. GERBER, INC.*

*CONSULTING CIVIL ENGINEERS AND GEOLOGISTS*
*FREEPORT, MAINE*

## DIAMOND ISLANDS

| DATE **JUNE 1986** | FIGURE **8** |
|---|---|




Financial assistance for preparation of this document was provided by a grant from MAINE'S COASTAL PROGRAM, through funding provided by U. S. Department of Commerce Office of Ocean and Coastal Resource Management, under the Coastal Zone Management Act of 1972, as amended.

## LEGEND

**SOIL THICKNESS CONTOURS** — 5 —

Contours were plotted using private well construction data, aerial photograph interpretation, and limited field checking.

# SOIL THICKNESS

FOR

CITY OF PORTLAND

ISLAND GROUND WATER MANAGEMENT STUDY

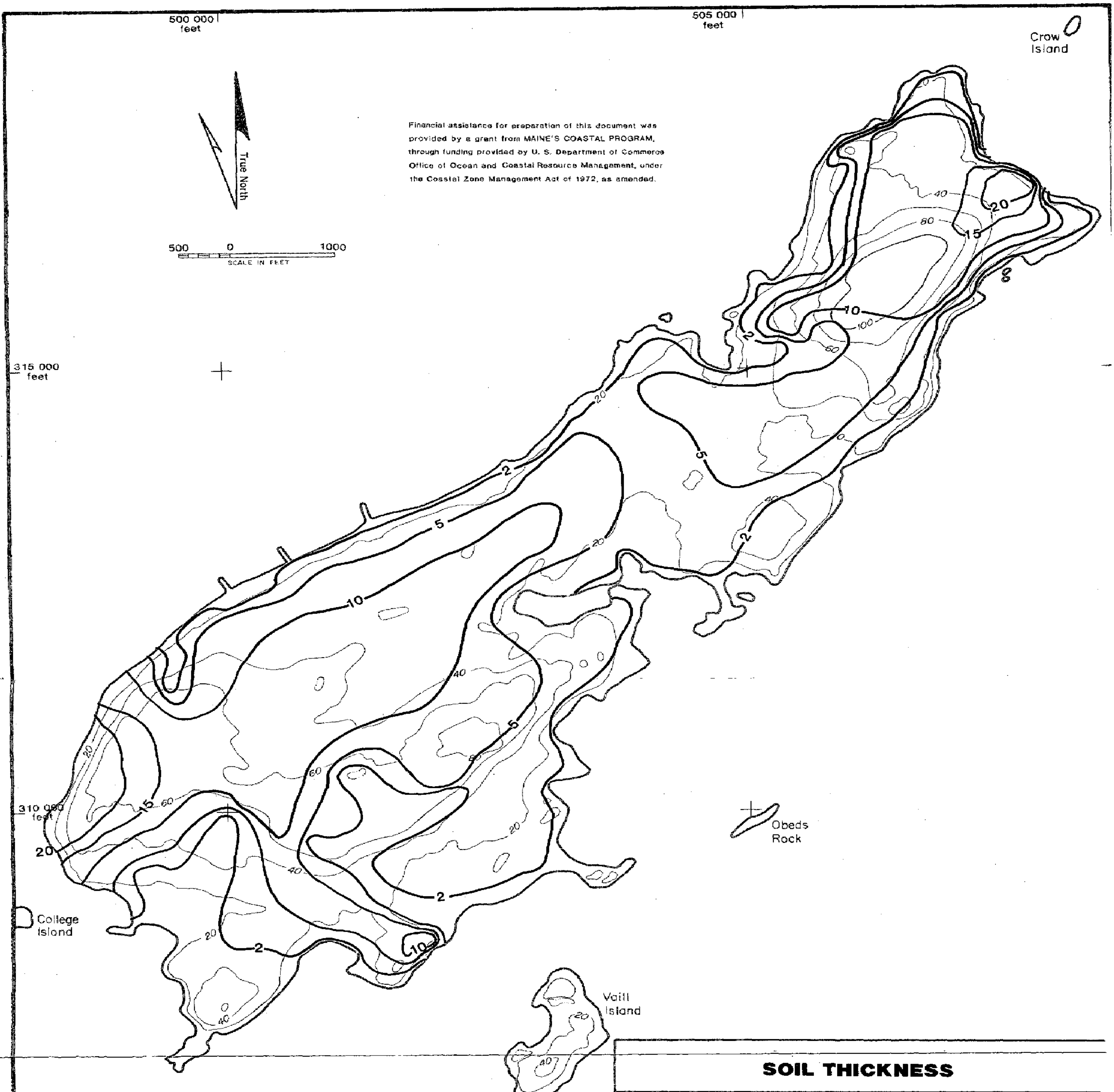
*BY*

*ROBERT G. GERBER, INC.*

*CONSULTING CIVIL ENGINEERS AND GEOLOGISTS*
*FREEPORT, MAINE*

## PEAKS ISLAND

DATE **JUNE 1986** | FIGURE **9**




## LEGEND

SOIL THICKNESS CONTOURS —5—

Contours were plotted using private well construction data, aerial photograph interpretation, and limited field checking.

## SOIL THICKNESS

FOR

CITY OF PORTLAND

ISLAND GROUND WATER MANAGEMENT STUDY

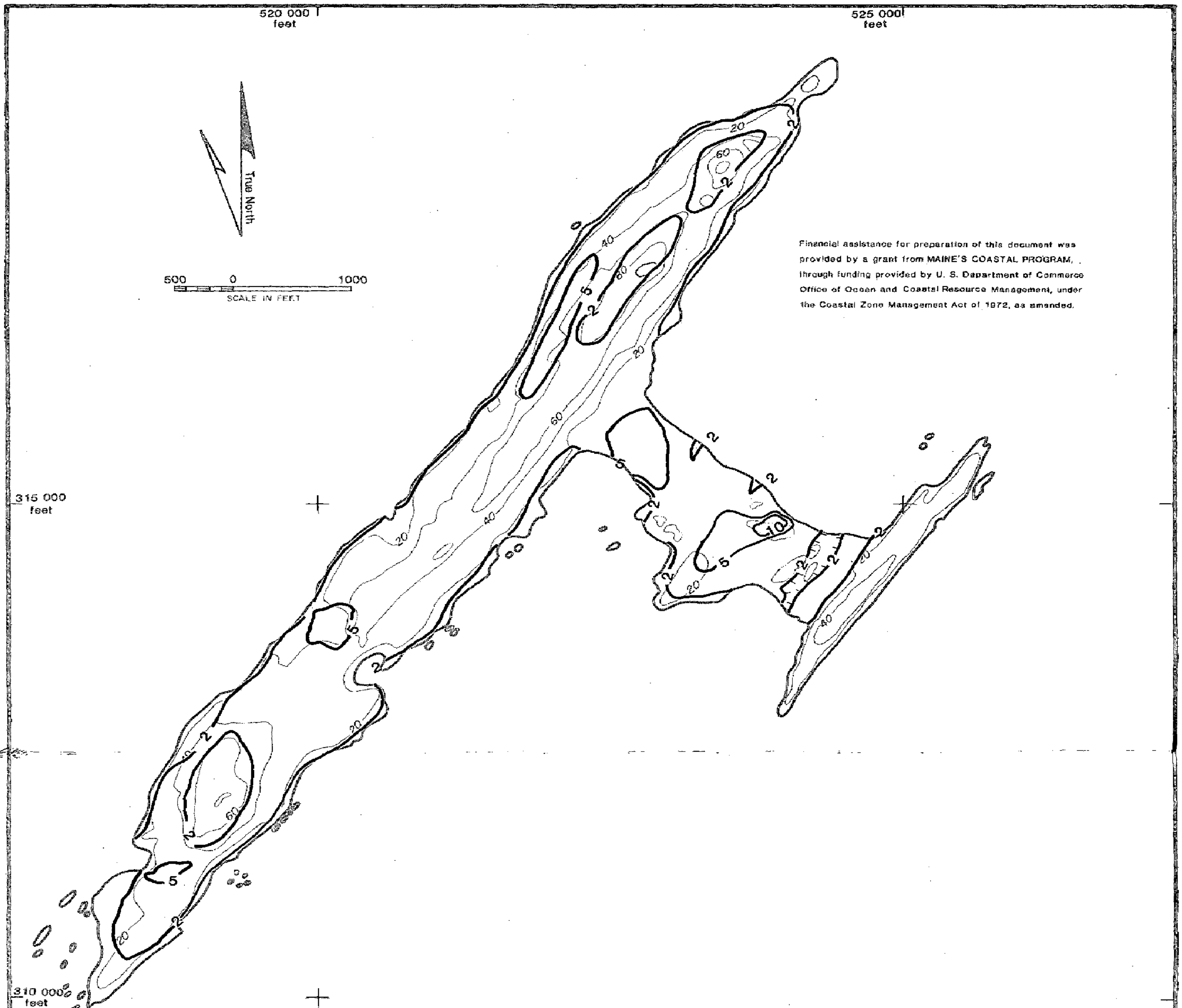
*BY*

*ROBERT G. GERBER, INC.*

*CONSULTING CIVIL ENGINEERS AND GEOLOGISTS*
*FREEPORT, MAINE*

LONG ISLAND

DATE **JUNE 1986** | FIGURE **10**




Financial assistance for preparation of this document was provided by a grant from MAINE'S COASTAL PROGRAM, through funding provided by U. S. Department of Commerce Office of Ocean and Coastal Resource Management, under the Coastal Zone Management Act of 1972, as amended.

## LEGEND

**SOIL THICKNESS CONTOURS** — 5 —

Contours were plotted using private well construction data, aerial photograph interpretation, and limited field checking.

**SOIL THICKNESS**

FOR

CITY OF PORTLAND

ISLAND GROUND WATER MANAGEMENT STUDY

*BY*

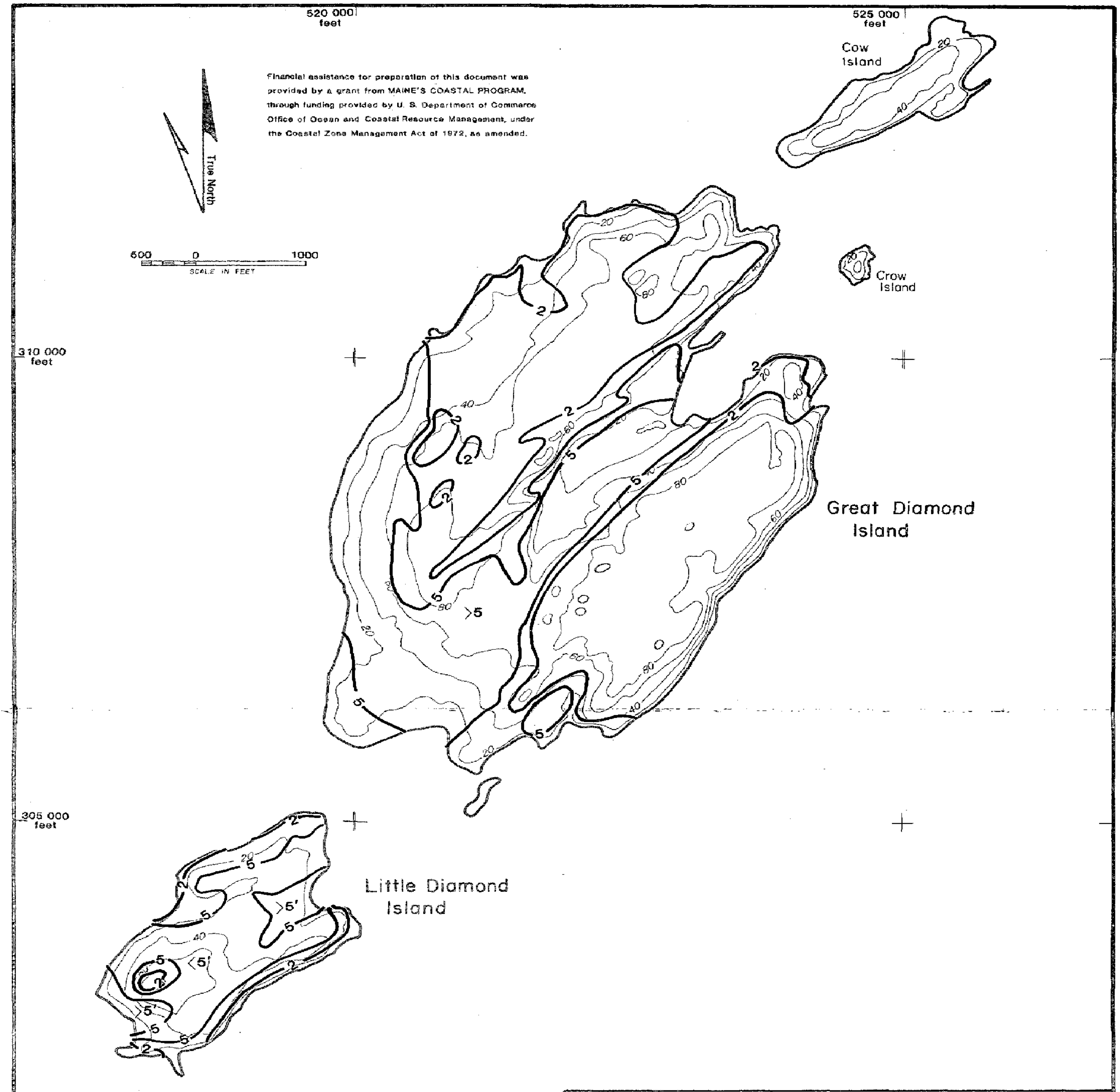
*ROBERT G. GERBER, INC.*

*CONSULTING CIVIL ENGINEERS AND GEOLOGISTS*

*FREEPORT, MAINE*

CLIFF ISLAND

DATE **JUNE 1986** FIGURE **11**




## LEGEND

**SOIL THICKNESS CONTOURS** — 5 —

**Contours were plotted using private well construction data, aerial photograph interpretation, and limited field checking.**

**SOIL THICKNESS**

FOR

CITY OF PORTLAND

ISLAND GROUND WATER MANAGEMENT STUDY

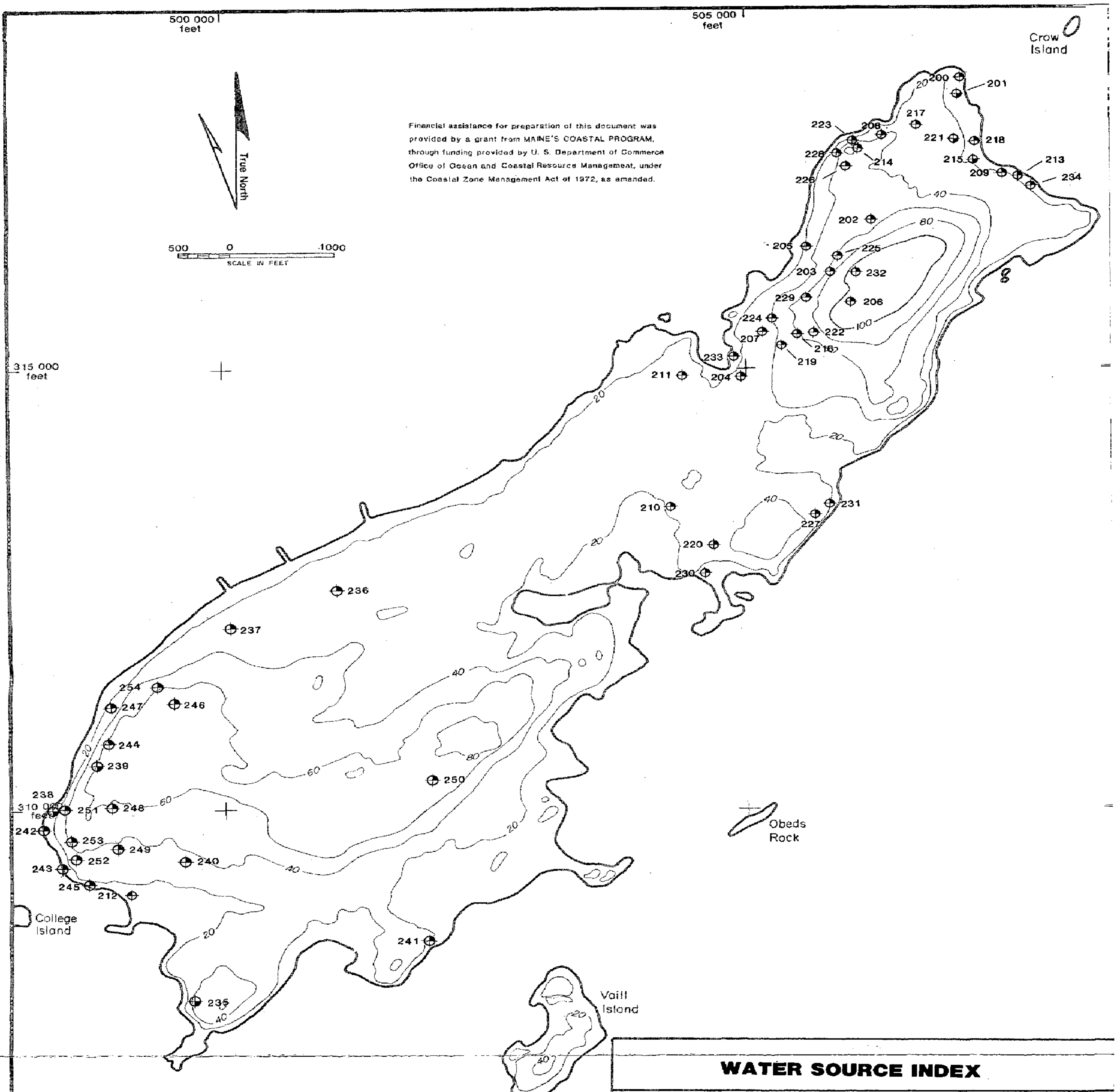
*BY*

*ROBERT G. GERBER, INC.*

*CONSULTING CIVIL ENGINEERS AND GEOLOGISTS*
*FREEPORT, MAINE*

DIAMOND ISLANDS

| DATE **JUNE 1986** | FIGURE **12** |
|---|---|




Financial assistance for preparation of this document was provided by a grant from MAINE'S COASTAL PROGRAM, through funding provided by U. S. Department of Commerce Office of Ocean and Coastal Resource Management, under the Coastal Zone Management Act of 1972, as amended.

## LEGEND

- Drilled Well
- Dug Well
- Spring In Soil
- Well Point

**WATER SOURCE INDEX**

FOR

CITY OF PORTLAND

ISLAND GROUND WATER MANAGEMENT STUDY

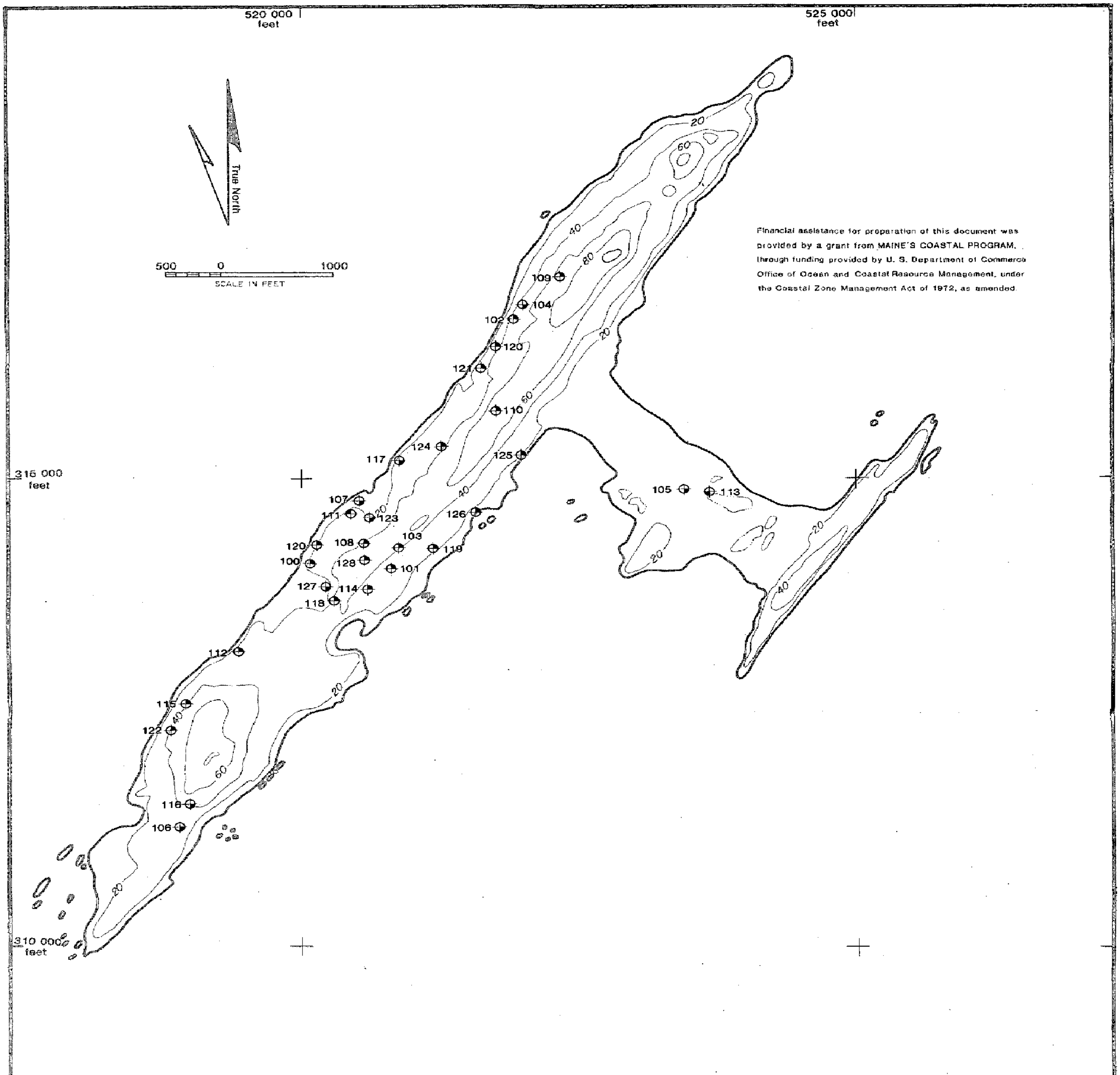
*BY*

*ROBERT G. GERBER, INC.*

*CONSULTING CIVIL ENGINEERS AND GEOLOGISTS*
*FREEPORT, MAINE*

LONG ISLAND

DATE **JUNE 1986** | FIGURE **13**




Financial assistance for preparation of this document was provided by a grant from MAINE'S COASTAL PROGRAM, through funding provided by U. S. Department of Commerce Office of Ocean and Coastal Resource Management, under the Coastal Zone Management Act of 1972, as amended.

## LEGEND

- Drilled Well ⊕
- Dug Well ⊕
- Spring In Soil ⊕
- Well Point ⊕

**WATER SOURCE INDEX**

FOR

CITY OF PORTLAND

ISLAND GROUND WATER MANAGEMENT STUDY

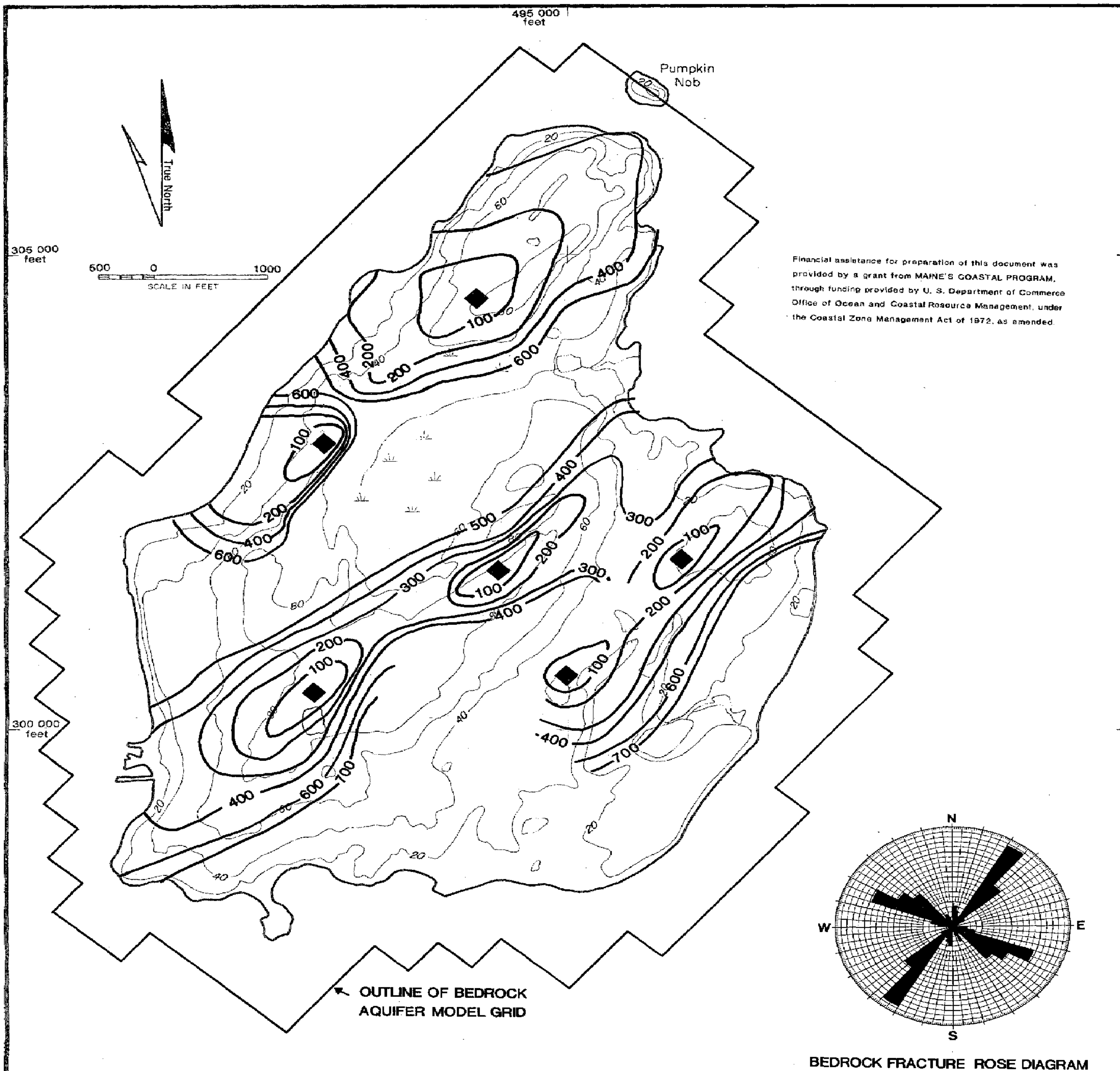
*BY*

*ROBERT G. GERBER, INC.*

*CONSULTING CIVIL ENGINEERS AND GEOLOGISTS*
*FREEPORT, MAINE*

# CLIFF ISLAND

DATE **JUNE 1986** FIGURE **14**




Financial assistance for preparation of this document was provided by a grant from MAINE'S COASTAL PROGRAM, through funding provided by U. S. Department of Commerce Office of Ocean and Coastal Resource Management, under the Coastal Zone Management Act of 1972, as amended.

-200— TRAVEL TIME WITHIN THE BEDROCK AQUIFER (IN DAYS) FROM HYPOTHETICAL CONTAMINANT SOURCES

■ SIMULATED CONTAMINANT SOURCE

**TIME OF TRAVEL CONTOURS**

FOR

CITY OF PORTLAND

ISLAND GROUND WATER MANAGEMENT STUDY

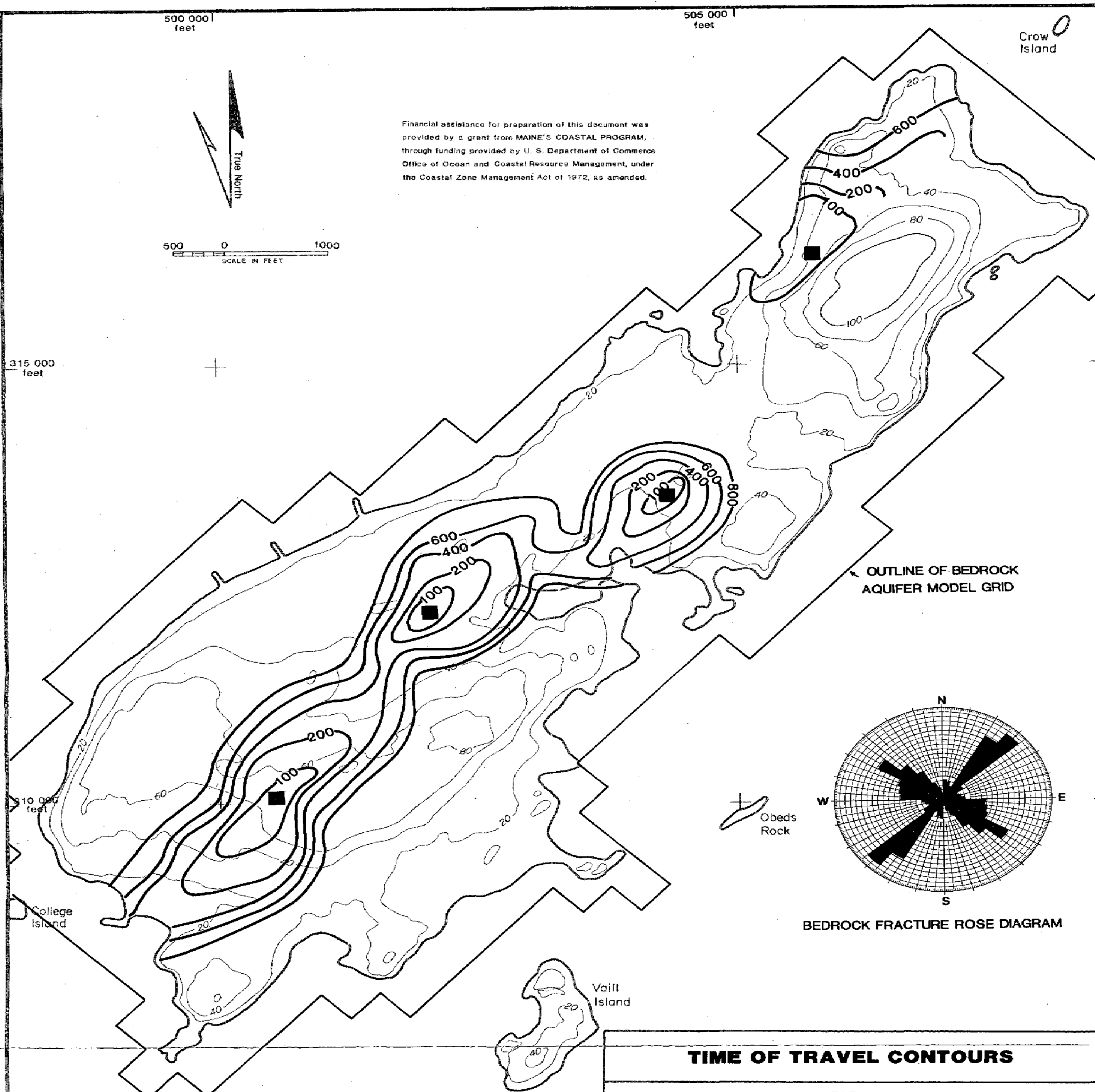
*BY*

*ROBERT G. GERBER, INC.*

*CONSULTING CIVIL ENGINEERS AND GEOLOGISTS*
*FREEPORT, MAINE*

PEAKS ISLAND

DATE **JUNE 1986** | FIGURE **15**




Financial assistance for preparation of this document was provided by a grant from MAINE'S COASTAL PROGRAM, through funding provided by U. S. Department of Commerce Office of Ocean and Coastal Resource Management, under the Coastal Zone Management Act of 1972, as amended.

—200— TRAVEL TIME WITHIN THE BEDROCK AQUIFER (IN DAYS) FROM HYPOTHETICAL CONTAMINANT SOURCES

■ SIMULATED CONTAMINANT SOURCE

# TIME OF TRAVEL CONTOURS

FOR

CITY OF PORTLAND

ISLAND GROUND WATER MANAGEMENT STUDY

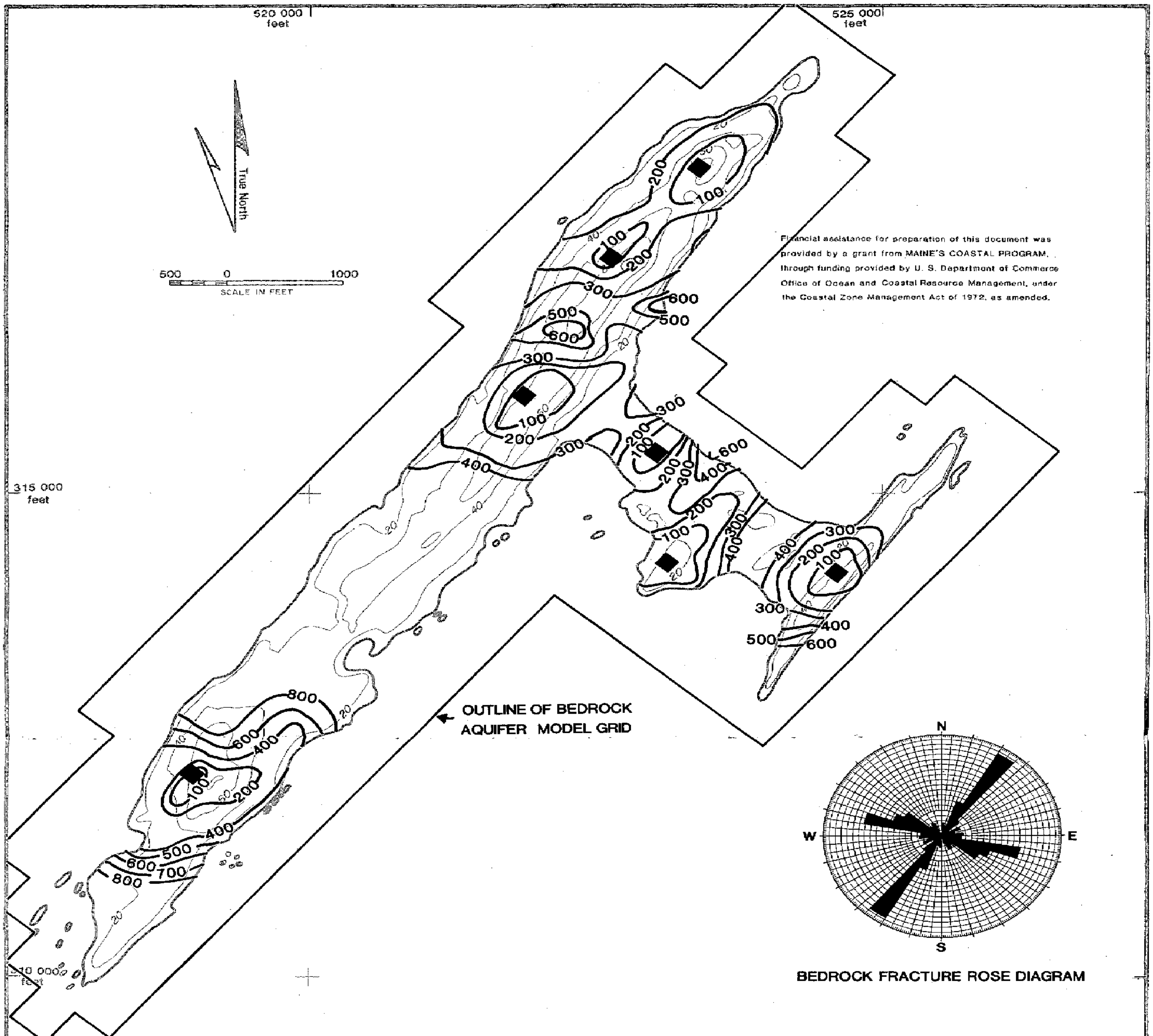
*BY*

*ROBERT G. GERBER, INC.*

*CONSULTING CIVIL ENGINEERS AND GEOLOGISTS*
*FREEPORT, MAINE*

LONG ISLAND

DATE **JUNE 1986** | FIGURE **16**




Financial assistance for preparation of this document was provided by a grant from MAINE'S COASTAL PROGRAM, through funding provided by U. S. Department of Commerce Office of Ocean and Coastal Resource Management, under the Coastal Zone Management Act of 1972, as amended.

— 200 — TRAVEL TIME WITHIN THE BEDROCK AQUIFER (IN DAYS) FROM HYPOTHETICAL CONTAMINANT SOURCES

■ SIMULATED CONTAMINANT SOURCE

**TIME OF TRAVEL CONTOURS**

FOR

CITY OF PORTLAND

ISLAND GROUND WATER MANAGEMENT STUDY

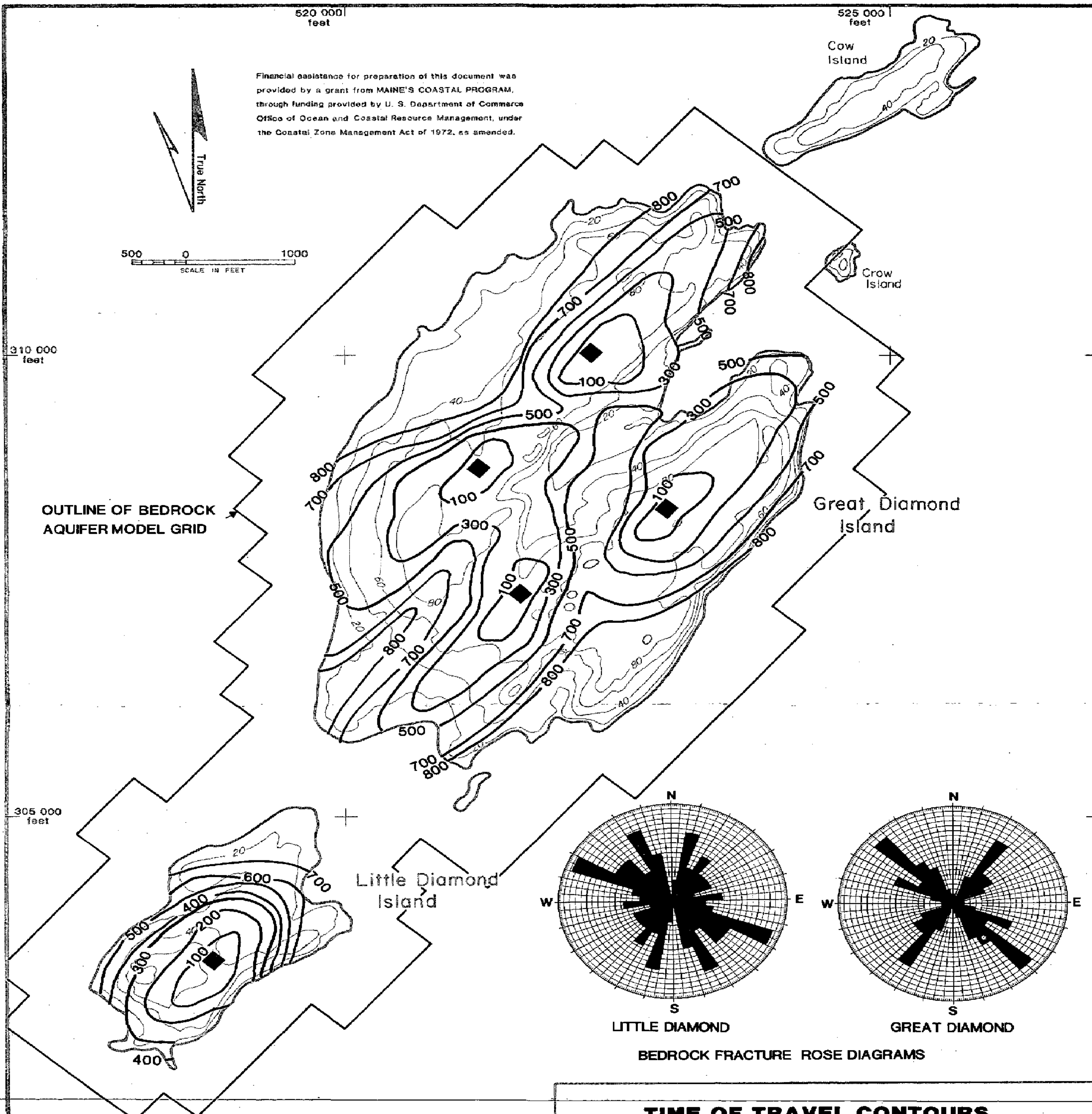
BY

*ROBERT G. GERBER, INC.*

*CONSULTING CIVIL ENGINEERS AND GEOLOGISTS*
*FREEPORT, MAINE*

CLIFF ISLAND

DATE **JUNE 1986** FIGURE **17**




-300— TRAVEL TIME WITHIN THE BEDROCK AQUIFER (IN DAYS) FROM HYPOTHETICAL CONTAMINANT SOURCES

■ SIMULATED CONTAMINANT SOURCE

**TIME OF TRAVEL CONTOURS**

FOR

CITY OF PORTLAND

ISLAND GROUND WATER MANAGEMENT STUDY

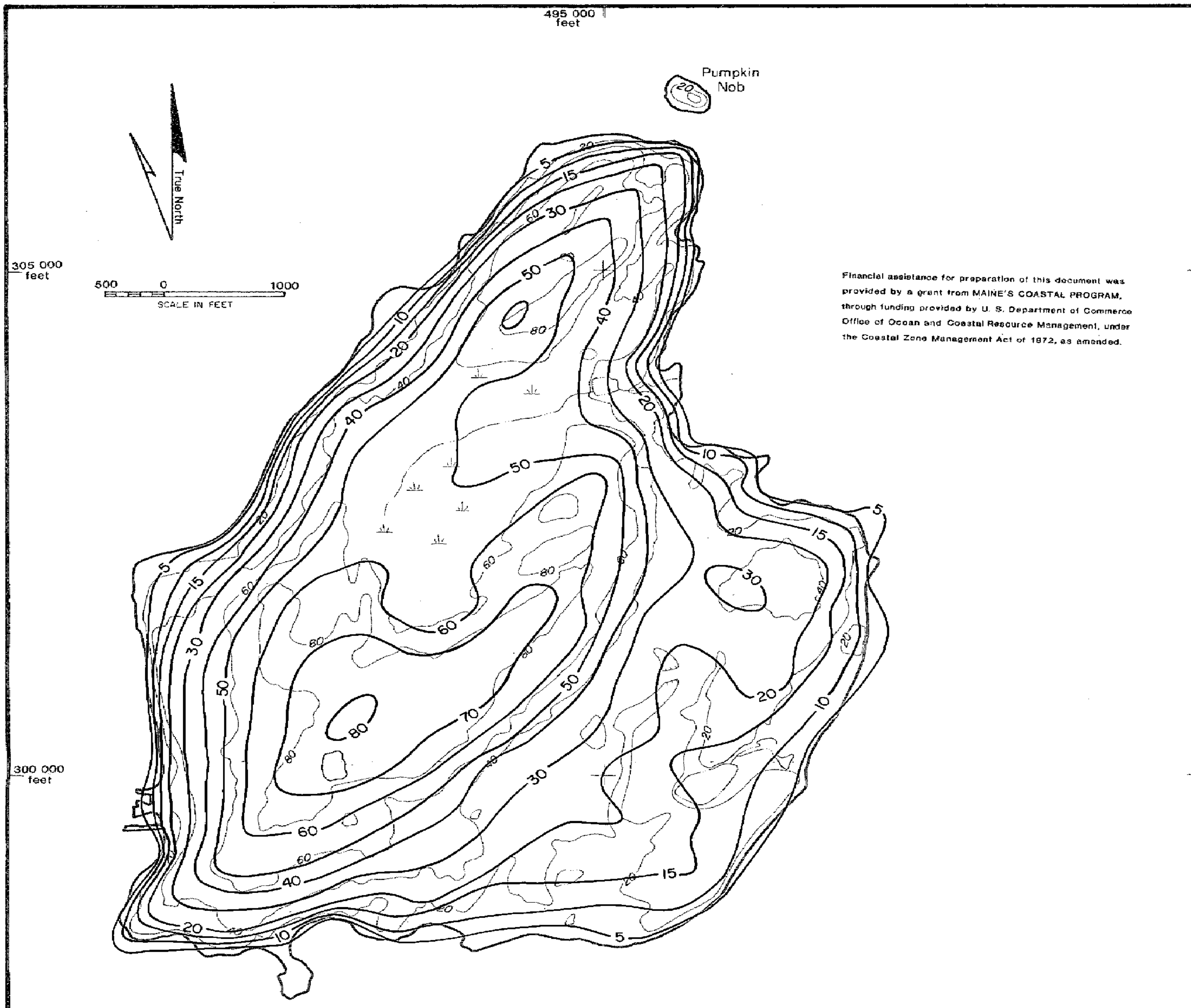
BY

*ROBERT G. GERBER, INC.*

*CONSULTING CIVIL ENGINEERS AND GEOLOGISTS*
*FREEPORT, MAINE*

DIAMOND ISLANDS

| DATE **JUNE 1986** | FIGURE **18** |
|---|---|




Financial assistance for preparation of this document was provided by a grant from MAINE'S COASTAL PROGRAM, through funding provided by U. S. Department of Commerce Office of Ocean and Coastal Resource Management, under the Coastal Zone Management Act of 1972, as amended.

—10— ELEVATION OF THE POTENTIOMETRIC SURFACE IN THE BEDROCK AQUIFER ABOVE MEAN SEA LEVEL (IN FEET)

# POTENTIOMETRIC SURFACE MAP

FOR

CITY OF PORTLAND

ISLAND GROUND WATER MANAGEMENT STUDY

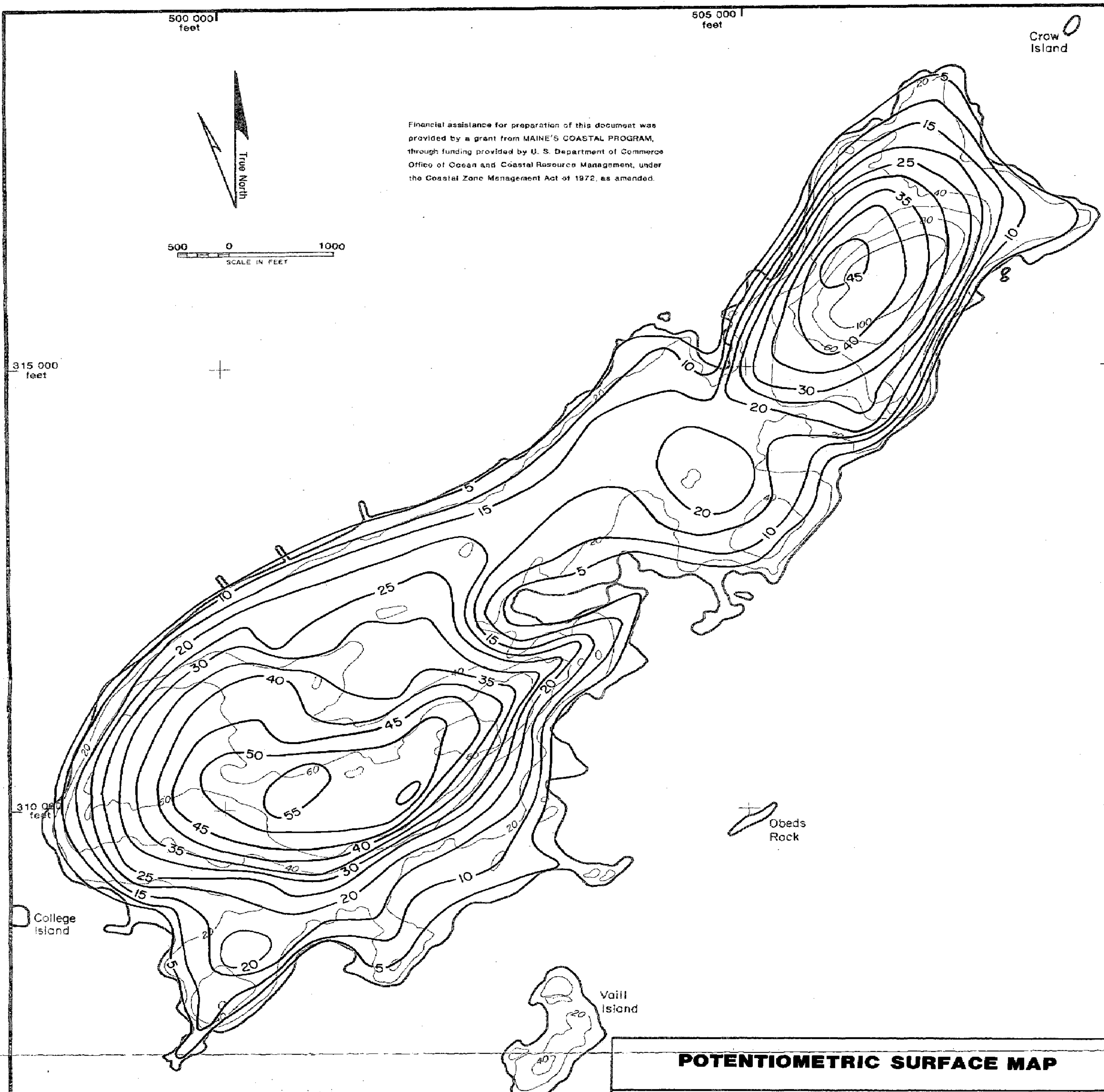
*BY*

*ROBERT G. GERBER, INC.*

*CONSULTING CIVIL ENGINEERS AND GEOLOGISTS*
*FREEPORT, MAINE*

PEAKS ISLAND

| | |
|---|---|
| DATE **JUNE 1986** | FIGURE **19** |




Financial assistance for preparation of this document was provided by a grant from MAINE'S COASTAL PROGRAM, through funding provided by U. S. Department of Commerce Office of Ocean and Coastal Resource Management, under the Coastal Zone Management Act of 1972, as amended.

—10— ELEVATION OF THE POTENTIOMETRIC SURFACE IN THE BEDROCK AQUIFER ABOVE MEAN SEA LEVEL (IN FEET)

**POTENTIOMETRIC SURFACE MAP**

FOR

CITY OF PORTLAND

ISLAND GROUND WATER MANAGEMENT STUDY

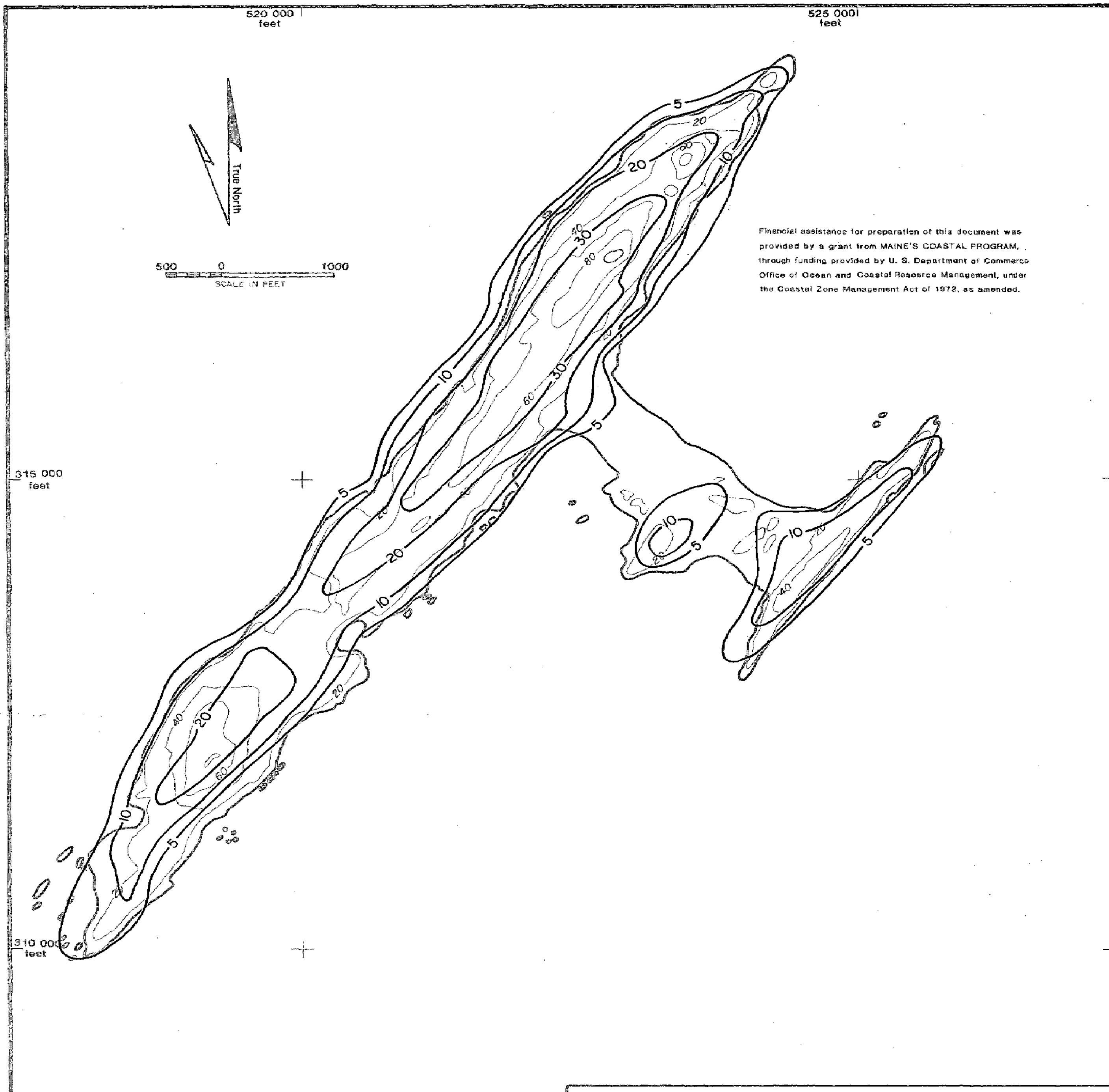
*BY*

*ROBERT G GERBER, INC.*

*CONSULTING CIVIL ENGINEERS AND GEOLOGISTS*
*FREEPORT, MAINE*

LONG ISLAND

DATE **JUNE 1986** | FIGURE **20**




Financial assistance for preparation of this document was provided by a grant from MAINE'S COASTAL PROGRAM, through funding provided by U. S. Department of Commerce Office of Ocean and Coastal Resource Management, under the Coastal Zone Management Act of 1972, as amended.

—10— ELEVATION OF THE POTENTIOMETRIC SURFACE IN THE BEDROCK AQUIFER ABOVE MEAN SEA LEVEL (IN FEET)

**POTENTIOMETRIC SURFACE MAP**

FOR

CITY OF PORTLAND

ISLAND GROUND WATER MANAGEMENT STUDY

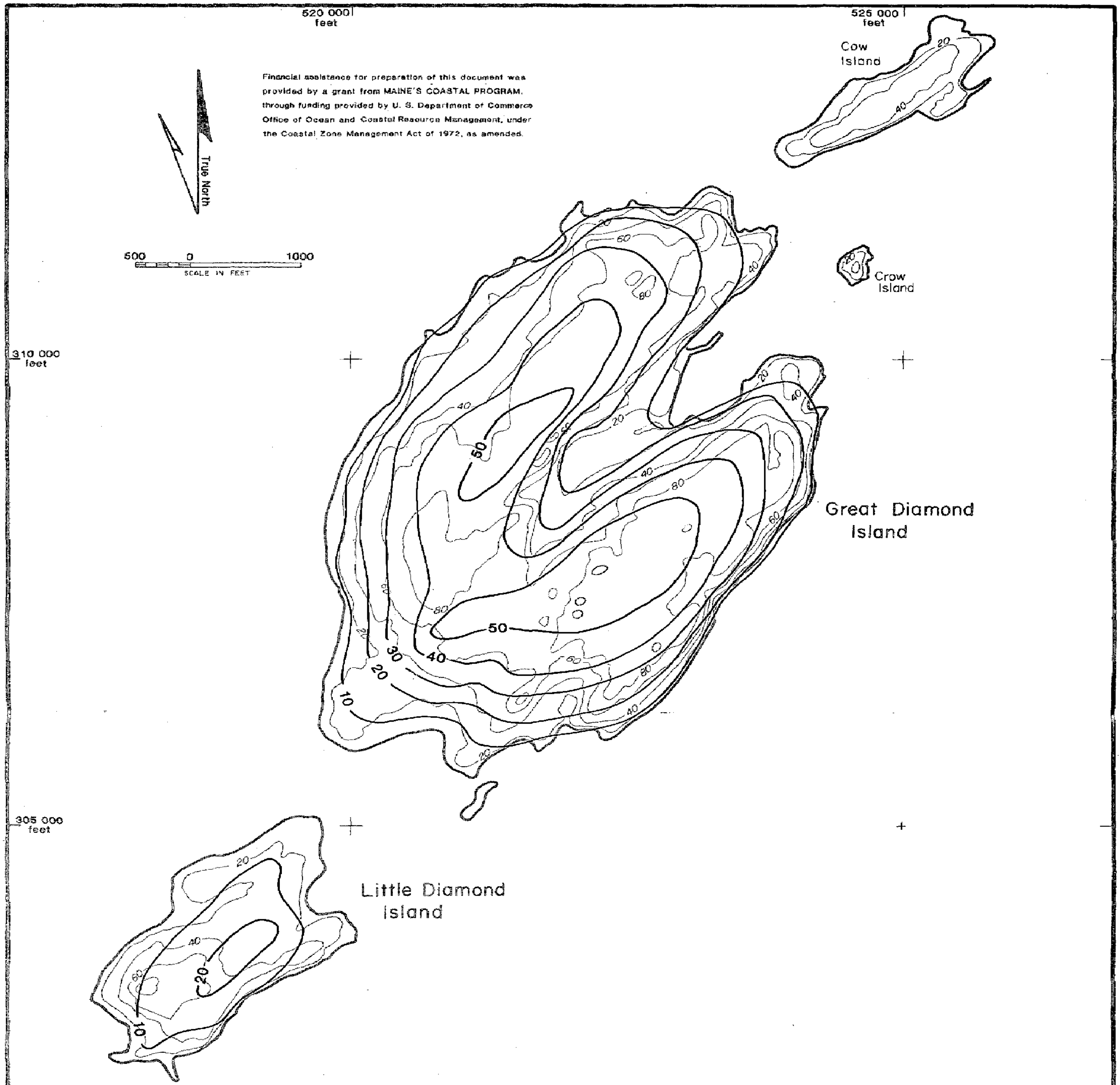
BY

*ROBERT G. GERBER, INC.*

*CONSULTING CIVIL ENGINEERS AND GEOLOGISTS*
*FREEPORT, MAINE*

CLIFF ISLAND

DATE **JUNE 1986** FIGURE **21**




Financial assistance for preparation of this document was provided by a grant from MAINE'S COASTAL PROGRAM, through funding provided by U. S. Department of Commerce Office of Ocean and Coastal Resource Management, under the Coastal Zone Management Act of 1972, as amended.

—10— ELEVATION OF THE POTENTIOMETRIC SURFACE IN THE BEDROCK AQUIFER ABOVE MEAN SEA LEVEL (IN FEET)

**POTENTIOMETRIC SURFACE MAP**

FOR

CITY OF PORTLAND

ISLAND GROUND WATER MANAGEMENT STUDY

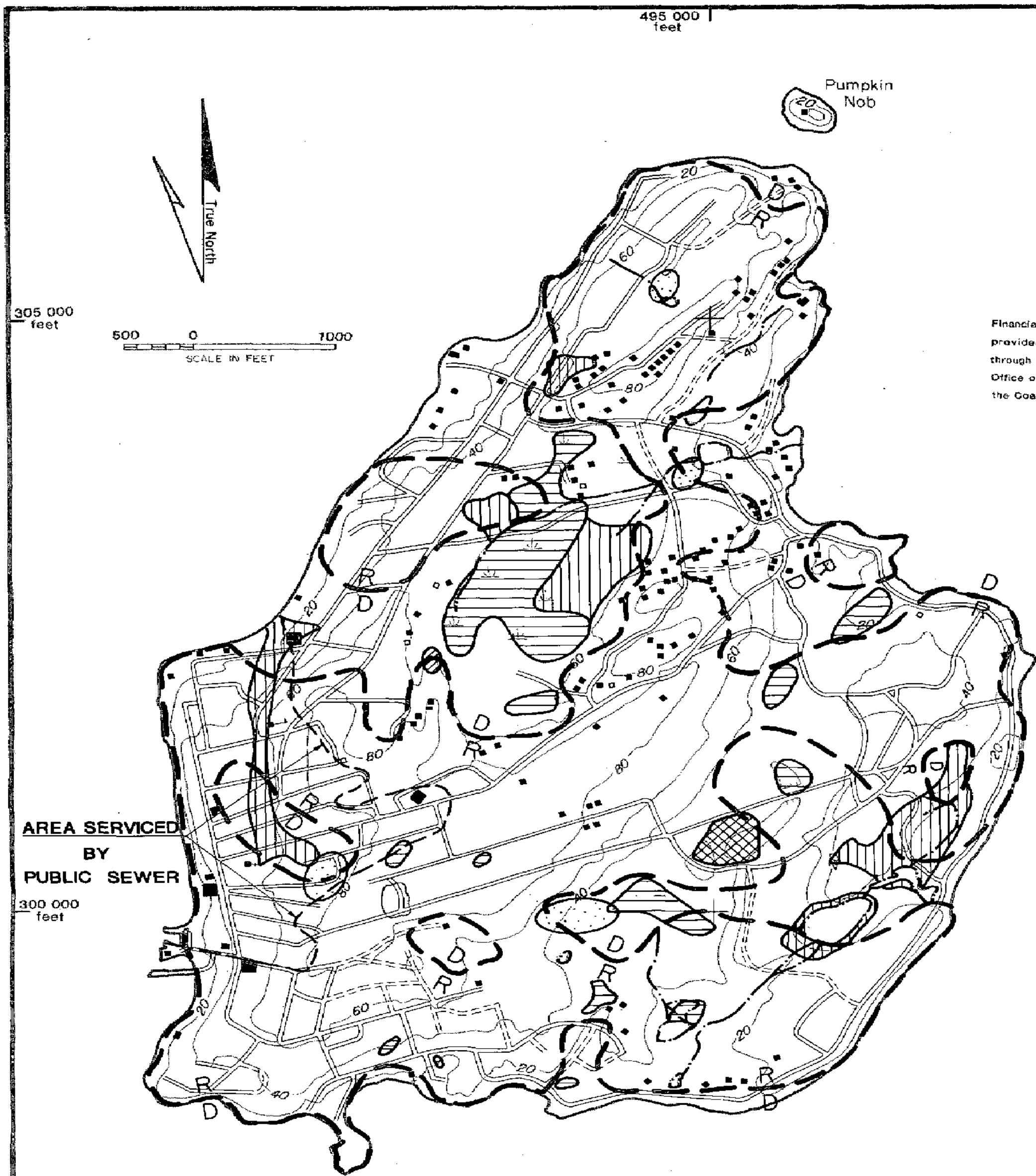
*BY*

*ROBERT G. GERBER, INC.*

*CONSULTING CIVIL ENGINEERS AND GEOLOGISTS*
*FREEPORT, MAINE*

DIAMOND ISLANDS

DATE **JUNE 1986** | FIGURE **22**




Financial assistance for preparation of this document was provided by a grant from MAINE'S COASTAL PROGRAM, through funding provided by U. S. Department of Commerce Office of Ocean and Coastal Resource Management, under the Coastal Zone Management Act of 1972, as amended.

**LEGEND**

- R/D Bedrock aquifer recharge/discharge boundary
- Potential high yield bedrock zone
- Petroleum product storage
- Suspected septic system contamination
- Chloride contamination
- Pond/stream
- Very poorly drained area
- Landfill debris disposal
- Potential high yield sand and gravel zones
- Septic sludge disposal site
- Sand/salt storage pile

**SPECIAL FEATURES MAP**

FOR

CITY OF PORTLAND

ISLAND GROUND WATER MANAGEMENT STUDY

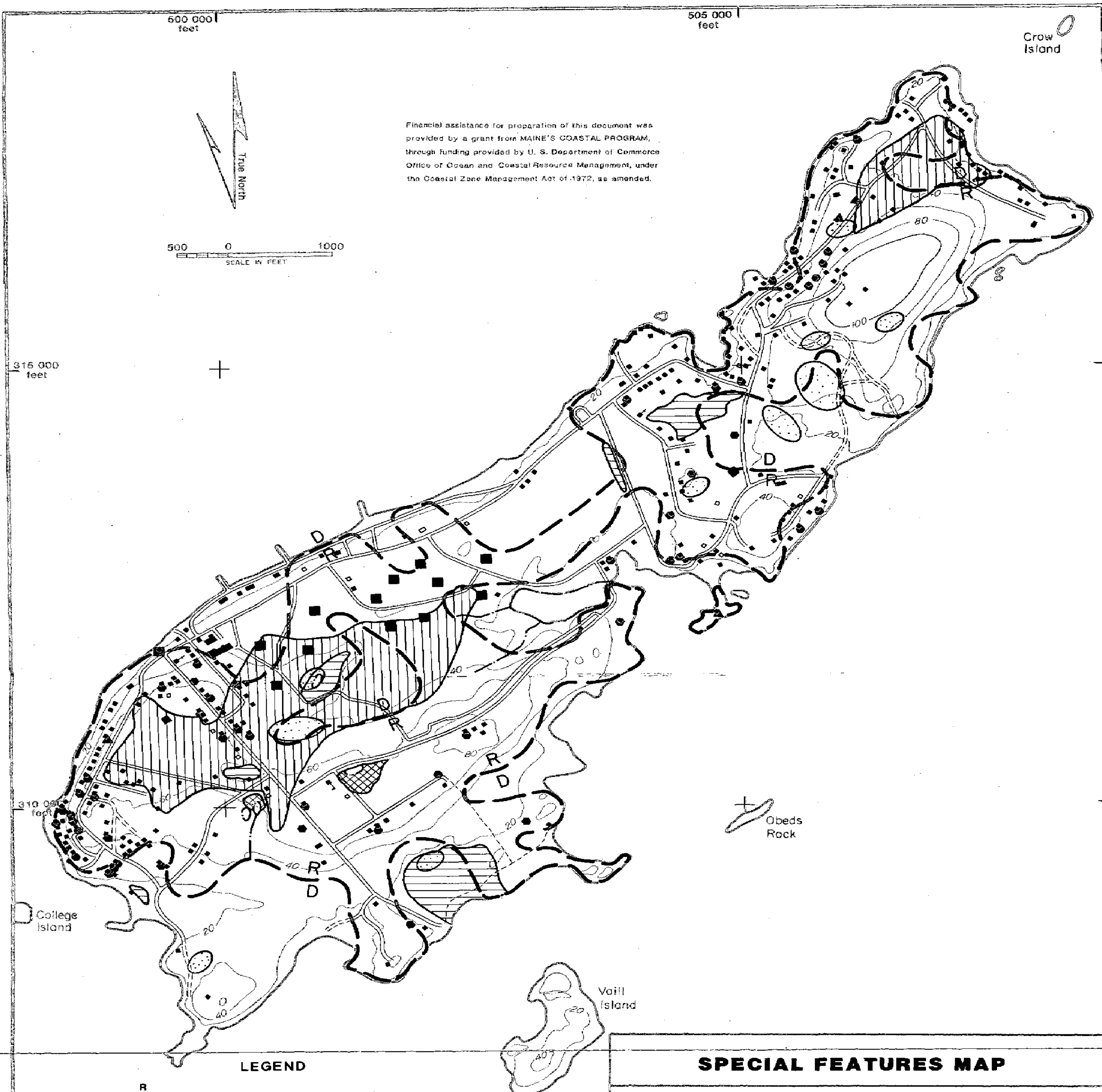
BY

*ROBERT G. GERBER, INC.*

*CONSULTING CIVIL ENGINEERS AND GEOLOGISTS*
*FREEPORT, MAINE*

PEAKS ISLAND

| DATE **JUNE 1986** | FIGURE **23** |
|---|---|




Financial assistance for preparation of this document was provided by a grant from MAINE'S COASTAL PROGRAM, through funding provided by U. S. Department of Commerce Office of Ocean and Coastal Resource Management, under the Coastal Zone Management Act of 1972, as amended.

## LEGEND

- R/D Bedrock aquifer recharge/discharge boundary
- Potential high yield bedrock zone
- Petroleum product storage
- Suspected septic system contamination
- Chloride contamination
- Pond/stream
- Very poorly drained area
- Landfill debris disposal
- Potential high yield sand and gravel zones
- Sand/salt storage pile

# SPECIAL FEATURES MAP

FOR

CITY OF PORTLAND

ISLAND GROUND WATER MANAGEMENT STUDY

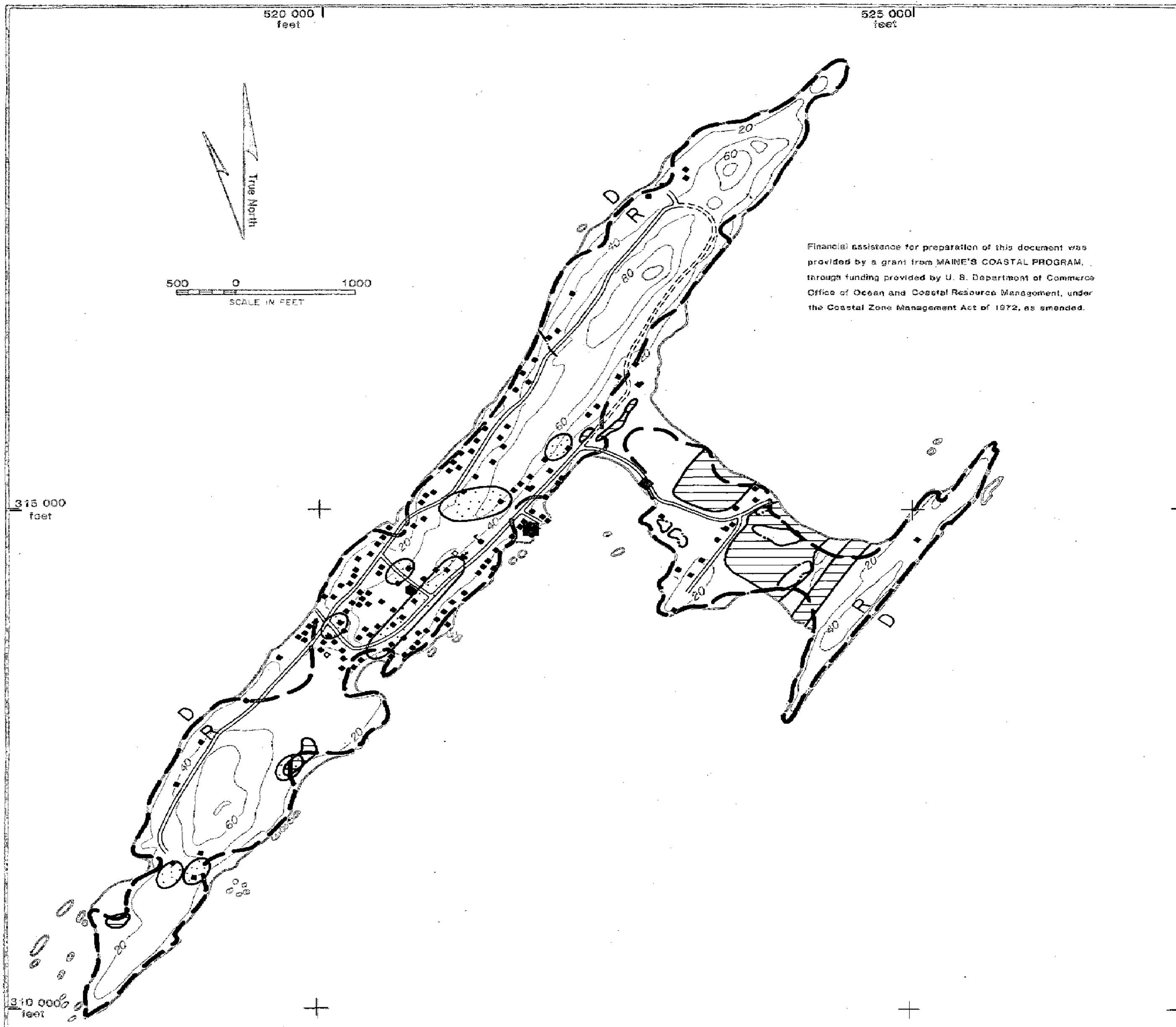
*BY*

*ROBERT G. GERBER, INC.*

*CONSULTING CIVIL ENGINEERS AND GEOLOGISTS*
*FREEPORT, MAINE*

LONG ISLAND

DATE JUNE 1986 | FIGURE 24




Financial assistance for preparation of this document was provided by a grant from MAINE'S COASTAL PROGRAM, through funding provided by U. S. Department of Commerce Office of Ocean and Coastal Resource Management, under the Coastal Zone Management Act of 1972, as amended.

## LEGEND

- R/D — Bedrock aquifer recharge/discharge boundary
- Potential high yield bedrock zone
- Petroleum product storage
- Suspected septic system contamination
- Chloride contamination
- Pond/stream
- Very poorly drained area
- Landfill debris disposal
- Potential high yield sand and gravel zones
- Sand/salt storage pile

# SPECIAL FEATURES MAP

FOR

CITY OF PORTLAND

ISLAND GROUND WATER MANAGEMENT STUDY

*BY*

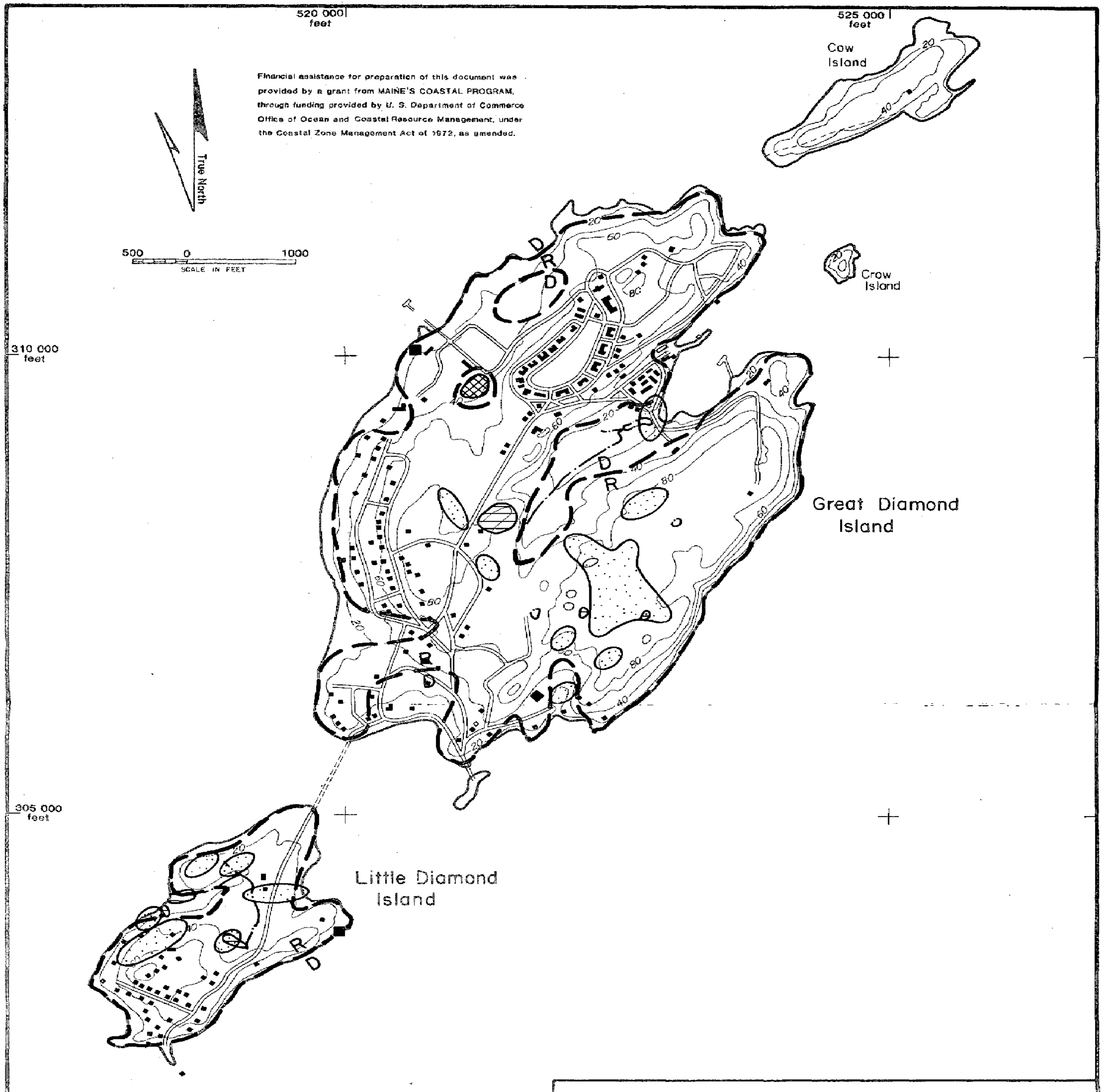
*ROBERT G. GERBER, INC.*

*CONSULTING CIVIL ENGINEERS AND GEOLOGISTS*

*FREEPORT, MAINE*

## CLIFF ISLAND

DATE JUNE 1986 FIGURE **25**




Financial assistance for preparation of this document was provided by a grant from MAINE'S COASTAL PROGRAM, through funding provided by U. S. Department of Commerce Office of Ocean and Coastal Resource Management, under the Coastal Zone Management Act of 1972, as amended.

## LEGEND

- Bedrock aquifer recharge/discharge boundary (R/D)
- Potential high yield bedrock zone
- Petroleum product storage
- Suspected septic system contamination
- Chloride contamination
- Pond/stream
- Very poorly drained area
- Landfill debris disposal
- Potential high yield sand and gravel zones
- Sand/salt storage pile

# SPECIAL FEATURES MAP

FOR

CITY OF PORTLAND

ISLAND GROUND WATER MANAGEMENT STUDY

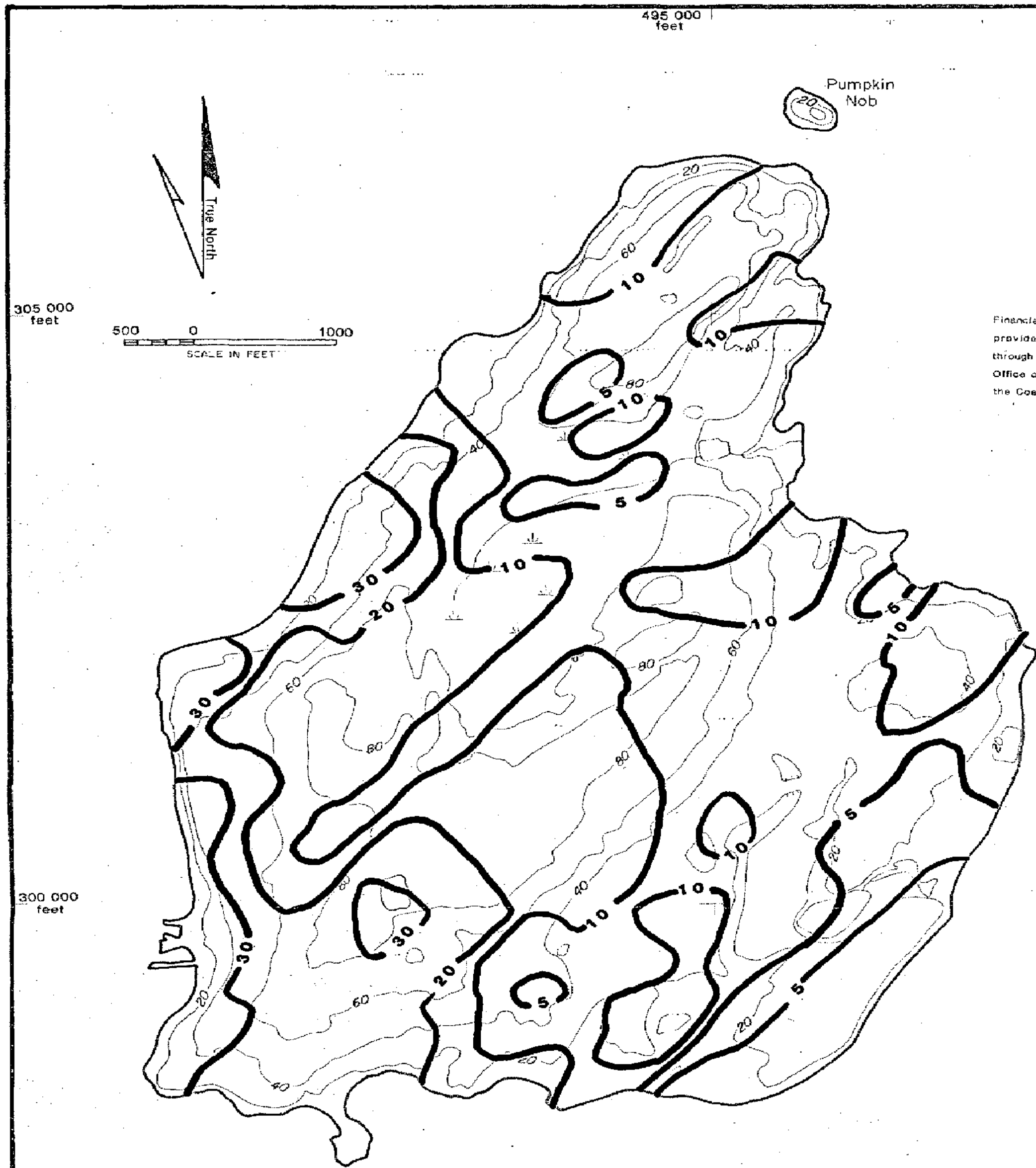
BY

*ROBERT G. GERBER, INC.*

*CONSULTING CIVIL ENGINEERS AND GEOLOGISTS*
*FREEPORT, MAINE*

## DIAMOND ISLANDS

DATE **JUNE 1986** | FIGURE **26**




Financial assistance for preparation of this document was provided by a grant from MAINE'S COASTAL PROGRAM, through funding provided by U. S. Department of Commerce Office of Ocean and Coastal Resource Management, under the Coastal Zone Management Act of 1972, as amended.

—10— ISOCONS (LINES OF EQUAL CHEMICAL CONCENTRATION) OF CONTAMINANTS FROM SUBSURFACE SEWAGE DISPOSAL SYSTEMS IF THE ENTIRE ISLAND IS DEVELOPED AT MAXIMUM ALLOWED RESIDENTIAL DENSITY. FOR NITRATE-NITROGEN, THE 30% ISOCON IS EQUIVALENT TO ABOUT 10 MG/L. ISOCONS WITH HIGHER PERCENTAGES REPRESENT GROUND WATER THAT WOULD BE UNFIT TO DRINK.

EFFECTS OF SEPTIC SYSTEM DEVELOPMENT AT MAXIMUM PERMITTED RESIDENTIAL DENSITIES

FOR

CITY OF PORTLAND

ISLAND GROUND WATER MANAGEMENT STUDY

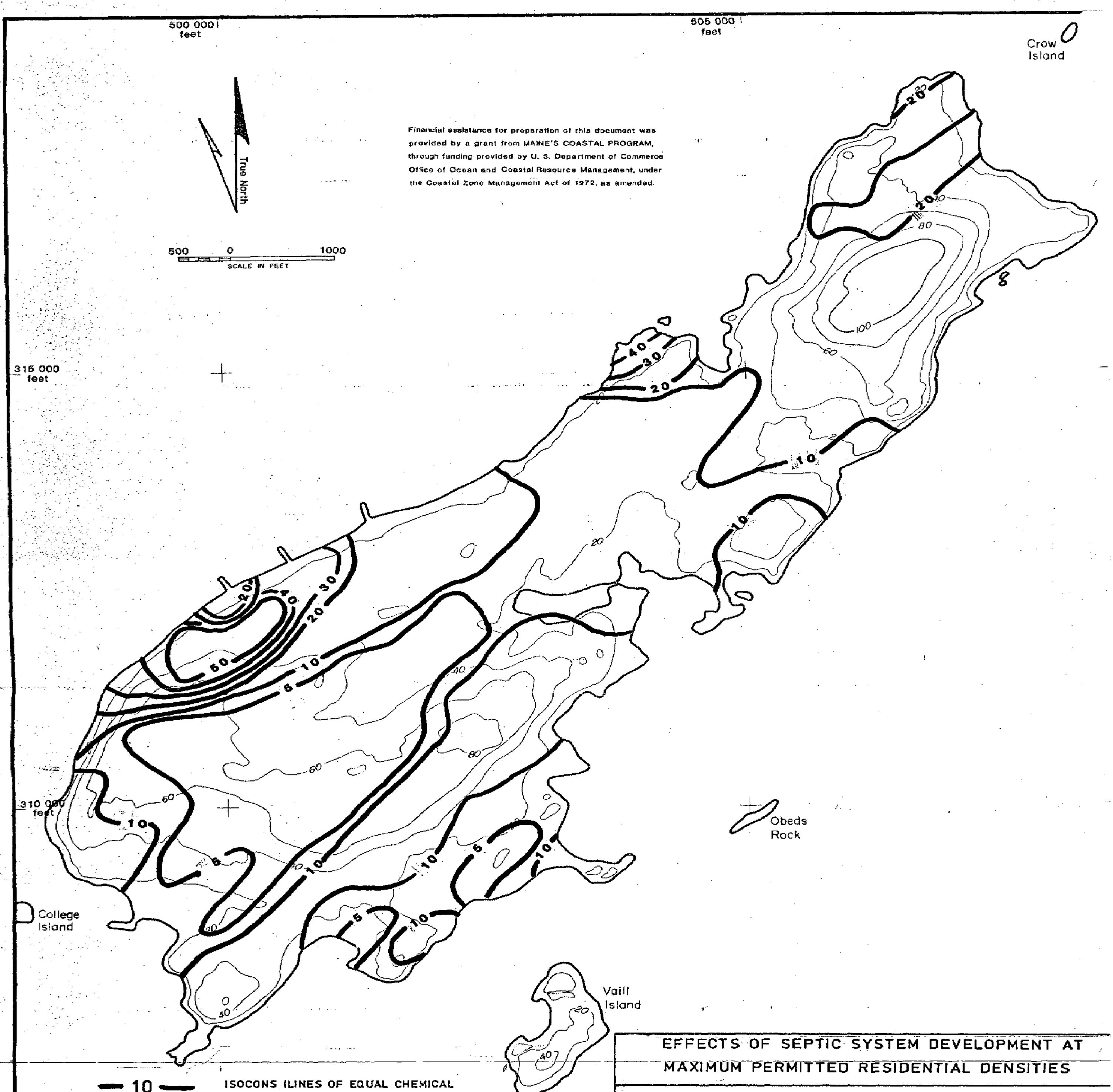
*BY*

*ROBERT G. GERBER, INC.*

*CONSULTING CIVIL ENGINEERS AND GEOLOGISTS*
*FREEPORT, MAINE*

PEAKS ISLAND

| DATE **JUNE 1986** | FIGURE **27** |
|---|---|




Financial assistance for preparation of this document was provided by a grant from MAINE'S COASTAL PROGRAM, through funding provided by U. S. Department of Commerce Office of Ocean and Coastal Resource Management, under the Coastal Zone Management Act of 1972, as amended.

— 10 — ISOCONS (LINES OF EQUAL CHEMICAL CONCENTRATION) OF CONTAMINANTS FROM SUBSURFACE SEWAGE DISPOSAL SYSTEMS IF THE ENTIRE ISLAND IS DEVELOPED AT MAXIMUM ALLOWED RESIDENTIAL DENSITY. FOR NITRATE-NITROGEN, THE 30% ISOCON IS EQUIVALENT TO ABOUT 10 MG/L. ISOCONS WITH HIGHER PERCENTAGES REPRESENT GROUND WATER THAT WOULD BE UNFIT TO DRINK.

EFFECTS OF SEPTIC SYSTEM DEVELOPMENT AT MAXIMUM PERMITTED RESIDENTIAL DENSITIES

FOR

CITY OF PORTLAND

ISLAND GROUND WATER MANAGEMENT STUDY

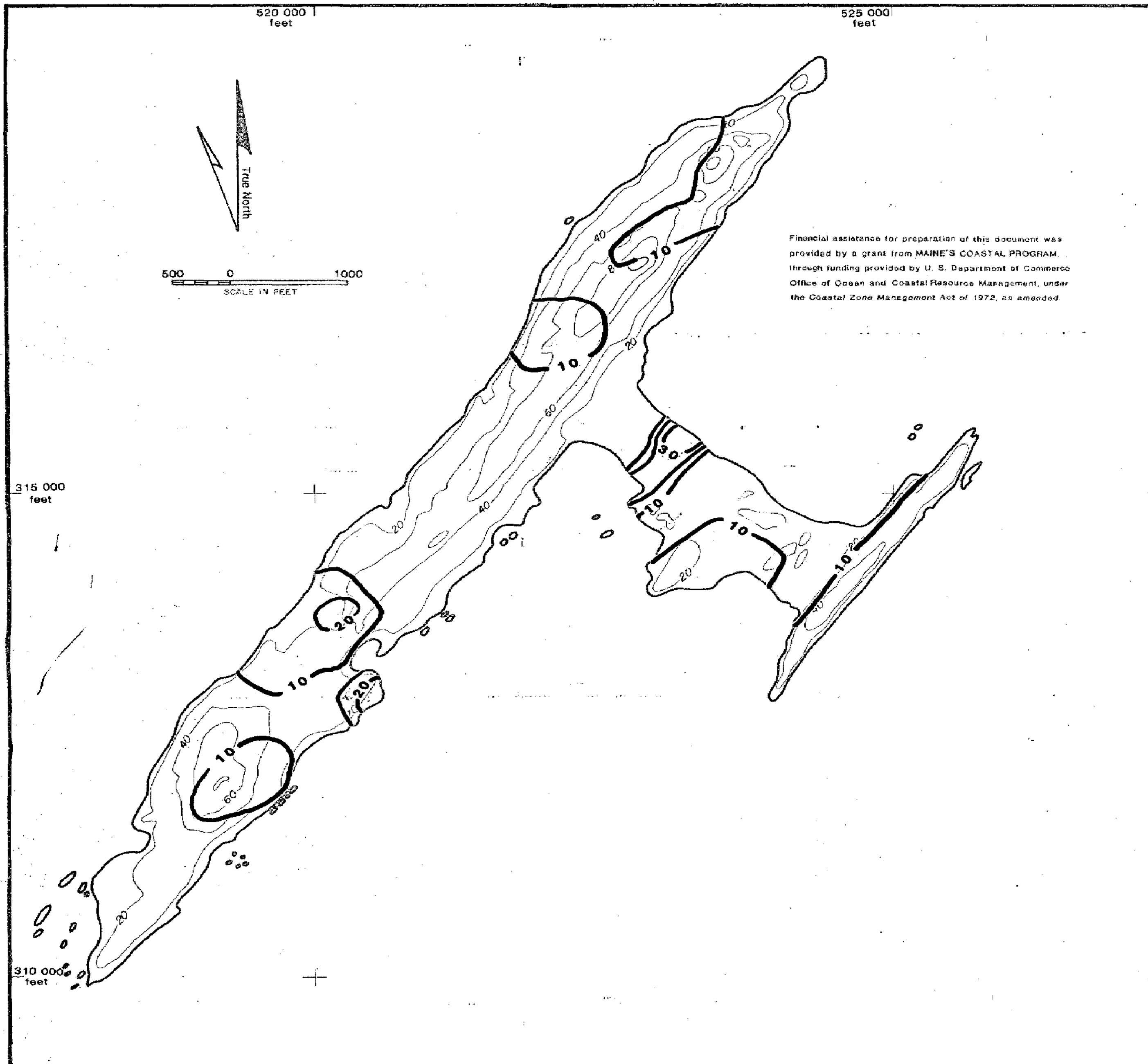
BY

*ROBERT G. GERBER, INC.*

*CONSULTING CIVIL ENGINEERS AND GEOLOGISTS*
*FREEPORT, MAINE*

LONG ISLAND

DATE **JUNE 1986** | FIGURE **28**




Financial assistance for preparation of this document was provided by a grant from MAINE'S COASTAL PROGRAM, through funding provided by U. S. Department of Commerce Office of Ocean and Coastal Resource Management, under the Coastal Zone Management Act of 1972, as amended.

—10— ISOCONS (LINES OF EQUAL CHEMICAL CONCENTRATION) OF CONTAMINANTS FROM SUBSURFACE SEWAGE DISPOSAL SYSTEMS IF THE ENTIRE ISLAND IS DEVELOPED AT MAXIMUM ALLOWED RESIDENTIAL DENSITY. FOR NITRATE-NITROGEN, THE 30% ISOCON IS EQUIVALENT TO ABOUT 10 MG/L. ISOCONS WITH HIGHER PERCENTAGES REPRESENT GROUND WATER THAT WOULD BE UNFIT TO DRINK.

EFFECTS OF SEPTIC SYSTEM DEVELOPMENT AT MAXIMUM PERMITTED RESIDENTIAL DENSITIES

FOR

CITY OF PORTLAND

ISLAND GROUND WATER MANAGEMENT STUDY

BY

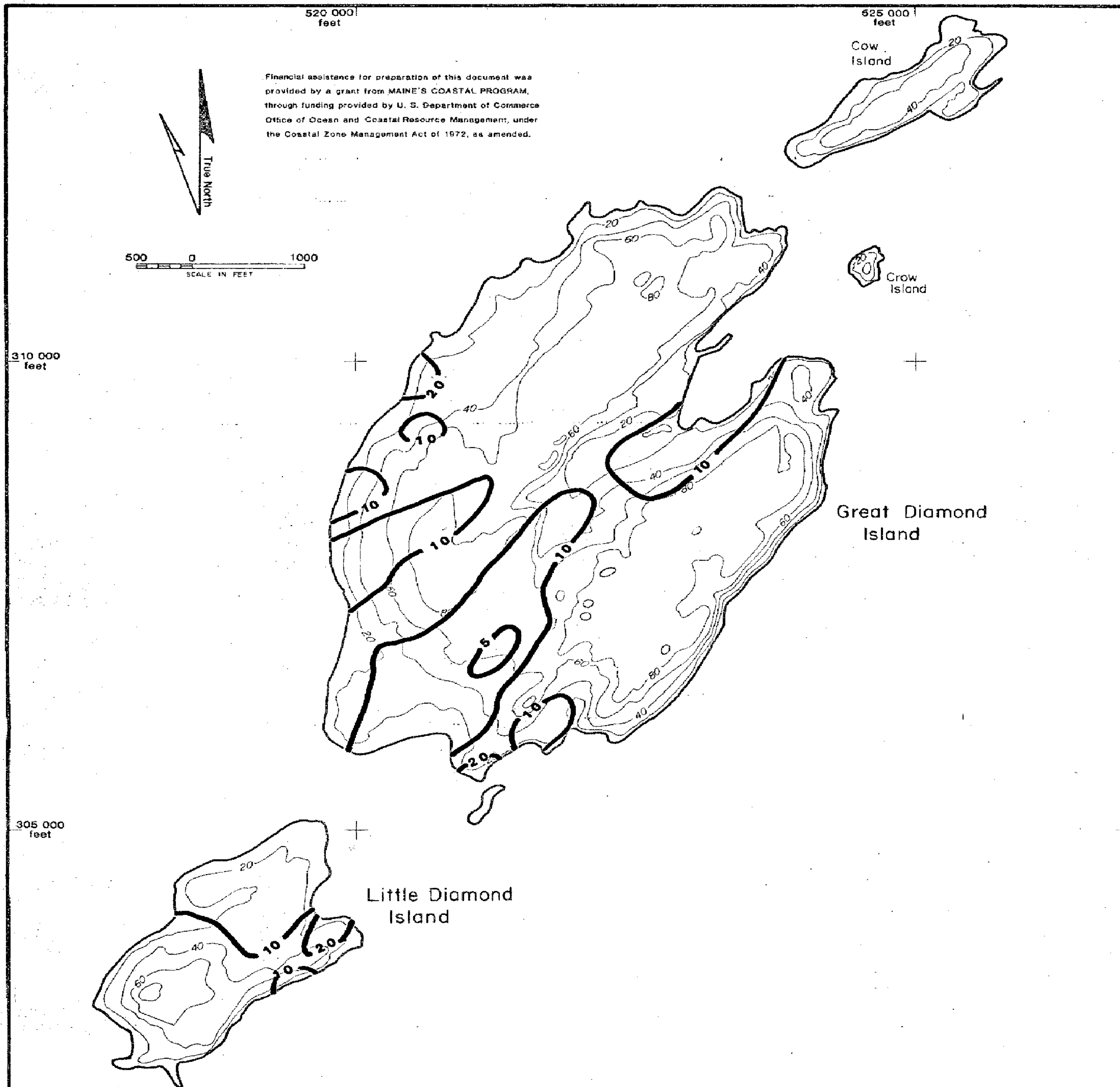
*ROBERT G. GERBER, INC.*

*CONSULTING CIVIL ENGINEERS AND GEOLOGISTS*

*FREEPORT, MAINE*

CLIFF ISLAND

DATE **JUNE 1986** FIGURE **29**




— 10 — ISOCONS (LINES OF EQUAL CHEMICAL CONCENTRATION) OF CONTAMINANTS FROM SUBSURFACE SEWAGE DISPOSAL SYSTEMS IF THE ENTIRE ISLAND IS DEVELOPED AT MAXIMUM ALLOWED RESIDENTIAL DENSITY. FOR NITRATE-NITROGEN, THE 30% ISOCON IS EQUIVALENT TO ABOUT 10 MG/L. ISOCONS WITH HIGHER PERCENTAGES REPRESENT GROUND WATER THAT WOULD BE UNFIT TO DRINK.

**EFFECTS OF SEPTIC SYSTEM DEVELOPMENT AT MAXIMUM PERMITTED RESIDENTIAL DENSITIES**

FOR

CITY OF PORTLAND

ISLAND GROUND WATER MANAGEMENT STUDY

*BY*

*ROBERT G. GERBER, INC.*

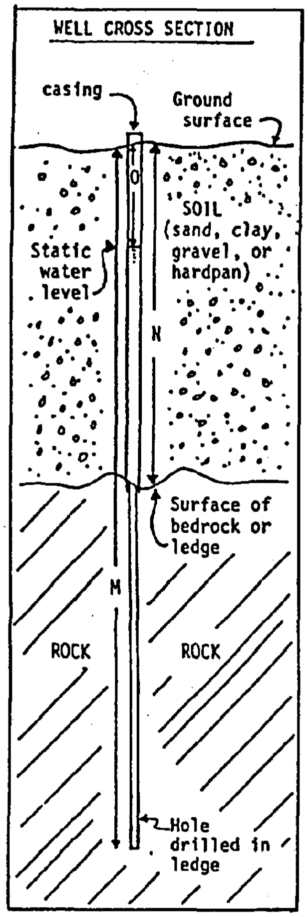
*CONSULTING CIVIL ENGINEERS AND GEOLOGISTS*
*FREEPORT, MAINE*

DIAMOND ISLANDS

DATE **JUNE 1986** | FIGURE **30**

# APPENDIX A

# WATER SUPPLY QUESTIONNAIRE -- PORTLAND ISLANDS GROUND WATER STUDY




Long Island and Cliff Island are not served by public water supplies. These island residents must obtain their water supplies from individual wells, springs, or streams that are located on their own lots. With the increasing pressure for development of the islands, it is imperative that the water resources of the islands be wisely used in order to ensure that present and future residents and businesses on these islands can be assured of an adequate and potable water supply. In order to plan for the wise use of the ground water resources, we must know how much is available, where the best aquifers are located, where the recharge occurs, and where the quality of the water is presently less than desirable. The purpose of this questionnaire is to gain information on the Island ground water resources so that the City of Portland can plan realistic ways of ensuring that the resource will be available not only for the benefit of present users, but for future generations.

This questionnaire is being circulated on behalf of the City of Portland with financial assistance provided by a grant from MAINE'S COASTAL PROGRAM, through funding provided by the U.S. Dept. of Commerce, Office of Coastal Zone Management, under the Coastal Zone Management Act of 1972, as amended. Consultant Robert G. Gerber, Inc., will compile and analyze the questionnaire returns, prepare a report for the public on the results of the study, and make recommendations to the City for ways to protect and enhance the ground water resource without unduly restricting the ability to develop private properties.

Please fill out the questionnaire as completely as you can, leaving blank any questions for which you do not know the answer. To aid in your understanding of the meaning of some of the questions, at the left we have drawn a small cross section of a typical drilled well. The letters in the diagram correspond to some of the questions identified by the same letters in the right margin, opposite the questions. Please fill out separate forms for each well or spring on your property that is being now, or has been used in the past, as a water supply. Questions concerning the form or the study may be addressed to: Robert G. Gerber, Inc., 17 West Street, Freeport, Maine 04032, 207-865-6138. Please return the forms directly to Robert G. Gerber, Inc. It would be most helpful if the questionnaires could be returned by February 28th. Thank you.

Property Owner ______________ Portland Tax Map Number (See mailing label) ______ A

Questionnaire Respondent ______________ Portland Tax Map Lot # ______ B

North Coordinate (Please leave blank) ______ C

East Coordinate (Please leave blank) ______ D

Estimated Ground Elevation (Please leave blank) ______ E

Geologic Unit Code (Please leave blank) ______ F

Type of water supply? Answer "1" if drilled artesian well and supply name of well driller ______________; "2" if well dug by hand or backhoe; "3" if spring in soil; "4" if spring in ledge; "5" if well point; "6" if other, and describe ______________ ______ G

Year in which the water supply was first developed or used ______ H

Approximate distance, in feet, from nearest public road to water supply ______ I

Has the water supply been tested? ______ Enter "1" if excessive coliform bacteria; "2" if excessive nitrate-nitrogen; "3" if excessive chloride; "4" if excessive iron and/or manganese; "5" if gas, oil, or other organic chemicals were detected; "6" if other excessive constituents, and describe ______________ ______ J

Do you have a water softener or other type of treatment system? ______ K

How many gallons per minute is the water supply reported to produce? (Check with your well driller for this, if you know who he is) ______ L

What is the total depth of the well or spring, in feet, below ground? ______ M

What is the depth to ledge, or length of well casing, if a drilled artesian well? (Again, you could check with your well driller or look at the bill he gave you for drilling the well) ______ N

When the pump is off, how many feet below ground is the water level in your well? (This is called the "static level") ______ O

If you answered the previous question, in what month and year was the level measured? ______ P

In which years has your water supply run dry, if ever? ______ Q

Please indicate the approximate location of your well on the map that is printed on the back of this form. The lot lines are taken from the GPCOG land use maps.

## EXPLANATION OF COMPUTER PRINTOUT

### Description of Well Tabulation Headings

WELL--unique well number assigned to the well

TAX #--tax map lot number on respective City tax map; left blank if not known

N COORD--Maine State Grid northern coordinate

E COORD--Maine State Grid eastern coordinate

GRD ELEV--estimated ground elevation at well, referenced to Mean Sea Level (NGVD)

GUC--geologic unit code (see Table 1)

WELL TYPE--type of well or spring (see questionnaire); left blank if not known

YEAR 1ST USED--the year the well or spring was first used or developed for a water supply; left blank if not known

DISTANCE FROM RD--distance in feet between the nearest public road and the water supply; left blank if not known

QUALITY TESTED?--indication as to whether the water from the water supply has been tested by a laboratory; "Y" if yes, "N" if no

BACTERIA--indication as to whether the water contained excessive coliform bacteria according to recommended drinking water standards; left blank if no or not known, "1" if excessive level was reported

NITRATE--indication as to whether the water contained excessive nitrate nitrogen according to recommended drinking water standards; left blank if no or not known, "1" if excessive level was reported

CHLORIDE--indication as to whether the water contained excessive chloride according to recommended drinking water standards; left blank if no or not known, "1" if excessive level was reported

IRON--indication as to whether the water contained excessive iron according to recommended drinking water standards; left blank if no or not known, "1" if excessive level was reported

ORGANICS--indication as to whether the water contained excessive organics according to recommended drinking water standards; left blank if no or not known, "1" if excessive level was reported

OTHER--indication as to whether the water contained excessive other constituents according to recommended drinking water standards; left blank if no or not known, "1" if excessive level was reported

WATER FILTER--indication as to whether a water softener or other treatment system is used to treat the water; "Y" if yes, "N" if no or not known

YIELD (GPM)--rated yield of the well in gallons per minute; left blank if not known

WELL DEPTH--total depth of well in feet; left blank if not known

CASING LENGTH--total length of well casing, or, if known, depth to bedrock in feet; left blank if not known.

WATER LEVEL--distance from ground surface to static water level in feet; left blank if not known

MONTH MEASURED--month of the year in which the static water level is measured; left blank if not known

YEAR MEASURED--year in which the static water level is measured; left blank if not known

YEAR DRY--a year in which the well went dry; left blank if not known

APPENDIX A:

PORTLAND ISLAND WATER SUPPLY SURVEY DATA FROM ROBERT G. GERBER, INC.

| WELL | TAX # | LOT # | N COORD | E COORD | GRD ELEV | GUC | WELL TYPE | YEAR 1ST USED | DISTANCE FROM RD | QUALITY TESTED? | BACTERIA | NITRATE | CHLORIDE | IRON | ORGANICS | OTHER | WATER FILTER | YIELD (GPM) | WELL DEPTH | CASING LENGTH | WATER LEVEL | MONTH MEASURED | YEAR MEASURED | YEAR DRY |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| LONG ISLAND | | | | | | | | | | | | | | | | | | | | | | | | |
| 200 | 103 | F-012 | 318240 | 507040 | 10 | 9 | 1 | 1971 | 200 | Y | - | - | - | - | - | - | Y | | 75 | | | | - | NEVER |
| 201 | 104-I | 65 | 318080 | 507040 | 10 | 13 | 2 | 1870 | 200 | Y | - | - | - | - | - | - | N | | 18 | | | | - | NEVER |
| 202 | 103 | K-8 | 316680 | 506200 | 55 | 9 | 1 | 1964 | 30 | Y | - | - | - | - | - | - | N | 7 | 78 | 14 | | | - | NEVER |
| 203 | 103 | I-005 | 316080 | 505800 | 65 | 10 | 1 | 1946 | 300 | Y | | | | — | | | Y | 12 | 75 | 0 | | | - | NEVER |
| 204 | 101 | C-001 | 314920 | 505960 | 25 | 10 | 1 | 1926 | 85 | Y | - | - | - | - | - | - | N | | 36 | | | | - | NEVER |
| 205 | 104 | I-048 | 316360 | 505560 | 20 | 9 | | | 40 | Y | - | - | - | - | - | - | Y | | | | | | - | - |
| 206 | 103 | I-010 | 315760 | 506000 | 105 | 10 | 1 | 1977 | 25 | N | - | - | - | - | - | - | N | 1.5 | 145 | 16 | 11 | 10 | 1985 | NEVER |
| 207 | 101 | D-005 | 315400 | 505160 | 30 | 10 | 1 | 1984 | 25 | Y | — | - | - | - | - | - | N | 1.5 | 185 | 6 | | | - | - |
| 208 | 104 | T-041 | 318360 | 506320 | 38 | 9 | 1 | 1975 | 250 | Y | 1 | - | - | - | - | - | N | 3 | 140 | 12 | 12 | 10 | 1974 | NEVER |
| 209 | 104 | I-035 | 317200 | 507440 | 20 | 11 | 1 | 1983 | 150 | Y | - | - | - | - | - | - | N | 7 | 65 | 18 | 8 | 08 | 1983 | NEVER |
| 210 | 100 | C-005 | 313480 | 504280 | 25 | 10 | 1 | 1948 | 100 | Y | - | - | - | - | - | - | N | 5 | 70 | | | | - | NEVER |
| 211 | 101 | G-008 | 314880 | 504400 | 22 | 11 | 1 | 1966 | 40 | Y | — | - | - | - | - | - | N | 10 | 110 | | 20 | 08 | 1985 | NEVER |
| 212 | 100 | A-001 | 309080 | 499120 | 10 | 15 | 5 | 1965 | 500 | Y | - | - | - | - | - | - | N | 5 | 6 | | 2 | 08 | 1985 | NEVER |
| 213 | 104 | D-026 | 315120 | 507600 | 20 | 10 | 1 | 1985 | 250 | Y | — | — | — | — | — | — | N | 2 | 142 | 20 | 12 | 09 | 1985 | NEVER |
| 214 | 103 | G-053 | 317480 | 506060 | 35 | 9 | 1 | 1980 | 300 | Y | - | - | - | - | - | - | N | 15 | 70 | | | | | NEVER |
| 215 | 104 | I-049 | 317320 | 507200 | 15 | 15 | 2 | | 80 | N | | | | | | | N | | 18 | | | | - | NEVER |
| 216 | 102 | D-007 | 315400 | 505320 | 40 | 10 | 1 | 1982 | 25 | Y | - | - | - | - | - | | N | 1 | 150 | 10 | 20 | 05 | 1985 | NEVER |
| 217 | 104 | F-005 | 317720 | 506640 | 30 | 9 | 1 | 1985 | 100 | Y | - | - | - | - | - | - | N | 1.5 | 100 | | | | - | - |
| 218 | 104 | I-054 | 317520 | 507200 | 10 | 9 | 1 | 1969 | 75 | Y | - | - | — | — | - | - | N | 20 | 125 | 20 | | | - | 1982 |
| 219 | 102 | D-003 | 315280 | 505320 | 45 | 10 | 1 | 1965 | 75 | N | | | | | | | N | | 25 | 0 | | | - | NEVER |
| 220 | 100 | C-010 | 313040 | 504680 | 30 | 10 | 1 | 1970 | 60 | N | | | | | | | N | | 136 | | 20 | 06 | 1970 | NEVER |
| 221 | 104 | I-053 | 317560 | 507000 | 10 | 15 | 2 | PRE-1900 | 90 | N | | | | | | | N | | 14 | | | | - | 1968 |
| 222 | 103 | A-009 | 315400 | 505640 | 40 | 10 | 1 | 1936 | 100 | Y | — | - | - | - | - | - | N | | 55 | 3 | 25 | 06 | 1985 | NEVER |
| 223 | 103 | G-64 | 317560 | 506040 | 30 | 9 | 1 | 1975 | 600 | Y | — | - | - | - | - | - | N | 3 | 160 | 6 | 20 | 05 | 1984 | NEVER |
| 224 | 101 | C-015 | 315560 | 505240 | 40 | 10 | 1 | 1980 | 30 | N | | | | | | | N | 2 | 80 | 10 | 6 | 01 | 1985 | NEVER |
| 225 | 103 | I-006 | 316280 | 505880 | 55 | 10 | 1 | 1950 | 200 | Y | - | - | - | - | - | - | N | 2 | 109 | | | | | NEVER |
| 226 | 103 | G-052 | 317240 | 505960 | 45 | 9 | 1 | 1956 | 400 | Y | - | - | - | - | - | - | N | 15 | 142 | 2 | 45 | | 1956 | NEVER |
| 227 | 102 | A-006 | 313360 | 505640 | 30 | 10 | 1 | 1966 | | Y | - | - | - | - | - | - | N | | 80 | | | | - | - |
| 228 | 103 | G-055 | 317400 | 505880 | 30 | 9 | 1 | 1975 | 500 | Y | — | - | - | — | - | - | Y | 2 | 85 | 6 | 35 | 07 | 1985 | NEVER |
| 229 | 103 | D-006 | 315800 | 505600 | 60 | 10 | 1 | 1930 | 150 | Y | - | - | - | - | - | - | N | | 45 | | 17.5 | | | NEVER |
| 230 | 104 | B-007 | 312720 | 504600 | 15 | 10 | 1 | 1972 | 40 | Y | - | - | - | - | - | - | N | 30 | 125 | | 10 | 09 | 1985 | NEVER |
| 231 | 102 | A-007 | 313480 | 505800 | 20 | 10 | 1 | 1953 | 120 | N | | | | | | | N | 0.75 | 80 | 2 | 18 | 04 | 1985 | NEVER |
| 232 | 103 | I-008 | 316080 | 506040 | 105 | 11 | 1 | 1962 | | Y | - | - | - | — | - | - | N | 5 | 157 | 0 | 90 | 05 | 1985 | 1980 |
| 233 | 101 | C-005 | 315120 | 504880 | 10 | 11 | 1 | | 200 | Y | — | - | - | - | - | - | N | | 6 | | | | | NEVER |
| 234 | 104 | I-025 | 317040 | 507720 | 20 | 10 | 1 | 1915 | 150 | N | | | | | | | N | | 60 | 15 | | | - | 1984 |
| 235 | 94 | ?-6 | 307800 | 499680 | 40 | 11 | 1 | 1924 | 600 | N | | | | | | | N | | | | 20 | | 1970 | NEVER |
| 236 | 96 | B-? | 312520 | 501080 | 20 | 10 | 1 | 1970 | 80 | N | | | | | | | N | 1.5 | 100 | | | | | NEVER |
| 237 | 97 | B-1 | 312080 | 500080 | 35 | 11 | 1 | 1937 | 10 | Y | 0 | 0 | 0 | 0 | 0 | 0 | N | | | | | | | NEVER |
| 238 | 93 | D-7 | 310000 | 498320 | 30 | 13 | 3 | 1940 | | Y | 1 | 0 | 0 | 0 | | 0 | N | | | | 1 | 6 | 1985 | NEVER |
| 239 | 93 | E-7 | 310520 | 498760 | 60 | 13 | 2 | 1935 | 15 | N | | | | | | | N | | 40 | | 32.5 | 8 | 1985 | NEVER |
| 240 | 93 | J-23 | 309440 | 499600 | 40 | 10 | 1 | 1958 | 75 | Y | 0 | 0 | 0 | 0 | 0 | 0 | N | 6 | 60 | | | | | NEVER |
| 241 | 95 | A-4 | 388520 | 501960 | 20 | 10 | 1 | 1961 | 30 | N | | | | | | | N | 6 | 150 | 14 | | | | NEVER |
| 242 | 93 | B-14 | 309800 | 498240 | 20 | 10 | 1 | 1960 | 200 | N | | | | | | | N | 15 | 92 | | 20 | | | NEVER |
| 243 | 93 | B-14 | 309360 | 493400 | 20 | 10 | 1 | 1959 | 200 | N | | | | | | | N | 2 | 68 | 65 | 8 | | 1959 | NEVER |

P. 2

| WELL | TAX # | LOT # | N COORD | E COORD | GRD ELEV | GUC | TYPE | USED | FROM RD | TESTED? | BACTERIA | NITRATE | CHLORIDE | IRON | ORGANICS | OTHER | FILTER | (GPM) | DEPTH | LENGTH | LEVEL | MEASURED | MEASURED | YEAR DRY |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| LONG ISLAND | | | | | | | | | | | | | | | | | | | | | | | | |
| 244 | 93 | E-11 | 310760 | 498880 | 60 | 10 | 1 | 1950 | 3 | N | | | | | | | N | | | | | | | NEVER |
| 245 | 93 | B-5 | 309200 | 498680 | 10 | 10 | 1 | 1973 | 400 | N | | | | | | | N | 25 | 125 | 0 | 11 | | | NEVER |
| 246 | 93 | I-53 | 311200 | 499520 | 50 | 10 | 1 | 1960 | | Y | | | | | | 1 | N | 3.5 | 140 | 100 | | | | NEVER |
| 247 | 93 | I-16 | 311160 | 498920 | 40 | 10 | 1 | 1982 | 150 | N | | | | | | | N | 2 | 240 | 15 | 10 | 8 | 1982 | NEVER |
| 248 | 93 | G-25 | 310040 | 498920 | 60 | 10 | 1 | 1967 | 300 | N | | | | | | | N | 3.5 | 110 | 20 | 15 | 8 | 1967 | NEVER |
| 249 | 93 | F-45 | 309560 | 498960 | 40 | 10 | 1 | 1979 | 200 | N | | | | | | | N | 3 | 125 | 7 | 8 | 8 | 1985 | NEVER |
| 250 | 96 | C-4 | 310360 | 502000 | 70 | 10 | 1 | 1980 | | Y | | | | 1 | | 1 | Y | 2.5 | 220 | 7 | 16 | 9 | 1985 | NEVER |
| 251 | 93 | D-5 | 310020 | 498440 | 30 | 10 | 1 | 1985 | 60 | N | | | | | | | N | 1.75 | 180 | 27 | 40 | | | NEVER |
| 252 | 93 | B-17 | 309480 | 498560 | 30 | 10 | 1 | 1900 | 150 | Y | | | | | | 0 | N | | 40 | | | | | 1978 |
| 253 | 93 | C-3? | 309680 | 485200 | 40 | 11 | 1 | 1950 | 100 | N | | | | | | | N | 2 | 120 | 20 | | | | NEVER |
| 254 | 93 | I-55 | 311400 | 499360 | 40 | 9 | 1 | 1973 | 300 | N | | | | | | | N | 1.5 | 212 | 15 | 3 | | 1973 | NEVER |
| 255 | 92 | | | | | | 2 | 1915 | 65 | Y | | | | | | | N | | 25 | | 15 | 7 | 1985 | NEVER |

| | GUC | TYPE |
|---|---|---|
| MEAN | 10.36 | 1.18 |
| STND DEV | 1.43 | 0.66 |
| MAX | 15.00 | 5.00 |
| MIN | 9.00 | 0.00 |

ALL WELLS

| | (GPM) | DEPTH | LENGTH |
|---|---|---|---|
| MEAN | 6.3 | 98.3 | 9.8 |
| STD DEV | 7.0 | 56.3 | 17.7 |
| MAX | 30 | 240 | 100 |
| MIN | 0.75 | 6.00 | 0.00 |
| COUNT | 36 | 51 | 46 |

DISTRIBUTIONS

| #CASES | GUC | % |
|---|---|---|
| 13 | 1 | 23.21% |
| 2 | 2 | 3.57% |
| 3 | 3 | 5.36% |
| 10 | 9 | 17.86% |
| 17 | 10 | 30.36% |
| 5 | 11 | 8.93% |
| 1 | 13 | 1.79% |
| 3 | 15 | 5.36% |
| 2 | UNK | 3.57% |

| #CASES | WELL TYPE | % |
|---|---|---|
| 48 | DRILLED | 87.3% |
| 5 | DUG | 9.1% |
| 1 | SPRING | 1.8% |
| 1 | WELL PT. | 1.8% |
| 1 | UNK | 900.0% |

WELLS TESTED

34/56 60.71%

FILTERS

| | |
|---|---|
| 5/56 | 8.93% |
| 1 | 3 |
| 5 | 2 |
| 1 | 5 |
| 48 | 1 |
| 1 UNK | |

| DEPTH | # WELLS | % |
|---|---|---|
| 0'-25' | 6 | 10.71% |
| 25'-100' | 21 | 37.50% |
| 100'-200' | 21 | 37.50% |
| 200'-300' | 3 | 5.36% |
| UNKNOWN | 5 | 8.93% |
| | 56 | |

| YIELDS | # WELLS | % |
|---|---|---|
| UNK | 20 | 35.7% |
| 0-1 | 2 | 3.6% |
| 1-2 | 13 | 23.2% |
| 2-5 | 9 | 16.1% |
| 5-10 | 5 | 8.9% |
| 10-25 | 6 | 10.7% |
| 25+ | 1 | 1.8% |
| | 56 | 100.0% |

WATER LEVELS

| | DRILLED WELLS | DUG WELLS |
|---|---|---|
| MEAN | 20.0 | 23.75 |
| STD DEV | 17.1 | 8.75 |
| MIN | 3 | 15 |
| MAX | 90 | 32.5 |
| COUNT | 26 | 2 |

| WELL | TAX # | LOT # | N COORD | E COORD | GRD ELEV | GUC | WELL TYPE | YEAR 1ST USED | DISTANCE FROM RD | QUALITY TESTED? | BACTERIA | NITRATE | CHLORIDE | IRON | ORGANICS | OTHER | WATER FILTER | YIELD (GPM) | WELL DEPTH | CASING LENGTH | WATER LEVEL | MONTH MEASURED | YEAR MEASURED | YEAR DRY |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CLIFF ISLAND | | | | | | | | | | | | | | | | | | | | | | | | |
| 100 | 109B | B-004 | 314280 | 520120 | 20 | 10 | 1 | 1981 | 150 | N | | | | | | | N | 15 | 115 | 1 | 43 | 04 | 1980 | NEVER |
| 101 | 109B | D-025 | 314080 | 500400 | 35 | 10 | 1 | 1974 | 100 | N | | | | | | | | 30 | 100 | 1 | 25 | 08 | 1974 | " |
| 102 | 190C | A-021 | 316720 | 521920 | 40 | 10 | 1 | 1985 | 250 | Y | | | | | | | N | 15 | 110 | 6 | 12 | 07 | 1982 | " |
| 103 | 109R | C-007 | 314160 | 520840 | 35 | 10 | 1 | 1974 | 100 | Y | | | | | | | N | 10 | 107 | | | | | " |
| 104 | 109C | A-021 | 316840 | 522000 | 50 | 13 | 2 | 1910 | 250 | N | | | | | | | N | | 80 | | | | | " |
| 105 | 109D | A-010 | 314840 | 523400 | 10 | 13 | 2 | 1954 | | Y | | | | | | | N | 50 | 110 | 20 | 10 | 07 | 1985 | " |
| 106 | 109A | B-015 | 311280 | 518880 | 28 | 13 | 2 | 1900 | 300 | Y | | | | | | | N | 7 | 93 | | | | | " |
| 107 | 109B | B-030 | 314720 | 520480 | 10 | 13 | 2 | 1912 | 50 | Y | | | --- | | | | N | 30 | 85 | 2 | 15 | 09 | 1974 | " |
| 108 | 109B | D-037 | 314120 | 520560 | 48 | 10 | 1 | 1985 | 200 | N | | | | | | | N | 12 | 100 | 9 | 26 | 06 | 1985 | " |
| 109 | 109C | B-001 | 317160 | 522320 | 65 | 10 | 1 | 1936 | 50 | Y | | | | | | | N | 6 | 150 | 12 | 10 | 01 | 1981 | NEVER |
| 110 | 109C | B-012 | 315720 | 521760 | 65 | 10 | 1 | 1980 | 350 | N | | | --- | | | HARDNESS | N | 8 | 190 | 10 | 40 | 03 | 1985 | " |
| 111 | 109B | B-010 | 314640 | 520440 | 22 | 13 | 5 | | 50 | N | | | | | | | | | | | | | | |
| 112 | 109A | B-006 | 313160 | 519400 | 22 | 10 | 1 | 1946 | 75 | N | | | | | | | | | | | | | | |
| 113 | 109D | A-002 | 314840 | 523680 | 10 | 17 | 3 | 1940 | 275 | Y | | | | | | | N | 9 | 6 | | 3 | 02 | 1986 | " |
| 114 | 109B | D-029 | 313840 | 520560 | 35 | 10 | 1 | 1978 | 600 | Y | | | | | | | N | | 14 | | 3 | 02 | 1986 | " |
| 115 | 109A | B-003 | 312600 | 518920 | 38 | 10 | 1 | 1980 | 75 | Y | | | | | | | N | | 23 | | | | | " |
| 116 | 109A | B-017 | 311520 | 518960 | 40 | 13 | 2 | 1976 | 2000 | N | | | | | | | N | | 12 | 12 | 10 | 08 | 1985 | " |
| 117 | | | 315200 | 520880 | 20 | 13 | 2 | 1923 | 60 | N | | | | | | | N | | 15 | | 1 | 02 | 1986 | " |
| 118 | 109B | D-003 | 313720 | 520280 | 40 | 10 | 1 | 1974 | 50 | N | | | | --- | | | N | 2 | 18 | 19 | 2 | 07 | 1985 | NEVER |

| WELL | TAX # | LOT # | N COORD | E COORD | GRD ELEV | GUC | TYPE | USED | FROM RD | TESTED? | BACTERIA | NITRATE | CHLORIDE | IRON | ORGANICS | OTHER | FILTER | (GPM) | DEPTH | LENGTH | LEVEL | MEASURED | MEASURED | YEAR DRY |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **CLIFF** ISLAND | | | | | | | | | | | | | | | | | | | | | | | | |
| 119 | 109B | D-014 | 314840 | 521760 | 22 | 9 | 1 | 1975 | 100 | N | | | | | | | N | | 14 | 14 | | | | 1949 |
| 120 | 109C | A-017 | 316400 | 521720 | 25 | 10 | 1 | 1930 | 100 | N | | | | | | | N | | 10 | 10 | 6 | | | MOST YEA |
| 121 | 109C | A-002 | 316160 | 521600 | 25 | 10 | 1 | 1972 | 150 | N | | | | | | | | | | | | | | |
| 122 | 109A | B-007 | 312280 | 508000 | 40 | 10 | 1 | 1982 | 50 | N | | | | | | | | | | | | | | |
| 123 | 109B | E-004 | 314600 | 520600 | 20 | 13 | 2 | | 60 | N | | | | | | | N | 10 | 5 | | 2 | 07 | 1985 | " |
| 124 | 109B | E-026 | 315640 | 521520 | 35 | 10 | 1 | 1978 | 30 | N | | | | | | | | | | | | | | |
| 125 | 109B | F-044 | 315240 | 521960 | 22 | 10 | 1 | 1966 | 30 | Y | | | | | | | | | | | | | | |
| 126 | 109B | F-020 | 314460 | 521520 | 18 | 10 | 1 | 1961 | 150 | Y | | | | | | | N | | 100 | | | | | " |
| 127 | 109B | D-041 | 313840 | 520200 | 15 | 13 | 2 | 1958 | 80 | Y | | | | | | | | | | | | | | |

ALL WELLS

| | (GPM) | DEPTH | LENGTH |
|---|---|---|---|
| MEAN | 16.0 | 78.2 | 8.7 |
| STD DEV | 13.5 | 50.8 | 5.9 |
| MAX | 50.00 | 190.00 | 20.00 |
| COUNT | 19 | 28 | 16 |
| MIN | 2 | 5 | 1 |

DISTRIBUTIONS

| GUC | #CASES | % |
|---|---|---|
| 9 | 1 | 3.57% |
| 10 | 17 | 60.71% |
| 13 | 9 | 32.14% |
| 17 | 1 | 3.57% |
| | 28 | 1 |

| | GUC | TYPE |
|---|---|---|
| MEAN | 11.178 | 1.5 |
| STND DEV | 1.8137 | 0.8660 |
| MAX | 17.00 | 5.00 |
| MIN | 9 | 1 |

| #CASES | | % |
|---|---|---|
| 18 | DRILLED | 64.29% |
| 8 | DUG | 28.57% |
| 1 | SPRING | 3.57% |
| 1 | WELL PT. | 3.57% |

| WELLS TESTED | |
|---|---|
| 12/28 | 42.86% |
| FILTERS | |
| 1/28 | 3.57% |

| WELLDEP | DEPTH | # WELLS | % | YIELDS | YIELDS | # WELLS | % |
|---|---|---|---|---|---|---|---|
| 5 | 0 | 0 | | 10 | | | |
| 6 | 50 | 9 | 32.1% | 9 | UNK | 9 | 32.14% |
| 10 | 100 | 9 | 32.1% | | 0-1 | 0 | 0.00% |
| 12 | 150 | 9 | 32.1% | | 1-5 | 1 | 3.57% |
| 14 | 200 | 1 | 3.6% | | 5-10 | 9 | 32.14% |
| 14 | | 0 | | | 10-25 | 5 | 17.86% |
| 15 | | | | | 25+ | 4 | 14.29% |
| 18 | | | | 2 | | 28 | |
| 23 | | | | | | | |
| 58 | | | | 10 | | | |
| 80 | | | | 10 | | | |
| 80 | | | | | | | |
| 85 | | | | 30 | | | |
| 93 | | | | 7 | | | |
| 100 | | | | 12 | | | |
| 100 | | | | 12 | | | |
| 100 | | | | 30 | | | |
| 100 | | | | | | | |
| 105 | | | | 11 | | | |
| 107 | | | | 10 | | | |
| 110 | | | | 15 | | | |
| 110 | | | | 50 | | | |
| 115 | | | | 15 | | | |
| 120 | | | | 7 | | | |
| 120 | | | | | | | |
| 150 | | | | 6 | | | |
| 150 | | | | 50 | | | |
| 190 | | | | 8 | | | |

CLIFF ISLAND WATER LEVELS
DRILLED WELLS

| | |
|---|---|
| MEAN | 20.5 |
| STD DEV | 12.6 |
| MAX | 43 |
| MIN | 0 |
| COUNT | 11 |

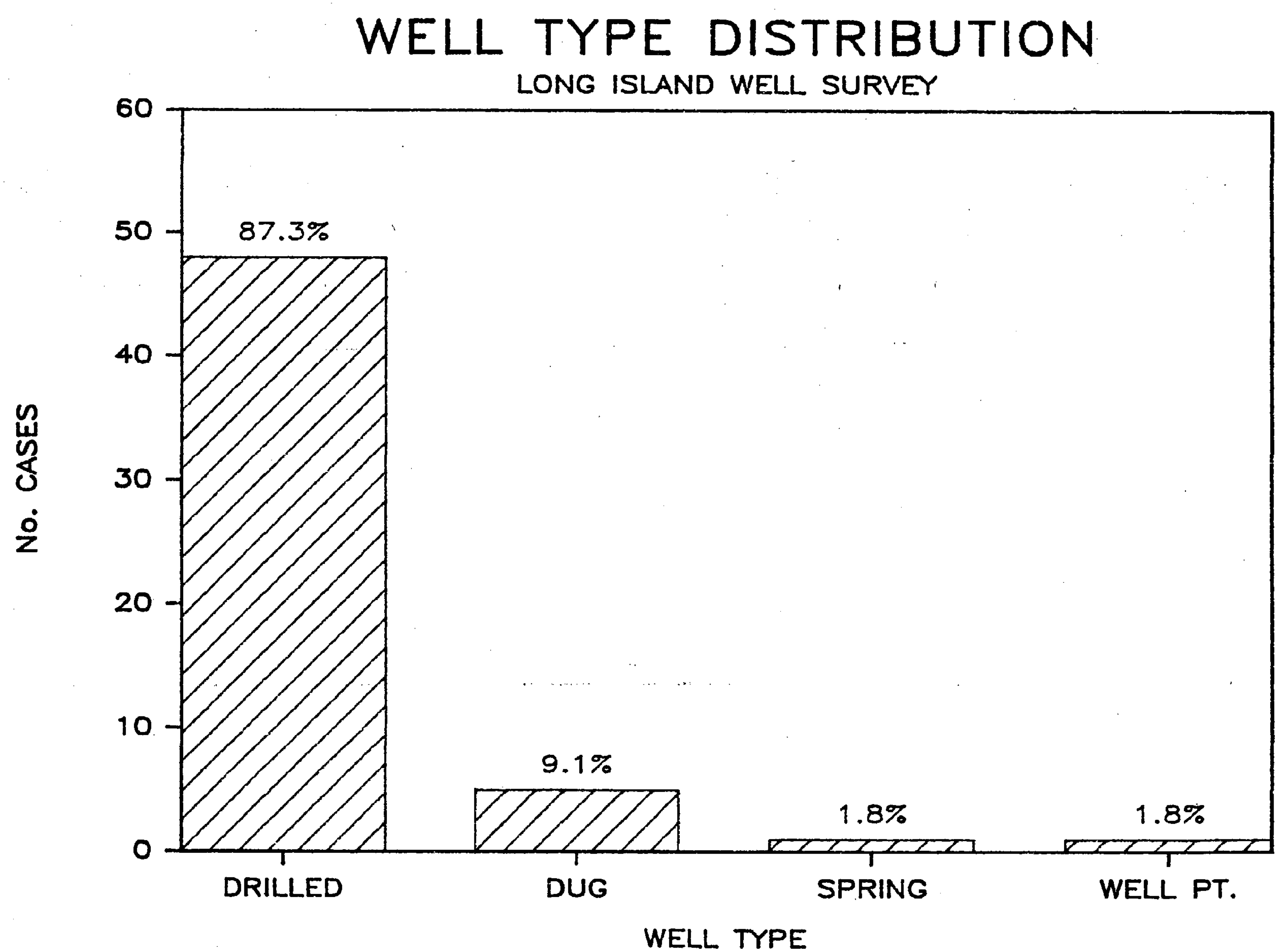

WELL TYPE DISTRIBUTION
LONG ISLAND WELL SURVEY
No. CASES
60
50
40
30
20
10
0
87.3%
9.1%
1.8%
1.8%
DRILLED
DUG
SPRING
WELL PT.
WELL TYPE

FIGURE A-1

# DISTRIBUTION OF WELL TYPES

CLIFF ISLAND WELL SURVEY

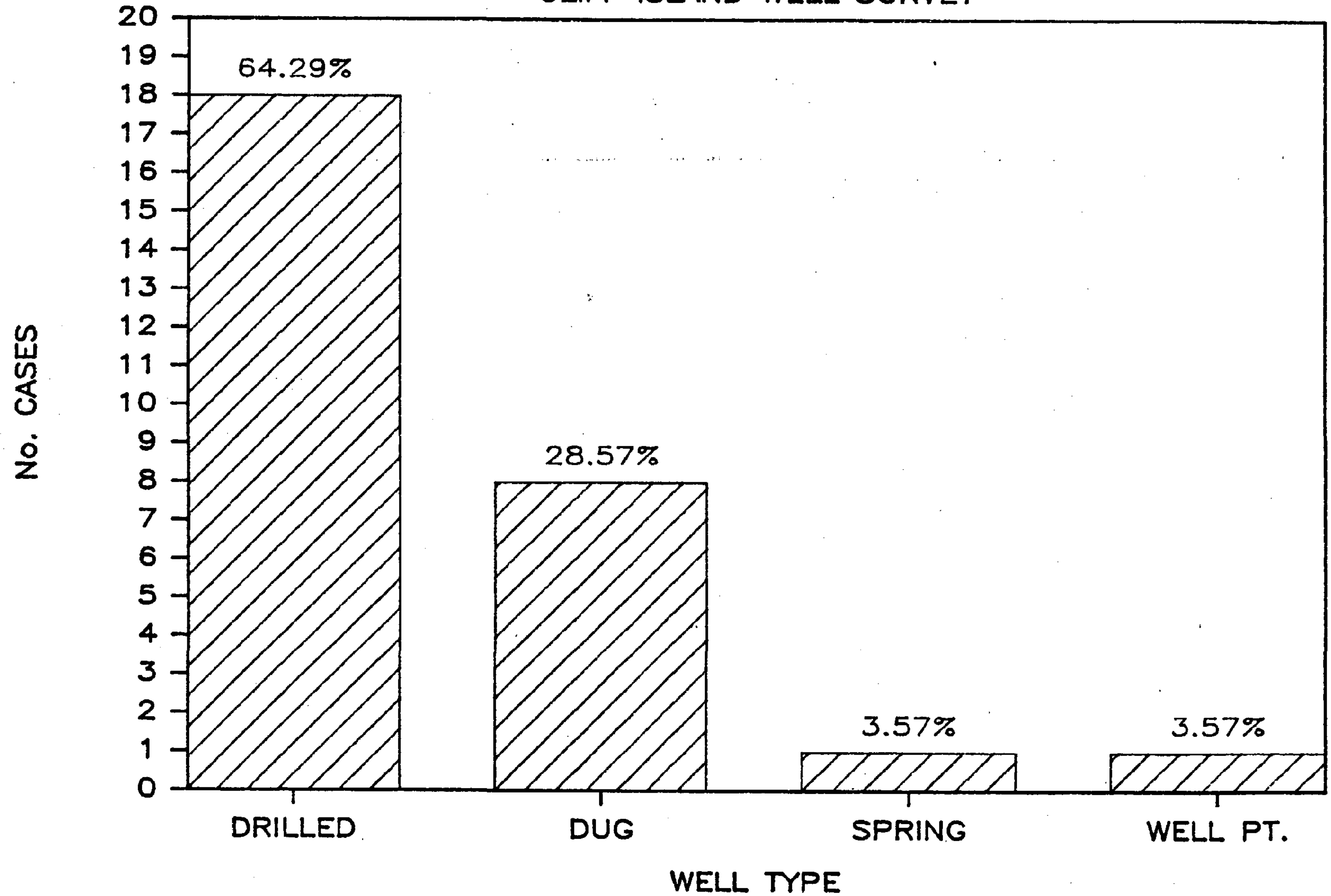



FIGURE A-2

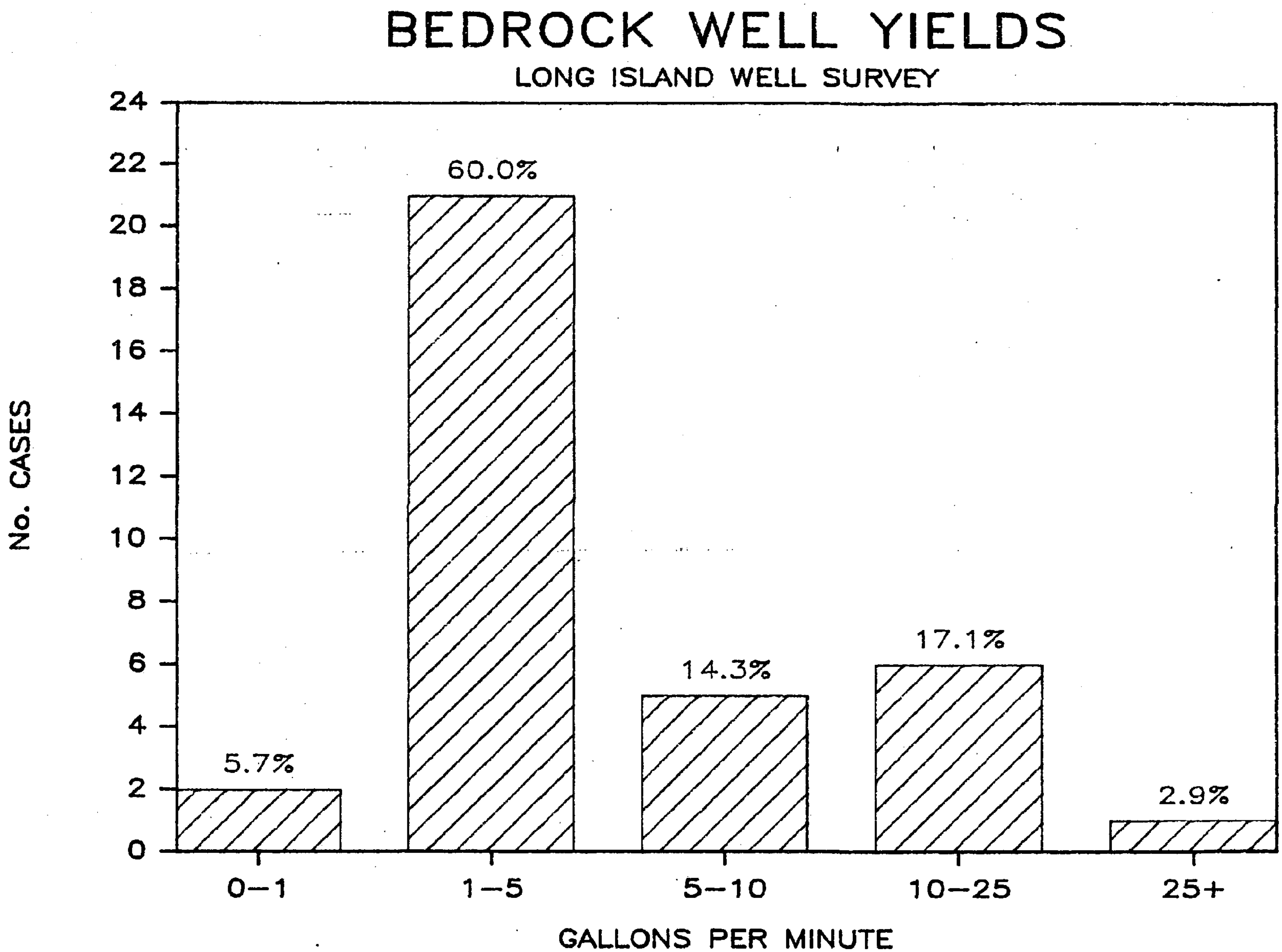

BEDROCK WELL YIELDS
LONG ISLAND WELL SURVEY
No. CASES
24
22
20
18
16
14
12
10
8
6
4
2
0
5.7%
60.0%
14.3%
17.1%
2.9%
0-1
1-5
5-10
10-25
25+
GALLONS PER MINUTE

FIGURE A-3

# DRILLED WELL YIELDS — H.C. HANSEN

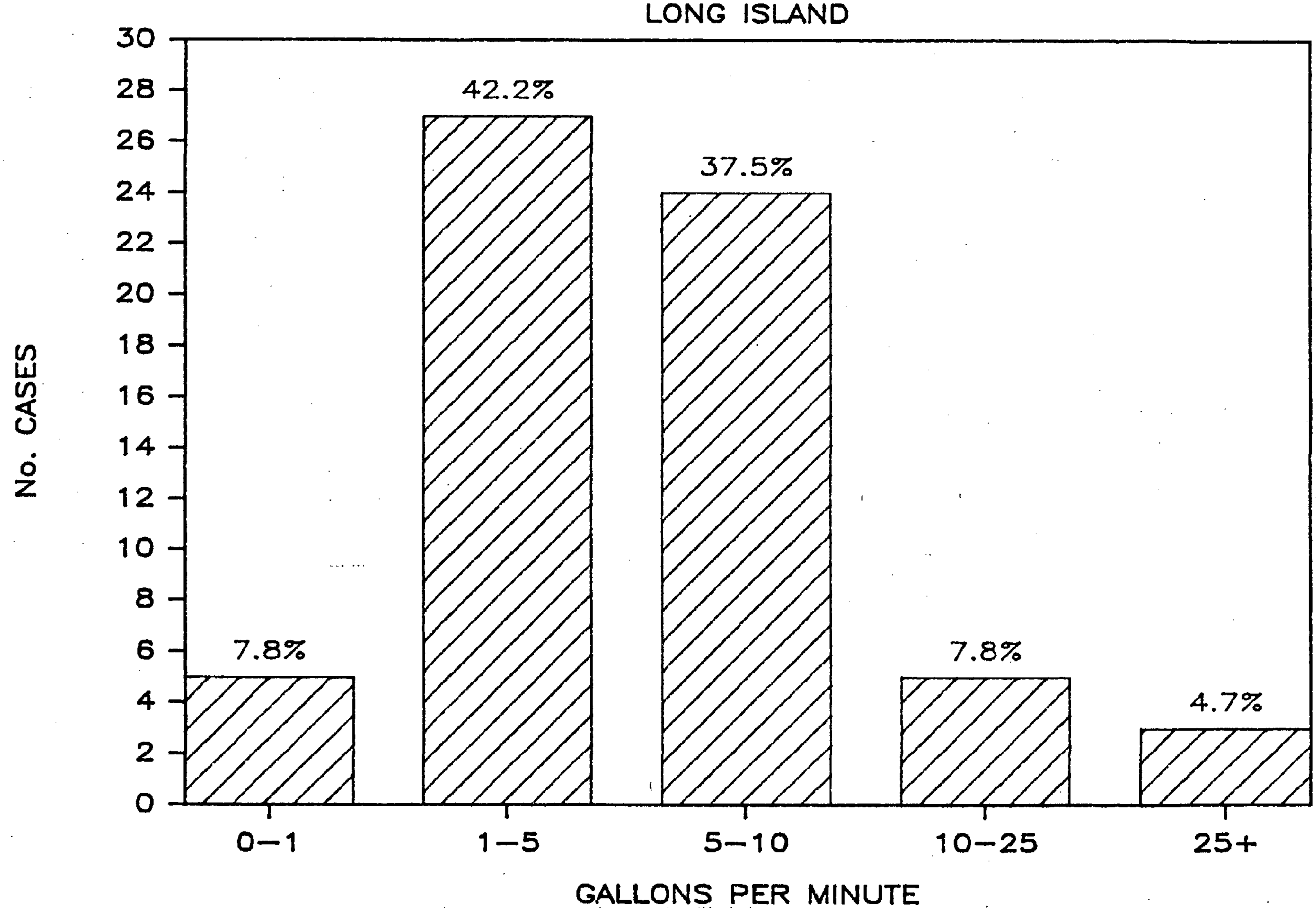



FIGURE A-4

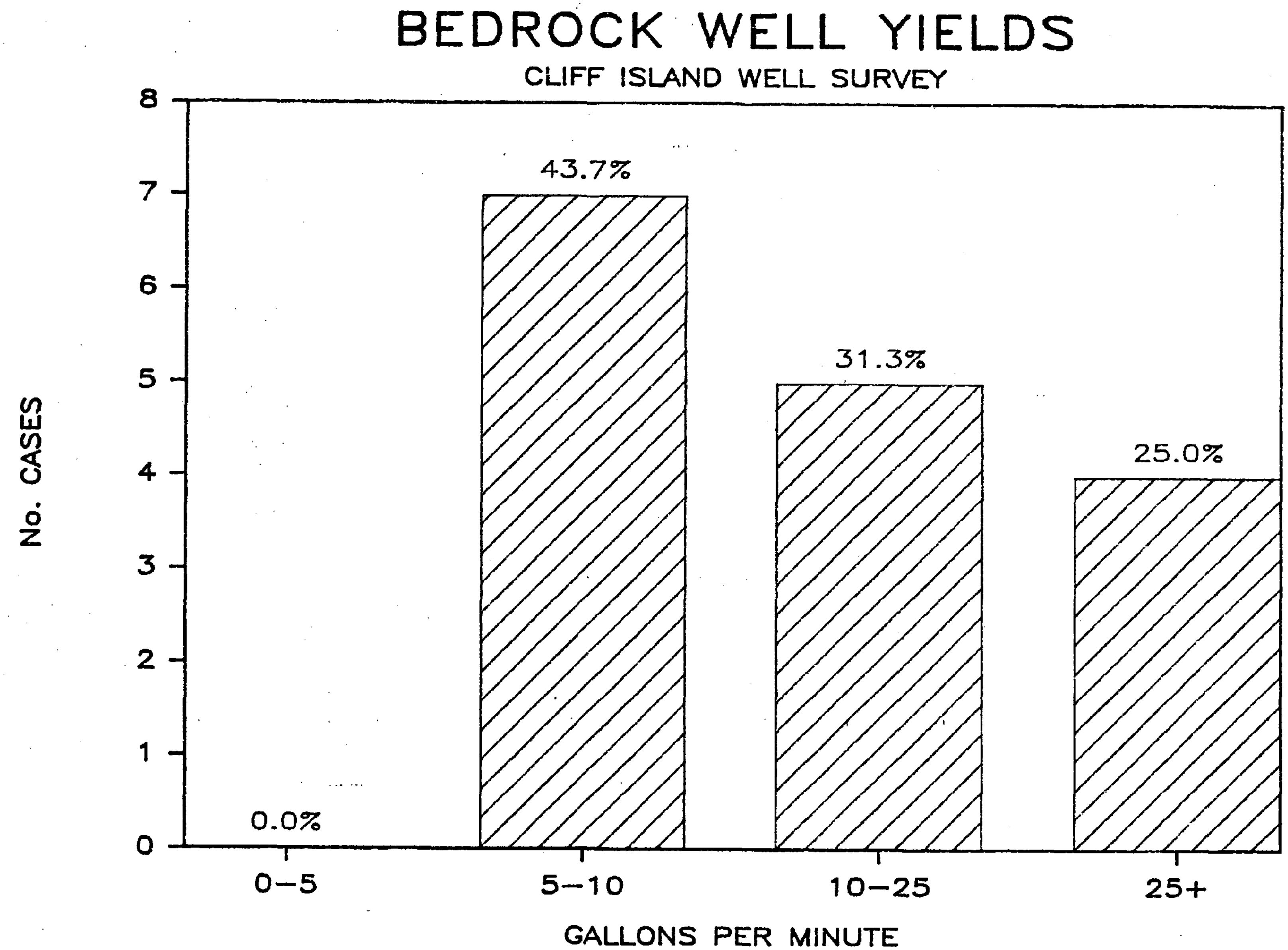

BEDROCK WELL YIELDS
CLIFF ISLAND WELL SURVEY
No. CASES
0
1
2
3
4
5
6
7
8
0.0%
43.7%
31.3%
25.0%
0–5
5–10
10–25
25+
GALLONS PER MINUTE

FIGURE A-5

# BEDROCK WELL DEPTHS

LONG ISLAND WELL SURVEY

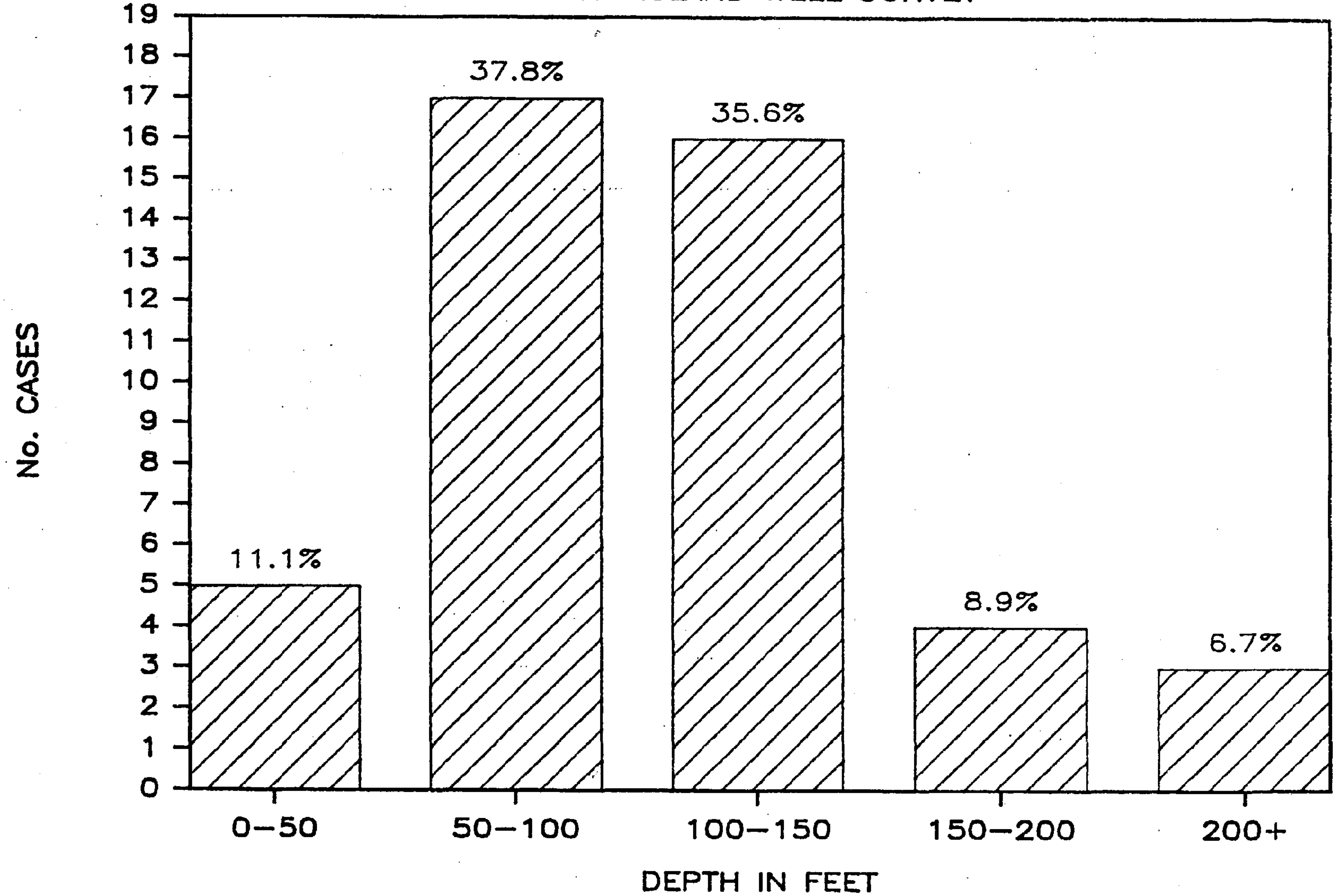



FIGURE A-6

# DRILLED WELL DEPTHS — H.C. HANSEN

LONG ISLAND

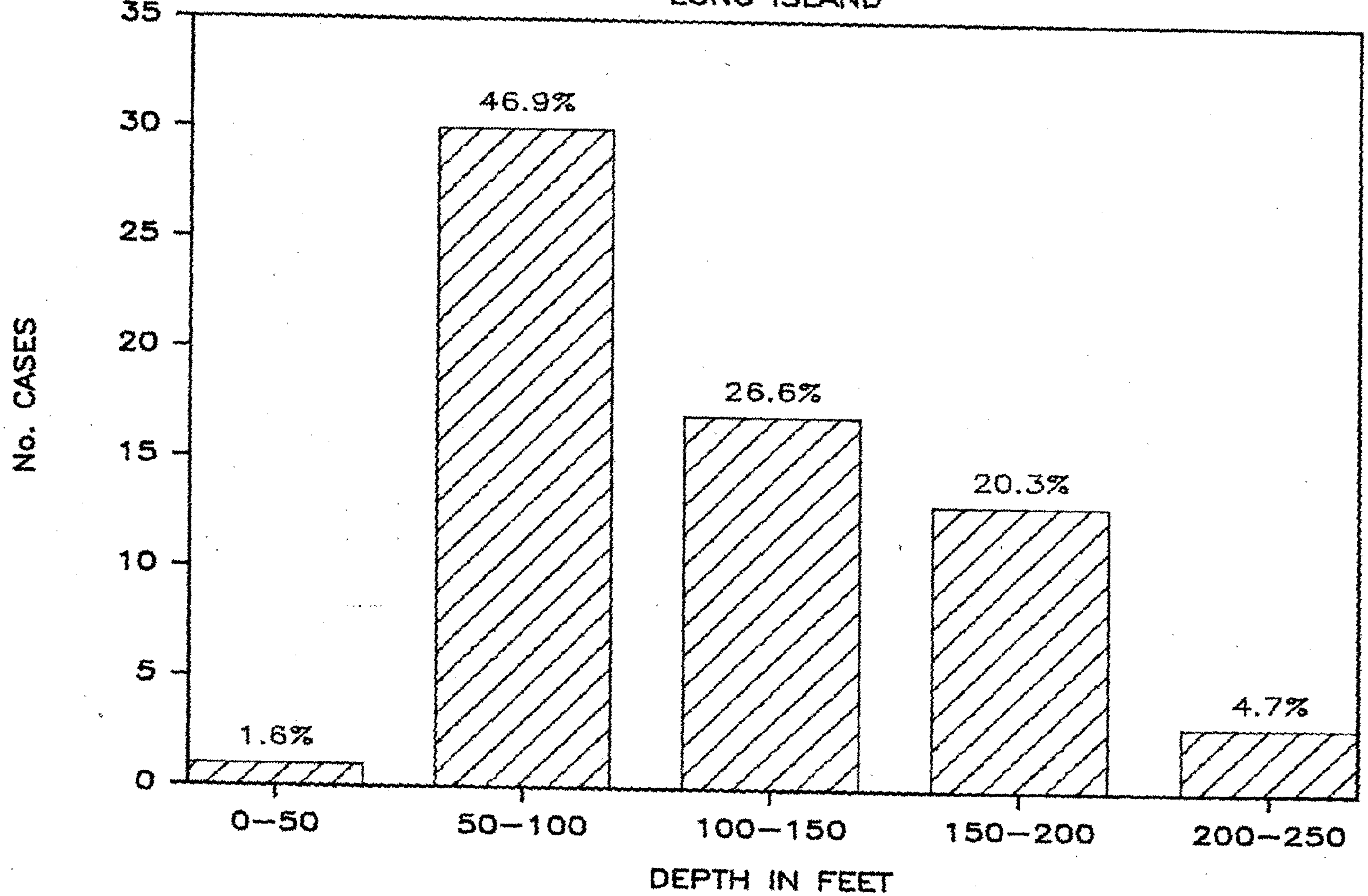



FIGURE A-7

# BEDROCK WELL DEPTHS

CLIFF ISLAND WELL SURVEY

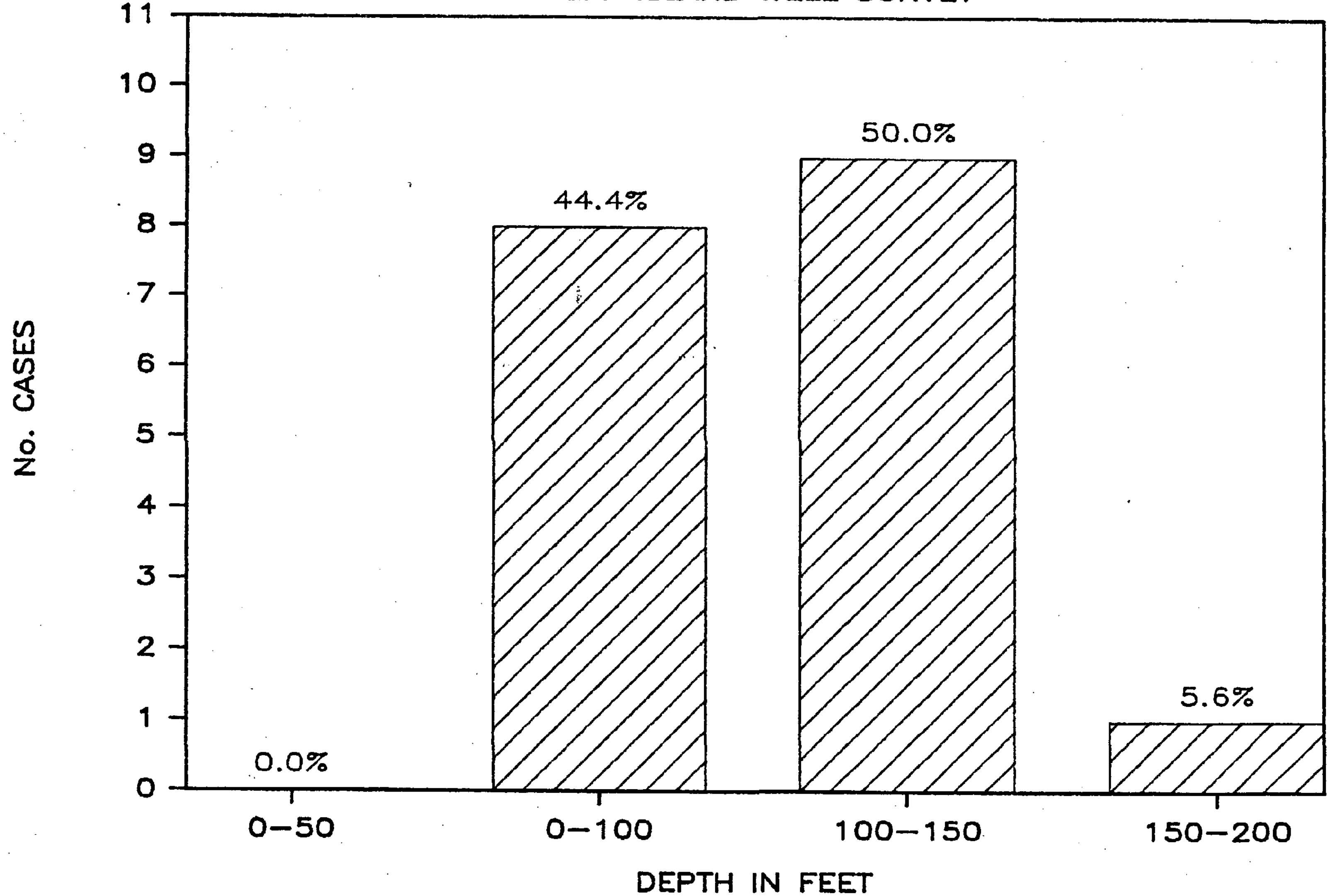



FIGURE A-8

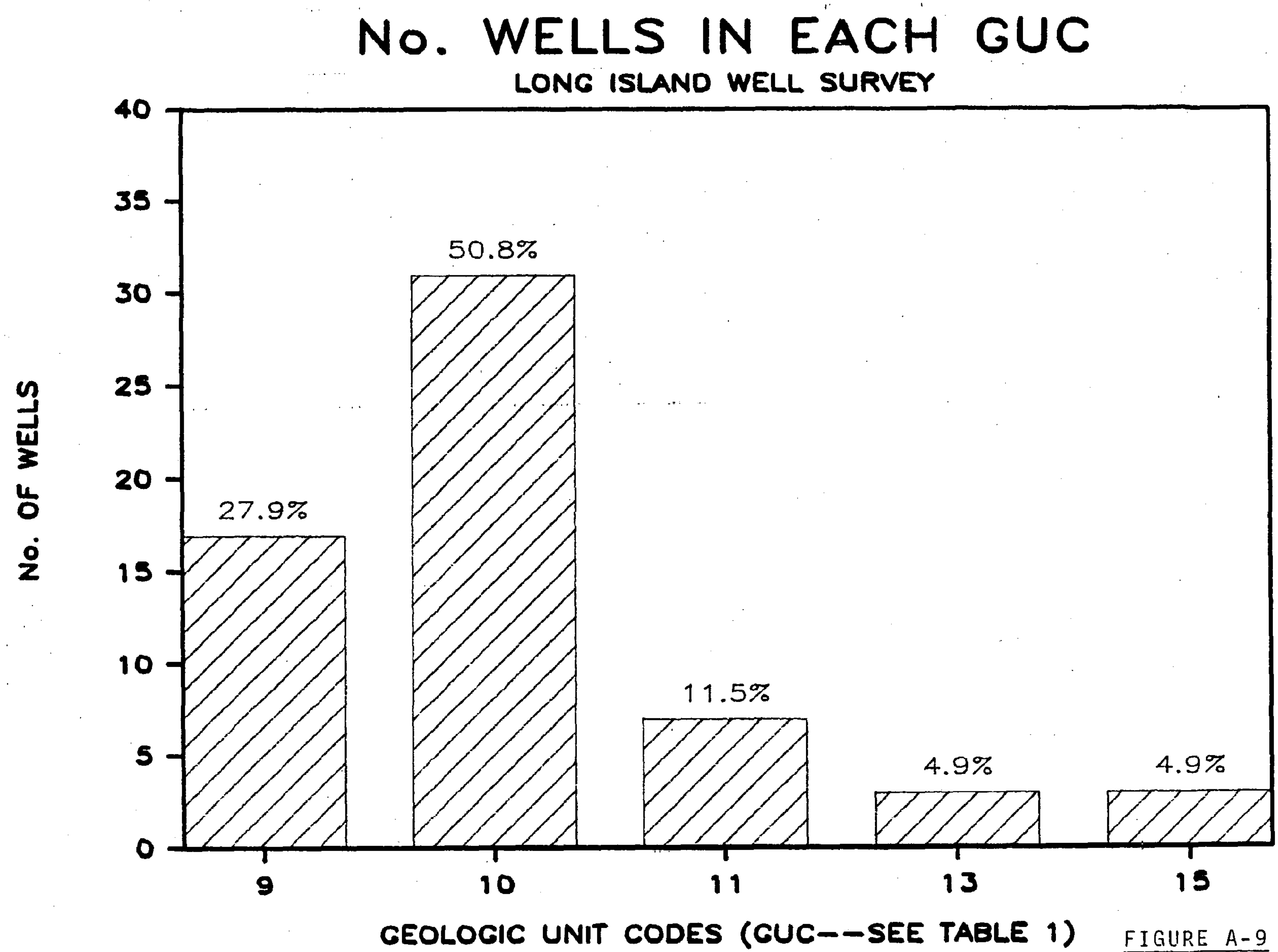

No. WELLS IN EACH GUC
LONG ISLAND WELL SURVEY
No. OF WELLS
0
5
10
15
20
25
30
35
40
27.9%
50.8%
11.5%
4.9%
4.9%
9
10
11
13
15
GEOLOGIC UNIT CODES (GUC--SEE TABLE 1)

FIGURE A-9

# No. WELLS IN EACH GUC

CLIFF ISLAND WELL SURVEY

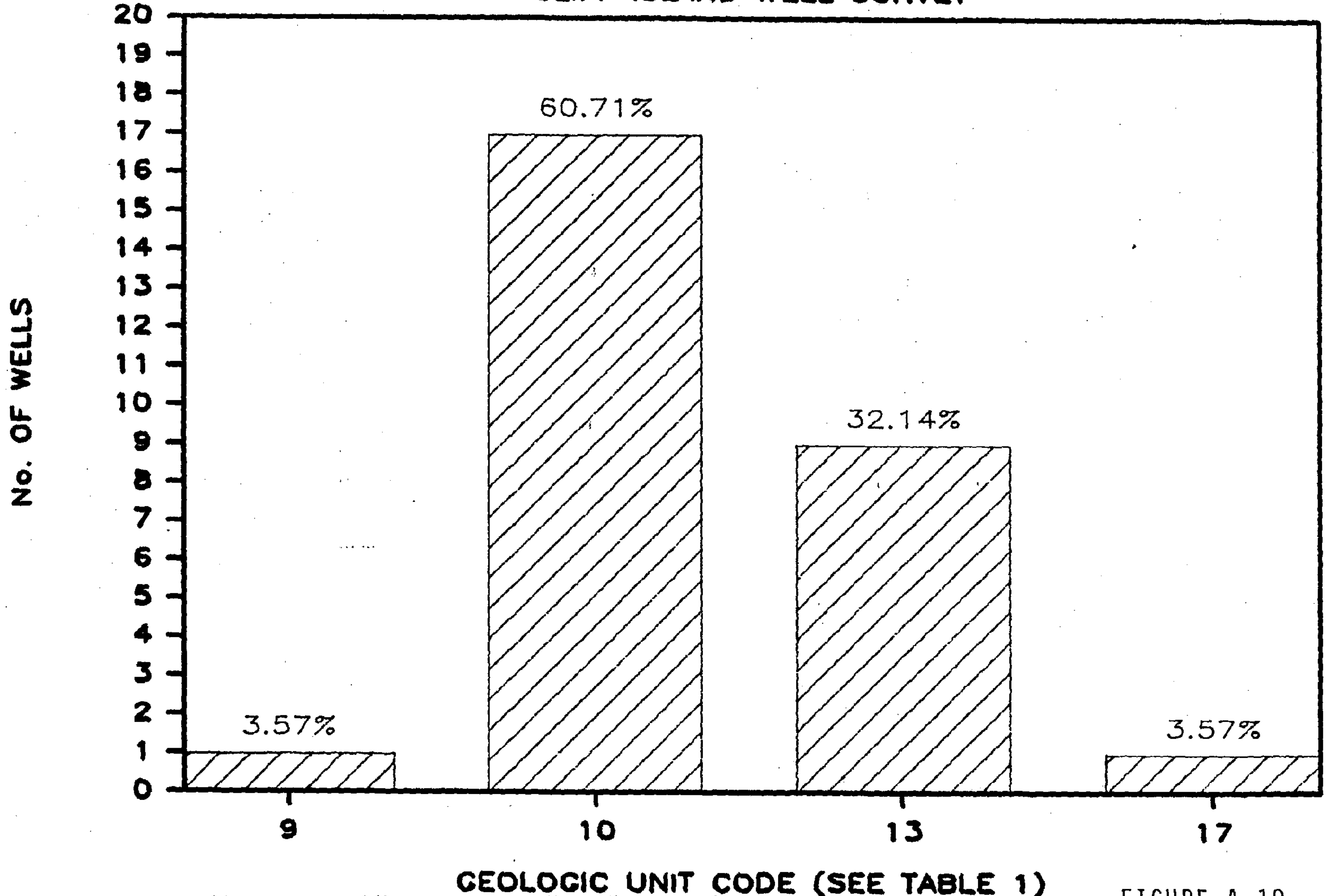



FIGURE A-10

# APPENDIX B

APPENDIX B

LONG ISLAND WELL WATER QUALITY DATA OBTAINED FROM RAOUL DIAZ AND OTHER RESIDENTS
AND CLIFF ISLAND WATER QUALITY RESULTS FROM SAMPLES OBTAINED BY ROBERT G. GERBER, INC.

| SAMPLE NUMBER | NITRITE -N * | NITRATE -N * | pH | IRON * | CHLORIDE * | HARDNESS | COPPER * | MANGANESE * | COLIFORMS ** | BACTERIA, OTHER ** | SODIUM * |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 101 | < 0.005 | 1.2 | 6.6 | < 0.05 | 23 | 47 | < 0.1 | < 0.02 | CWOC | — | NA |
| 102 | < 0.005 | < 1.0 | 6.4 | < 0.05 | 17 | 67 | < 0.1 | 0.33 | CWC | — | NA |
| 103 | 0.026 | < 1.0 | 9.4 | 1.50 | 20 | 31 | < 0.1 | 0.21 | 7 | 0 | NA |
| 104 | < 0.005 | < 1.0 | 5.3 | < 0.05 | 25 | 27 | 1.7 | < 0.02 | 0 | 150 | NA |
| 105 | < 0.005 | < 1.0 | 5.7 | < 0.05 | 22 | 39 | < 0.1 | < 0.02 | 0 | 100 | NA |
| 106 | < 0.005 | < 1.0 | 6.8 | 0.14 | 33 | 114 | < 0.1 | 0.62 | CWC | — | 10.6 |
| 107 | < 0.005 | < 1.0 | 7.4 | < 0.05 | 25 | 82 | < 0.1 | < 0.02 | 0 | 0 | NA |
| 108 | < 0.005 | < 1.0 | 5.6 | < 0.05 | 18 | 24 | < 0.1 | < 0.02 | 10 | 1 | 1.0 |
| 109 | < 0.005 | < 1.0 | 6.4 | < 0.05 | 11 | 27 | < 0.1 | < 0.02 | CWC | — | NA |
| 110 | < 0.005 | < 1.0 | 7.4 | < 0.05 | 17 | 47 | < 0.1 | < 0.02 | 0 | 0 | 8.1 |
| 111 | < 0.005 | < 1.0 | 7.4 | < 0.05 | 18 | 90 | < 0.1 | 0.59 | 2 | TNTC | NA |
| 112 | < 0.005 | < 1.0 | 6.5 | < 0.05 | 12 | 35 | < 0.1 | < 0.02 | 69 | 51 | NA |
| 113 | < 0.005 | 2.7 | 6.4 | < 0.05 | 16 | 47 | < 0.1 | < 0.02 | 25 | 150 | NA |
| 114 | < 0.005 | < 1.0 | 7.2 | < 0.05 | 17 | 78 | < 0.1 | < 0.02 | CWOC | — | NA |
| 115 | | | | | | | | | | | |
| 116 | < 0.005 | 3.4 | 6.0 | < 0.05 | 34 | 82 | < 0.1 | < 0.02 | CWC | — | NA |
| 117 | < 0.005 | < 1.0 | 6.4 | < 0.05 | 10 | 20 | < 0.1 | < 0.02 | 0 | 10 | NA |
| 118 | < 0.005 | < 1.0 | 6.2 | 2.80 | 17 | 20 | < 0.1 | 0.09 | 0 | 0 | NA |
| 119 | < 0.005 | 1.2 | 5.6 | < 0.05 | 19 | 39 | < 0.1 | < 0.02 | 20 | 150 | 8.0 |
| 120 | < 0.005 | < 1.0 | 5.7 | < 0.05 | 21 | 35 | < 0.1 | < 0.02 | 0 | 5 | NA |
| 121 | < 0.005 | 4.8 | 6.6 | < 0.05 | 18 | 59 | < 0.1 | < 0.02 | 10 | 53 | NA |
| 122 | < 0.005 | 2.9 | 6.4 | < 0.05 | 8 | 43 | < 0.1 | < 0.02 | 1 | 5 | NA |
| 123 | < 0.005 | < 1.0 | 6.7 | < 0.05 | 17 | 35 | < 0.1 | 0.69 | 0 | 17 | NA |
| 124 | < 0.005 | 3.0 | 6.7 | < 0.05 | 12 | 51 | < 0.1 | < 0.02 | CWC | — | NA |
| 125 | < 0.005 | < 1.0 | 5.8 | < 0.05 | 12 | 27 | < 0.1 | < 0.02 | 42 | 500 | NA |
| 126 | < 0.005 | < 1.0 | 6.6 | < 0.05 | 17 | 43 | 0.32 | < 0.02 | 0 | 5 | NA |
| 127 | < 0.005 | < 1.0 | 6.0 | < 0.05 | 18 | 35 | < 0.1 | < 0.02 | 0 | 0 | NA |
| 128 | < 0.005 | 4.5 | 7.0 | < 0.05 | 15 | 55 | < 0.1 | < 0.02 | 0 | 0 | NA |
| 129 | < 0.005 | < 1.0 | 6.1 | < 0.05 | 14 | 39 | < 0.1 | < 0.02 | CWOC | — | NA |
| 130 | < 0.005 | < 1.0 | 6.4 | 0.68 | 16 | 39 | < 0.1 | 0.29 | CWOC | — | NA |
| 131 | < 0.005 | 1.2 | 5.6 | < 0.05 | 19 | 24 | < 0.1 | < 0.02 | 0 | 10 | 8.0 |
| 132 | < 0.005 | < 1.0 | 7.4 | < 0.05 | 18 | 102 | < 0.1 | < 0.02 | 0 | 0 | NA |
| 133 | < 0.005 | 3.4 | 5.8 | < 0.05 | 14 | 31 | < 0.1 | 0.12 | 90 | TNTC | NA |
| 134 | < 0.005 | 1.5 | 6.2 | 0.23 | 16 | 31 | < 0.1 | < 0.02 | 0 | 1 | NA |
| 135 | < 0.005 | < 1.0 | 6.6 | < 0.05 | 13 | 39 | < 0.1 | < 0.02 | CWC | — | NA |
| 136 | < 0.005 | < 1.0 | 5.9 | 0.31 | 20 | 39 | < 0.1 | < 0.02 | 30 | 18 | NA |
| 137 | < 0.005 | < 1.0 | 5.9 | < 0.05 | 29 | 39 | < 0.1 | < 0.02 | 0 | 10 | 13.6 |
| 138 | < 0.005 | < 1.0 | 6.0 | < 0.05 | 22 | 47 | 2.5 | < 0.02 | CWOC | — | NA |
| 139 | < 0.005 | < 1.0 | 6.2 | < 0.05 | 16 | 35 | 0.26 | < 0.02 | 0 | 0 | NA |
| 140 | < 0.005 | 1.5 | 7.1 | < 0.05 | 15 | 39 | < 0.1 | < 0.02 | 0 | 5 | NA |
| 141 | < 0.005 | < 1.0 | 7.0 | 0.24 | 23 | 1 | < 0.1 | < 0.02 | 0 | 2 | NA |
| 142 | < 0.005 | 1.3 | 6.4 | 1.20 | 15 | 47 | < 0.1 | 0.07 | 0 | 0 | NA |
| 143 | < 0.005 | < 1.0 | 6.6 | < 0.05 | 11 | 12 | 0.16 | < 0.02 | 0 | 100 | NA |
| 144 | < 0.005 | 1.2 | 6.3 | < 0.05 | 15 | 43 | < 0.1 | < 0.02 | CWC | — | NA |
| 145 | < 0.005 | 1.8 | 5.9 | < 0.05 | 17 | 27 | < 0.1 | < 0.02 | 0 | 98 | NA |
| 146 | | | | | | | | | | | |

| SAMPLE NUMBER | NITRITE -N * | NITRATE -N * | pH | IRON * | CHLORIDE * | HARDNESS | COPPER * | MANGANESE * | COLIFORMS ** | BACTERIA, OTHER ** | SODIUM * |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 147 | < 0.005 | 4.5 | 5.3 | < 0.05 | 16 | 31 | 0.2 | < 0.02 | 0 | 0 | NA |
| 148 | < 0.005 | 1.6 | 5.6 | < 0.05 | 22 | 27 | 0.44 | < 0.02 | CWOC | — | NA |
| 149 | < 0.005 | 1.2 | 5.5 | < 0.05 | 15 | 20 | 0.18 | < 0.02 | 7 | 0 | NA |
| 150 | | | | | | | | | | | |
| 151 | < 0.005 | < 1.0 | 5.8 | < 0.05 | 18 | 24 | < 0.1 | < 0.02 | 0 | 0 | NA |
| 152 | < 0.005 | < 1.0 | 5.6 | < 0.05 | 15 | 27 | 0.3 | < 0.02 | 31 | TNTC | NA |
| 153 | < 0.005 | < 1.0 | 5.3 | < 0.05 | 14 | 12 | < 0.1 | < 0.02 | CWC | — | NA |
| 154 | < 0.005 | < 1.0 | 5.3 | < 0.05 | 15 | 20 | < 0.1 | < 0.02 | 5 | 100 | NA |
| 155 | < 0.005 | 1.0 | 5.3 | < 0.05 | 21 | 27 | < 0.1 | 0.10 | CWC | — | NA |
| 156 | < 0.005 | < 1.0 | 6.5 | < 0.05 | 27 | 94 | < 0.1 | < 0.02 | 0 | 0 | NA |
| 157 | < 0.005 | < 1.0 | 7.2 | < 0.05 | 24 | 102 | < 0.1 | < 0.02 | 0 | 1 | NA |
| 158 | < 0.005 | < 1.0 | 6.9 | < 0.05 | 14 | 74 | < 0.1 | 0.77 | 1 | 50 | NA |
| 159 | < 0.005 | < 1.0 | 7.0 | < 0.05 | 16 | 59 | < 0.1 | < 0.02 | 0 | 0 | NA |
| 160 | < 0.005 | < 1.0 | 6.8 | < 0.05 | 22 | 74 | < 0.1 | < 0.02 | 0 | 80 | NA |
| 161 | < 0.005 | < 1.0 | 6.4 | < 0.05 | 17 | 55 | < 0.1 | < 0.02 | 10 | 25 | NA |
| 162 | | | | | | | | | | | |
| 163 | < 0.005 | < 1.0 | 5.3 | < 0.05 | 30 | 31 | < 0.1 | 0.14 | CWC | — | NA |
| 164 | 0.031 | 4.5 | 6.6 | 0.32 | 21 | 31 | < 0.1 | < 0.02 | CWOC | — | NA |
| 165 | < 0.005 | 1.9 | 6.7 | < 0.05 | 15 | 74 | < 0.1 | < 0.02 | 0 | 0 | NA |
| 166 | < 0.005 | < 1.0 | 6.0 | 2.50 | 12 | 35 | < 0.1 | 0.55 | 0 | 2 | NA |
| 167 | < 0.005 | < 1.0 | 6.3 | < 0.05 | 19 | 43 | < 0.1 | 0.39 | 0 | TNTC | NA |
| 168 | < 0.005 | 1.2 | 5.2 | < 0.05 | 36 | 31 | < 0.1 | < 0.02 | 5 | 1 | NA |
| 169 | | | | | | | | | | | |
| 170 | < 0.005 | 5.8 | 6.3 | < 0.05 | 34 | 74 | < 0.1 | < 0.02 | 25 | 250 | NA |
| 171 | < 0.005 | < 1.0 | 6.6 | < 0.05 | 175 | 169 | < 0.1 | 0.14 | 25 | 250 | NA |
| 172 | < 0.005 | 1.7 | 5.6 | < 0.05 | 9 | 12 | < 0.1 | < 0.02 | CWC | — | NA |
| 173 | < 0.005 | < 1.0 | 7.9 | < 0.05 | 8 | 31 | < 0.1 | < 0.02 | 0 | 0 | NA |
| 174 | < 0.005 | < 1.0 | 7.4 | < 0.05 | 13 | 59 | < 0.1 | < 0.02 | 0 | 2 | NA |
| 175 | < 0.005 | 2.1 | 7.7 | < 0.05 | 12 | 51 | < 0.1 | < 0.02 | 10 | TNTC | NA |
| 176 | < 0.005 | < 1.0 | 6.2 | < 0.05 | 14 | 47 | < 0.1 | < 0.02 | 16 | TNTC | NA |
| 177 | < 0.005 | < 1.0 | 6.2 | < 0.05 | 25 | 51 | < 0.1 | < 0.02 | CWOC | — | NA |
| 178 | < 0.005 | < 1.0 | 6.4 | 0.32 | 15 | 43 | < 0.1 | < 0.02 | CWC | — | NA |
| 179 | < 0.005 | < 1.0 | 6.3 | 0.33 | 14 | 43 | < 0.1 | 0.34 | 0 | 10 | NA |
| 180 | < 0.005 | < 1.0 | 6.8 | < 0.05 | 13 | 1 | < 0.1 | < 0.02 | 0 | 3 | NA |
| 181 | < 0.005 | 2.5 | 5.8 | < 0.05 | 8 | 16 | 0.35 | < 0.02 | 1 | 0 | NA |
| 182 | < 0.005 | < 1.0 | 6.2 | 0.47 | 15 | 32 | < 0.1 | 0.86 | 0 | 0 | NA |
| 183 | < 0.005 | < 1.0 | 6.1 | < 0.05 | 16 | 31 | < 0.1 | < 0.02 | CWC | — | NA |
| 184 | < 0.005 | < 1.0 | 6.0 | < 0.05 | 14 | 27 | < 0.1 | 0.10 | 4 | 0 | NA |
| 185 | 0.072 | 5.9 | 5.9 | < 0.05 | 17 | 27 | < 0.1 | 0.18 | CWC | — | NA |
| 186 | < 0.005 | 2.8 | 7.0 | < 0.05 | 13 | 47 | < 0.1 | < 0.02 | 5 | TNTC | NA |
| 187 | < 0.005 | < 1.0 | 7.0 | < 0.05 | 20 | 90 | < 0.1 | 0.10 | CWC | — | NA |
| 188 | | | | | | | | | | | |
| 189 | < 0.005 | 4.4 | 7.0 | < 0.05 | 19 | 63 | < 0.1 | < 0.02 | 0 | 0 | NA |
| 190 | < 0.005 | 4.6 | 6.2 | < 0.05 | 18 | 59 | < 0.1 | < 0.02 | 9 | 50 | NA |
| 191 | < 0.005 | 1.1 | 6.2 | < 0.05 | 14 | 35 | 0.17 | < 0.02 | 0 | 0 | NA |
| 192 | < 0.005 | < 1.0 | 6.2 | 5.90 | 15 | 27 | 0.11 | 0.09 | CWC | — | NA |
| 193 | | | | | | | | | | | |
| 194 | | | | | | | | | | | |
| 195 | | | | | | | | | | | |
| 196 | < 0.005 | 5.2 | 6.2 | < 0.05 | 12 | 43 | 0.32 | < 0.02 | 5 | 5 | NA |
| 197 | < 0.005 | < 1.0 | 6.1 | < 0.05 | 17 | 24 | < 0.1 | < 0.02 | CWC | — | NA |
| 198 | < 0.005 | < 1.0 | 5.5 | < 0.05 | 20 | 24 | 0.16 | 0.11 | 0 | 0 | NA |
| 199 | | | | | | | | | | | |
| 200 | < 0.005 | < 1.0 | 7.2 | < 0.05 | 17 | 110 | < 0.1 | 0.44 | CWC | — | NA |
| 201 | 0.026 | 4.7 | 6.3 | < 0.05 | 52 | 106 | < 0.1 | 0.08 | CWC | — | NA |
| 202 | < 0.005 | < 1.0 | 6.2 | 1.60 | 16 | 55 | < 0.1 | < 0.02 | 0 | 0 | NA |
| 203 | < 0.005 | < 1.0 | 7.4 | < 0.05 | 14 | 39 | < 0.1 | < 0.02 | 0 | 0 | NA |

| SAMPLE NUMBER | NITRITE -N * | NITRATE -N * | pH | IRON * | CHLORIDE * | HARDNESS | COPPER * | MANGANESE * | COLIFORMS ** | BACTERIA, OTHER ** | SODIUM * |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 204 | < 0.005 | 4.7 | 6.0 | < 0.05 | 14 | 39 | < 0.1 | < 0.02 | 0 | 0 | NA |
| 205 | < 0.005 | < 1.0 | 4.7 | < 0.05 | 20 | 20 | < 0.1 | 0.16 | CWC | — | NA |
| 206 | < 0.005 | < 1.0 | 5.6 | 0.22 | 7 | 12 | < 0.1 | 0.32 | CWC | — | NA |
| 207 | < 0.005 | 1.0 | 5.9 | 1.20 | 15 | 16 | < 0.1 | < 0.02 | 0 | 0 | NA |
| 208 | | | | | | | | | | | |
| 209 | < 0.005 | < 1.0 | 7.0 | 0.67 | 28 | 59 | < 0.1 | 0.23 | 1 | 0 | NA |
| 210 | < 0.005 | < 1.0 | 5.8 | 0.25 | 20 | 27 | < 0.1 | 0.22 | 5 | 100 | NA |
| 211 | | | | | | | | | | | |
| 212 | < 0.005 | < 1.0 | 6.3 | < 0.05 | 63 | 74 | 0.1 | 0.19 | CWC | — | NA |
| 213 | < 0.005 | 1.7 | 7.0 | < 0.05 | 18 | 31 | < 0.1 | < 0.02 | 0 | 0 | NA |
| 214 | | | | | | | | | | | |
| 215 | < 0.005 | 6.0 | 6.7 | < 0.05 | 16 | 39 | < 0.1 | < 0.02 | 1 | 16 | NA |
| 216 | < 0.005 | < 1.0 | 5.6 | 1.10 | 25 | 27 | 1.3 | 2.00 | 0 | 3 | NA |
| 217 | < 0.005 | < 1.0 | 5.9 | 0.22 | 18 | 27 | < 0.1 | < 0.02 | 0 | 0 | NA |
| MEAN | 0.0064 | 1.670 | 6.36 | 0.239 | 19.543 | 45.734 | 0.161 | 0.093 | 4.947 | 24.149 | 0.524 |
| STND DEV | 0.0078 | 1.294 | 0.68 | 0.737 | 17.410 | 27.122 | 0.297 | 0.175 | 13.613 | 68.873 | 2.227 |
| MAXIMUM | 0.072 | 6 | 9.4 | 5.9 | 175 | 169 | 2.5 | 2 | 90 | 500 | 13.6 |
| MINIMUM | 0.005 | 1 | 5.2 | 0.05 | 8 | 1 | 0.1 | 0.02 | 0 | 0 | 0 |
| COUNT | 104 | 104 | 104 | 104 | 104 | 104 | 104 | 104 | 104 | | |
| | >1 | >1 | | >0.25 | >50 | | >0.1 | >.05 | >1 | | |
| | 0.00% | 33.65% | | 15.38% | 2.88% | | 14.42% | 28.85% | 49.04% | | |
| | 0/104 | 35/104 | | 16/104 | 3/104 | | 15/104 | 30/104 | 51/104 | | |

NOTES:

| | | | | |
|---|---|---|---|---|
| *: | CONCENTRATIONS IN mg/l - PARTS PER MILLION | 0 | NO2 | 0.0% |
| **: | CONCENTRATIONS IN COLONIES PER PLATE | 35 | NO3 | 33.7% |
| CWOC: | CONFLUENT WITH OUT COLIFORMS | 16 | Fe+ | 15.4% |
| CWC: | CONFLUENT WITH COLIFORMS | 3 | Cl- | 2.9% |
| TNTC: | TOO NUMEROUS TO COUNT - OVER 200 COLONIES PER PLAT | 15 | Cu+ | 14.4% |
| NA: | NOT ANALYZED | 30 | Mn+ | 28.9% |
| —: | NOT REPORTED | 51 | C'FMS | 49.0% |

CLIFF ISLAND

| SAMPLE NUMBER | NITRITE -N * | NITRATE -N * | pH | IRON * | CHLORIDE * | MANGANESE * | COLIFORMS ** | SODIUM * |
|---|---|---|---|---|---|---|---|---|
| 1 | 0.001 | 0.187 | 6.5 | 0.15 | 28 | 0.17 | 0 | 16.8 |
| 2 | 0.001 | 0.172 | 5.9 | 0.06 | 27 | 0.03 | 0 | 13.5 |
| 3 | 0.001 | 0.088 | 6.4 | 0.60 | 30 | 0.62 | 0 | 18.9 |
| 4 | 0.001 | 0.065 | 6.3 | 5.98 | 36 | 0.57 | 0 | 18.7 |
| 5 | 0.001 | 0.032 | 4.8 | 0.27 | 27 | 0.17 | 0 | 14.9 |

NOTES:

*: CONCENTRATIONS IN mg/l - PARTS PER MILLION
**: CONCENTRATIONS IN COLONIES PER PLATE
CWOC: CONFLUENT WITH OUT COLIFORMS
CWC: CONFLUENT WITH COLIFORMS
TNTC: TOO NUMEROUS TO COUNT - OVER 200 COLONIES PER PLATE
NA: NOT ANALYZED
—: NOT REPORTED
SAMPLE #3—HAS IRON FILTER INSTALLED

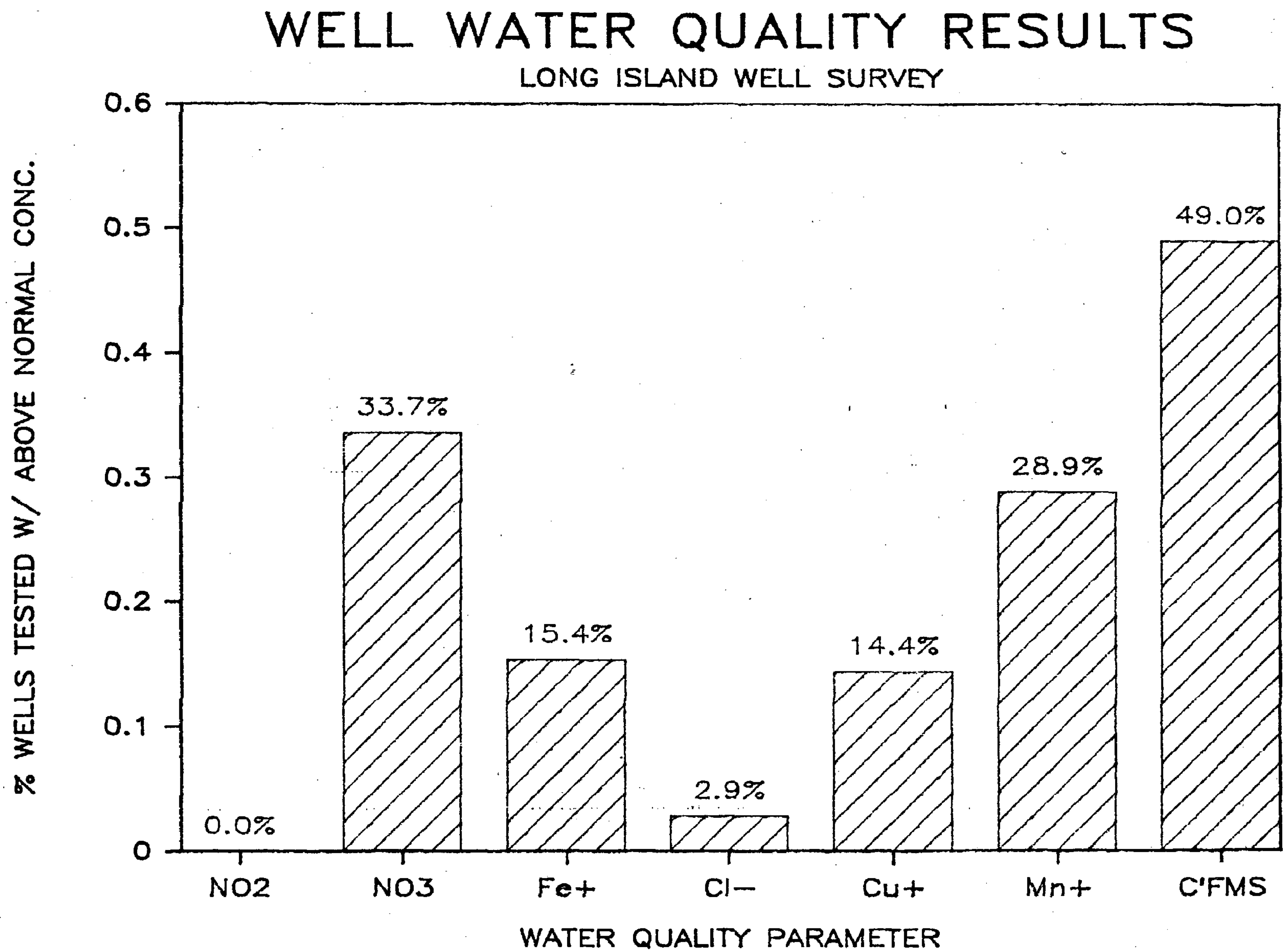

WELL WATER QUALITY RESULTS
LONG ISLAND WELL SURVEY
% WELLS TESTED W/ ABOVE NORMAL CONC.
0.6
0.5
0.4
0.3
0.2
0.1
0
0.0%
33.7%
15.4%
2.9%
14.4%
28.9%
49.0%
NO2
NO3
Fe+
Cl−
Cu+
Mn+
C'FMS
WATER QUALITY PARAMETER

FIGURE B-1

# APPENDIX C

APPENDIX C:

PORTLAND ISLAND WELL WATER QUALITY DATA OBTAINED FROM HEALTH ENGINEERING, AUGUSTA, ME.

WELL TYPES: 1 = DRILLED, 2 = DUG, 3 = SPRING, 4 = OTHER

| WELL No. | WELL TYPE | WELL DEPTH | YEAR 1ST | COLI FORMS ** | COL-OR | TUR-BID | pH | HARD-NESS | CHLOR-IDES * | NIT-RITES * | NIT-RATES * | COP-PER * | IRON * | MANG-ANESE * | SOD-IUM * | OTHER | COMMENTS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| LONG ISLAND | | | | | | | | | | | | | | | | | |
| 1001 | 1 | 90 | 1964 | - | 25 | 6.20 | 5.8 | 16 | 8 | 0 | 0.44 | 0.02 | 1.78 | 0.02 | 8 | ZN=0.11 | |
| 1002 | 1 | 90 | | | | | | | | | | | | | | | RADON=4400 |
| 1003 | 1 | 110 | 1975 | 0 | | | | | | 0 | 0 | | | | | | |
| 1004 | 1 | 119 | 1975 | 0 | | | | | | <.005 | <.005 | | | | | | |
| 1005 | 2 | 30 | 1953 | 0 | | | | | | <.005 | 2.72 | | | | | | |
| 1006 | 1 | - | | 0 | | | | | | <.005 | <.005 | | | | | | |
| 1007 | 1 | | | 0 | | | | | | <.005 | <.005 | | | | | | |
| 1008 | 1 | 85 | 1976 | 5 | 50 | 0.45 | 6.3 | 35 | 21 | 0 | 0 | 0.01 | 4.72 | 1.35 | 13 | ZN=0.06 | |
| 1009 | 1 | 60 | 1964 | 0 | | | | | | <.005 | <.005 | | | | | | |
| 1010 | 1 | 60 | 1964 | 0 | 5 | 2.40 | 6.7 | 82 | 15 | 0 | 0 | 0.00 | 0.92 | 0.58 | 10 | ZN=0.01 | |
| 1011 | 1 | 110 | 1958 | 5 | 0 | 0.26 | 7.2 | 24 | 14 | 0 | 0 | 0.19 | 0.14 | 0.00 | | ZN=0.07 | |
| 1012 | 1 | 70 | 1947 | 0 | | | 6.4 | 43 | 20 | <.005 | <.005 | 1.60 | 0.23 | 0.00 | | | |
| 1013 | 2 | 18 | 1961 | 0 | | | | | | <.005 | <.005 | | | | | | |
| 1014 | 2 | | 1984 | 0 | | | | | | <.005 | <.005 | | | | | | |
| 1015 | 1 | 40 | 1963 | 0 | | | | | | 0 | 0 | | | | | | |
| 1016 | 1 | | | | | | | | | | | | | | | | RADON=10500 |
| 1017 | 1 | | | | | | | | | | | | | | | | RADON=4000 |
| 1018 | 1 | 150 | 1961 | 0 | | | | | | <.005 | 1.6 | | | | | | |
| 1019 | 1 | 100 | 1955 | TNTC | 5 | 2.10 | 6.5 | 104 | 20 | 0 | 0 | 0.00 | 0.30 | 0.22 | | | |
| 1020 | 4 | | | TNTC | 40 | 0.56 | 5.2 | 21 | 14 | 0 | 0 | 0.00 | 0.06 | 0.03 | 9 | SOLIDS=77 | STREAM |
| 1021 | 4 | | | TNTC | 20 | 0.35 | 7.7 | 77 | 20 | 0 | 0.05 | 0.00 | 0.04 | 0.00 | | | STREAM |
| 1022 | 1 | | | 0 | | | 7 | 78 | 20 | 0 | 0 | | 3.98 | 0.23 | | | RUSTY |
| 1023 | 1 | | | | | | | | | | | | | | | | GASOLINE |
| 1024 | | | | | | | | | | | | | | | | | GASOLINE |
| 1025 | 1 | 85 | 1983 | 0 | | | | 25 | 13 | 0 | 0.91 | | | | | | |
| 1026 | 1 | 165 | 1984 | CG | | | 7.1 | 172 | 84 | <.005 | <.005 | | 0.47 | 2.99 | | | |
| 1027 | 1 | 165 | 1984 | 0 | | | | 430 | 585 | <.005 | <.005 | | | | 876 | PB=.5 | LEAD=.009 |
| 1028 | 1 | 90 | 1966 | 0 | | | | | | <.005 | <.005 | | | | | | |
| 1029 | 3 | 6 | 1959 | TNTC | | | | | | | 1.2 | | | | | | |
| 1030 | 1 | | | 4 | | | | | | 0 | 0 | | | | | | |
| 1031 | 1 | | 1979 | 0 | | | | | | <.005 | <.005 | | | | | | |
| 1032 | | | | | | | | | | | | | | | | | HYDROCARBONS |
| 1033 | | | | | | | | | | | | | | | | | HYDROCARBONS |
| 1034 | 1 | | 1970 | 0 | | | | | | <.005 | <.005 | | | | | | |
| 1035 | 1 | 190 | 1958 | 0 | | | | | | <.005 | <.005 | | | | | | |
| 1036 | 1 | | | 60 | | | | | | <.005 | <.005 | | | | | | |
| 1037 | 1 | 68 | 1958 | 0 | | | | | | <.005 | <.005 | | | | | | |
| 1038 | 1 | 46 | 1969 | 0 | | | | | | <.005 | <.005 | | | | | | |
| 1039 | 1 | 100 | 1956 | 60 | | | | | | <.005 | <.005 | | | | | | |
| 1040 | 1 | 100 | 1957 | TNTC | | | | | | <.005 | <.005 | | | | | | |
| 1041 | 1 | | 1957 | 7 | | | | | | <.005 | <.005 | | | | | | |
| 1042 | 1 | 100 | 1957 | 0 | | | | | | <.005 | <.005 | | | | | | |
| 1043 | 2 | 20 | 1930 | 7 | | | | 13 | 14 | <.005 | <.005 | | | | | | |
| 1044 | 2 | 25 | | 22 | | | | 51 | | <.005 | 1.2 | | | | | | |
| 1045 | 1 | 55 | | 0 | | | | 22 | 13 | <.005 | <.005 | | | | | | |

| WELL No. | WELL TYPE | WELL DEPTH | YEAR 1ST | COLI FORMS | COL- OR | TUR- BID | pH | HARD- NESS | CHLOR- IDES | NIT- RITES | NIT- RATES | COP- PER | IRON | MANG- ANESE | SOD- IUM | OTHER | COMMENTS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1046 | 2 | 30 | 1955 | 102 | | | | | | <.005 | 1.2 | | | | | | |
| 1047 | 2 | 8 | 1973 | 0 | 5 | 1.00 | | 148 | 12 | <.005 | <.005 | | | | | | |
| 1048 | 1 | | 1958 | 0 | | | | | | | | | | | | | |
| 1049 | 1 | | | 8 | | | | | | <.005 | <.005 | | | | | | |
| 1050 | 1 | 168 | 1965 | 0 | | | 6.5 | 29 | 13 | | | | | | | | |
| 1051 | 2 | 12 | 1935 | 0 | 10 | 0.50 | 6.2 | | 32 | <.005 | <.005 | | 0.94 | 0.15 | | | |
| 1052 | 1 | 50 | 1956 | 0 | | | | | | <.005 | 1.5 | | | | | | |
| 1053 | 2 | 13 | 1966 | 0 | | | | | | <.005 | 1.9 | | | | | | |
| 1054 | 1 | 80 | | 2 | 5 | 4.00 | 6.4 | 47 | 16 | <.005 | <.005 | | | | | | |
| 1055 | 1 | | | 50 | | | | 51 | 18 | <.005 | 4.2 | | | | | | |
| 1056 | 2 | 20 | 1948 | 6 | 0 | 0.95 | 6.6 | 56 | | <.005 | <.005 | | 0.39 | | | | |
| 1057 | 1 | 88 | 1958 | 30 | 15 | 1.00 | 6.9 | 24 | | <.005 | <.005 | | | | | | |
| 1058 | 1 | 88 | 1958 | 380 | 10 | 1.00 | | | | | | | | | | | |
| 1059 | 1 | 88 | 1958 | 1 | 0 | 0.00 | 6.6 | 57 | 0.5 | <.005 | 1.1 | | | | | | |
| 1060 | 1 | | 1975 | TNTC | | | | | | <.005 | <.005 | | | | | | |
| 1061 | 1 | 100 | 1970 | 0 | 5 | 2.00 | 7.4 | 17 | 16 | <.005 | <.005 | | | | | | |
| 1062 | 2 | 16 | 1897 | 12 | 0 | 0.00 | 6.6 | 45 | 20 | <.005 | <.005 | | | | | | |
| 1063 | 2 | 11 | 1925 | 46 | 5 | 1.00 | 6.7 | | | <.005 | <.005 | | | | | | |
| 1064 | 2 | 12 | 1945 | 16 | | | | | | <.005 | 1.7 | | | | | | |
| 1065 | 2 | 20 | 1957 | 2 | | | | | | <.005 | <.005 | | | | | | |
| 1066 | 1 | 30 | | 0 | | | 7.2 | 37 | 10 | <.005 | <.005 | | | | | | |
| 1067 | 1 | 90 | 1975 | 0 | | | | | | <.005 | <.005 | | | | | | |
| 1068 | 1 | 115 | 1974 | 14 | | | | 291 | 322 | <.005 | <.005 | | | | | | |
| 1069 | 2 | | 1956 | 0 | | | | | | <.005 | <.005 | | | | | | |
| PEAK'S ISLAND | | | | | | | | | | | | | | | | | |
| 1070 | 1 | | 1980 | 0 | | | | | | <.005 | <.005 | | | | | | |
| 1071 | 1 | 65 | 1980 | 0 | | | 6.9 | 87 | 26 | <.005 | <.005 | | 0.25 | 0.00 | | | |
| 1072 | 1 | 65 | 1980 | 2 | 10 | 0.22 | 6.8 | 87 | 19 | <.005 | 1.1 | 0.08 | 0.00 | 0.00 | | | |
| 1073 | 1 | | | | | | | | | | | | | | | | RADON=1500 |
| 1074 | 1 | | 1980 | CG | | | | | | <.005 | <.005 | | | | | | |
| 1075 | 1 | 120 | 1979 | 0 | | | 7 | 95 | 38 | <.005 | <.005 | | 0.65 | 0.31 | | | |
| 1076 | 1 | 75 | 1982 | 0 | 15 | 2.40 | 8 | 100 | 25 | <.005 | <.005 | 0.01 | | 0.46 | | PB=.005 | |
| 1077 | 1 | | | | | | | | | | | | | | | | RADON=600 |
| 1078 | 1 | 180 | 1929 | 0 | | | 6.8 | 49 | 23 | <.005 | <.005 | | 1.90 | 0.02 | | | |
| CLIFF ISLAND | | | | | | | | | | | | | | | | | |
| 1079 | 1 | 190 | 1984 | 0 | | | | 112 | 23 | <.005 | <.005 | | | | | PB= 0 | |
| 1080 | 1 | 140 | 1980 | 0 | 5 | 0.60 | 6.9 | 41 | 28 | <.005 | <.005 | 0.01 | 0.09 | 0.31 | 17 | | |
| 1081 | 1 | 130 | 1979 | 0 | 70 | 6.00 | 7.2 | 56 | 31 | <.005 | <.005 | 0.05 | 2.80 | 0.43 | | ZN=.08 | |
| 1082 | 1 | 105 | 1974 | 0 | | | | | 29 | <.005 | <.005 | | | | | | |
| 1083 | 1 | 140 | 1984 | 0 | | | | | 16 | 0 | <.005 | | | | | | |
| 1084 | 2 | 20 | 1960 | TNTC | | | | | | <.005 | 5.1 | | | | | | |
| 1085 | 1 | 120 | 1961 | 0 | 0 | 9.50 | | 38 | 34 | 0 | 0 | | | 16.40 | | | |
| 1086 | 2 | | 1975 | 0 | | | | | 50 | <.005 | <.005 | | 2.56 | | | PB=.187 | |
| 1087 | 1 | | 1910 | 0 | | | 7.2 | 130 | 26 | 0 | 0 | | 0.22 | 0.21 | | | |
| 1088 | 1 | 100 | 1976 | 0 | | | | | | <.005 | <.005 | | | | | | |
| 1089 | | | | | | | | | | | | | | | | H2S=.10 | |
| 1090 | 1 | 50 | 1960 | 0 | | | | | | | | | | | | | |
| 1091 | 1 | | | 0 | | | | | | | | | | | | | |
| 1092 | 2 | 15 | 1950 | CG | 20 | 3.60 | 6.3 | 47 | 23 | <.005 | <.005 | 0.00 | 0.61 | 0.05 | 14 | | |
| 1093 | 1 | 260 | 1980 | | | | 6.3 | 99 | 28 | <.005 | <.005 | | 0.57 | 0.79 | | | |
| 1094 | 2 | 12 | | TNTC | | | 5.9 | 108 | 32 | <.005 | <.005 | | 1.20 | 0.26 | | | |
| 1095 | 1 | | | 0 | | | | | | <.005 | <.005 | | | | | | |
| 1096 | 1 | 105 | 1959 | 88 | | | | | | <.005 | <.005 | | | | | | |

NOTES: same as for APPENDIX B

# APPENDIX D

## APPENDIX D--GLOSSARY

anisotropic--a term applied to a physical property of an aquifer, such as the permeability, where the permeability at a given point varies with direction at that point

aquiclude--a relatively impervious soil or rock that abuts an aquifer and which does not allow flow to or from the adjacent aquifer

aquifer--a saturated body of soil or rock that will yield economically significant quantities of water to wells or springs

aquitard--a soil or rock body that has a relatively lower permeability than the adjacent aquifer, but which does allow some leakage of ground water to or from the aquifer

artesian aquifer--an aquifer in which ground water will rise in a well to an elevation greater than the depth at which the aquifer was encountered

artesian well--a well that taps an artesian aquifer; often a bedrock well in which the static water level rises above the elevation of the fracture at which the water was encountered

barometric efficiency--the ratio of the fluctuation of water level in a well to the change in atmospheric pressure causing the fluctuation; see Figure D-1 at end of Glossary

coefficient of variation--a statistical term which is derived by dividing the standard deviation by the mean; this is a measure of how tightly grouped the values are in the vicinity of the mean

cone of depression--a depression that is created by a well in the potentiometric surface of a body of ground water and that has the shape of an inverted cone and develops around the well from which water is being withdrawn

confined aquifer--same as artesian aquifer; i.e., a porous saturated material confined by a less permeable material

constant head boundary--a term used in ground water modeling which is applied to a large water body or other constant level source or sink of water adjacent to an aquifer and controls the position of the potentiometric surface to a constant elevation at the boundary

convection--the transportation of water or solute in an aquifer solely by consideration of conservation of mass; i.e. along the direction of the ground water flow vector

Darcy velocity--the volume of ground water moved through a unit area, normal to flow direction, per unit time

dip--the direction in which a planar structure of a soil or rock body slopes, measured from the horizontal and in the direction of greatest slope; dip is perpendicular to strike

discharge area--the area of land or water where ground water leaves an aquifer; ground water flow can occur in an upward direction at the discharge area

dispersion--a mechanism of solute transport in ground water that causes a decrease in concentration of solute with time and distance from a solute source and is due to molecular diffusion and "hydrodynamic" dispersion; hydrodynamic dispersion results from the scatter of mass as it flows through a labyrinth-like structure like the pores within sand; dispersion is proportional to seepage velocity and to the differences between concentrations of solute between two adjacent points

drawdown--the difference between the elevation of the static water elevation at a point near a well, and the elevation of the water table at that point when the well is being pumped

fault--a structural planar disruption or separation in a soil or rock in which one side of the break has moved relative to the other side; faults in bedrock may constitute high yield aquifers

glacial till--a surficial geologic unit developed on, within, or under a glacier, characterized by little sorting and containing a wide range of texture, from boulders to clay

gradient--the slope of the potentiometric surface; the change in ground water elevation per unit of distance measured along the direction of flow

ground water--the water that is contained within the voids of saturated soil or bedrock and that is available to flow

ground water divide--a ridge in the water table or other potentiometric surface from which the ground water represented by that surface moves away in opposite directions

head--the elevation to which water rises at a given point as a result of aquifer pressure

heterogeneous--a well mixed, or poorly sorted material; a property of an aquifer, such as permeability, which varies along a given direction

high yield aquifer--an aquifer that yields significantly greater rates of ground water production to wells than the average yield for the region; typically, in Maine, high yield aquifers are those that consistently yield over 10 gallons per minute

homogeneous--a uniform material; a property of an aquifer, such as permeability, which is constant along a given direction

hydraulic conductivity--a physical property of a medium carrying a specific fluid; i.e., the volume per unit time transmitted through a unit cross sectional area normal to flow direction under unit gradient at the prevailing viscosity of the fluid

hydraulic "head"--see the discussion in Appendix E

intermittent stream--a stream that flows only part of a year, but usually for at least one month continuously each year, as a result of surface water inflow or spring discharge; an intermittent stream is usually a partially-penetrating stream

isotropic--a property of an aquifer, such as permeability, which is constant in all directions at a given point

joint--a structural planar break or separation in soil or rock across which no relative movement has occurred; in low-permeability rock, joints may be a major avenue of ground water flow leakance--leakage rate into or out of an aquifer per unit area of the aquifer; calculated as the difference between the potentiometric levels in two adjacent aquifers (e.g., soil and bedrock) multiplied by a leakage parameter which is equal to the vertical permeability of the aquitard separating the aquifers divided the aquitard thickness

leaky aquifer (semi-artesian aquifer)--an artesian aquifer which can take water from or discharge water to an adjacent aquitard; the rate of ground water transfer from the aquifer is proportional to the difference in total head between the aquifer and the adjacent aquitard; see Figure D-2 at end of Glossary

lineament--a straight or gently curved feature on the earth's surface that is frequently expressed topographically as a depression or line of depressions; these features represent weaknesses in the underlying bedrock, such as faults, and may, therefore, constitute high yield aquifers

line sink--a term used in ground water modelling that is applied to a line of connected constant head boundaries; a stream that fully penetrates an aquifer is a line sink and controls the elevations of the ground water table in vicinity of the stream

mean--the statistical mean or average value which is computed by adding all data values and dividing by the number of individual data points

median--the statistical median or middle value in an ordered array of all data values being analyzed

no-flow boundary--a term used in ground water modelling which is applied to the boundary of an aquifer at which no ground water transfer can take place either into or out of the aquifer across the boundary

partially-penetrating stream--a stream that penetrates only part of the total thickness of an aquifer, and therefore allows ground water to flow beneath the stream bed

perennial stream--a stream that usually flows year-round as a result of surface water inflow or spring discharge; the upper surface of the stream usually lies below the local ground water table; if a perennial stream fully penetrates an aquifer, it can be treated as a line sink

permeability--an intrinsic property of an aquifer that does not depend upon the characteristics of the fluid that it transmits; it is a measure of the ability of the aquifer to transmit fluid and is equal to hydraulic conductivity except that the fluid properties are not considered in the determination of permeability

piezometric surface--see potentiometric surface

porosity--the volume of voids in an aquifer divided by the total volume of the aquifer; in rock, secondary porosity is created by fractures and foliation openings in the rock and is most important in ground water flow as opposed to primary porosity which includes the interstices that were created when the rock was formed; effective porosity is important in pollutant transport studies and includes only those voids that allow ground water to flow through them

potentiometric surface--an imaginary surface that connects points to which water would rise in tightly cased wells from a given point in an aquifer; in an unconfined aquifer, the water table is the potentiometric surface; the term "potentiometric" is preferred over "piezometric" by some writers, but is otherwise equal

radius of influence--the maximum radial extent, measured from the center of a well, of the well's cone of influence; in artesian aquifers, the radius of influence can extend for miles

recharge area--the area of land or water where water enters an aquifer and becomes ground water and begins to flow downward or laterally

recovery--the rise in ground water level at a point in an aquifer that occurs upon the cessation of pumping of a nearby well

safe yield--the maximum rate of water removal from a well that will not result in undesirable consequences such as: exceeding the rate of recharge to the aquifer; exceeding the capacity of the aquifer to deliver water to the well at the desired pumping rate; causing salt-water intrusion (see Figure D-3 at end of Glossary); causing unacceptable ground subsidence; drawing water into the aquifer with undesirable quality; causing loss of water from a perennial stream at an unacceptable rate

salt-water intrusion--the displacement of fresh surface water or ground water by the advance of salt water due to its greater density; see Figure D-3 at end of Glossary

seepage velocity--the Darcy velocity divided by the effective porosity of the aquifer; the actual rate at which seepage water is discharged through a porous medium per unit area of pore space perpendicular to the direction of flow

skewness (also called the coefficient of skewness)--the measure of the degree to which a frequency distribution of a statistical variable has a long "tail" to one side or the other of the mean value; a negative skew indicates a long tail to the left (or direction of decreasing values), which means that most values are grouped around one relatively high value, but a few values are much lower than the majority of values; a positive skew indicates a long tail to the right, or direction of increasing values; a skew of "0" implies a symmetrical frequency distribution about the mean value; the larger the absolute value of the skew, the more pronounced the tail is

specific capacity--the yield of a well per unit of well drawdown, usually expressed in units such as gallons per minute per foot of drawdown

specific yield--the volume of water that will be drained by gravity from a saturated soil or rock divided by the total volume of the saturated material

spring--a location where ground water flows naturally from soil or rock onto the ground surface or into a body of surface water; an intersection of the water table with the land's surface

standard deviation--a statistical measure of the tightness with which all data in a frequency distribution are grouped; for a variable that is "normally" distributed, 68% of all values would be expected to lie within the range of one standard deviation below to one standard deviation above the mean value; 95% of all values would lie within two standard deviations of the mean, and 99.7% of all values would lie within three standard deviations of the mean; note, however, that most well statistics are not normally distributed

static water level--normally defined in the vicinity of a well as the level of the ground water or potentiometric surface when it is not affected by withdrawal from the well

steady state condition--a term used in ground water modeling that defines a ground water flow pattern that does not vary in time, and therefore, a potentiometric surface that does not vary in time

storativity (also called storage coefficient)--the volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in potentiometric elevation; storativity for an unconfined aquifer in sand and gravel averages 0.1 to 0.2, but for an artesian bedrock aquifer, it may be 0.00001 to 0.000001

strike--a term which describes the direction or trend in which a structural feature in soil or rock is directed; the direction is defined by the intersection of a horizontal plane with the feature of interest, and is expressed in terms such as degrees from true north or south

texture--when applied to the physical characteristic of a soil, it refers to the relative proportions and mixtures of particle sizes, including gravel, sand, silt, and clay

tidal efficiency--the ratio of the range in fluctuation of water level in a well to the range in tidal fluctuation causing it; see Figure D-4 at end of Glossary

transient condition--a term used in ground water modelling to describe a condition of ground water flow that is unsteady, or changing with time, and therefore causes the potentiometric surface to change with time

transmissivity--the rate at which water of the prevailing viscosity is transmitted through a unit width of aquifer under a unit hydraulic gradient

unconfined aquifer (also called a water table or phreatic aquifer)--an aquifer in which the potentiometric surface is equal to the water table and the top of the aquifer is open to atmospheric pressure

variance--a statistical term that represents the square of standard deviation

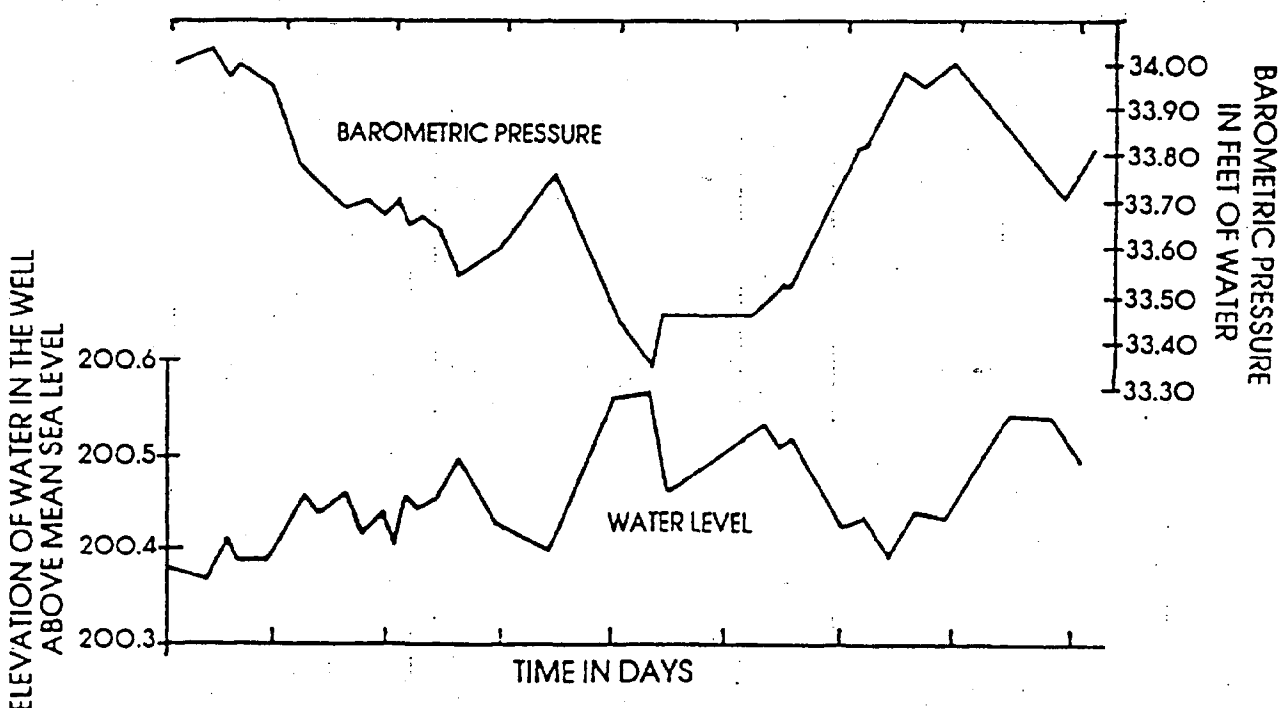
water table well--a well that penetrates an unconfined aquifer

well efficiency--the ratio of the theoretical drawdown of a well for a given well pumping rate to the actual drawdown at the given pumping rate; well efficiency decreases with drawdown and is proportional to the flow rate squared; well efficiency is usually evaluated with a step-drawdown test

well interference--the phenomenon of a lowering of the potentiometric surface in the vicinity of a well to a level greater than would be created by the one well alone, and caused by the additive effects of overlapping cones of influence from one or more nearby pumping wells; see Figure D-5 at end of Glossary

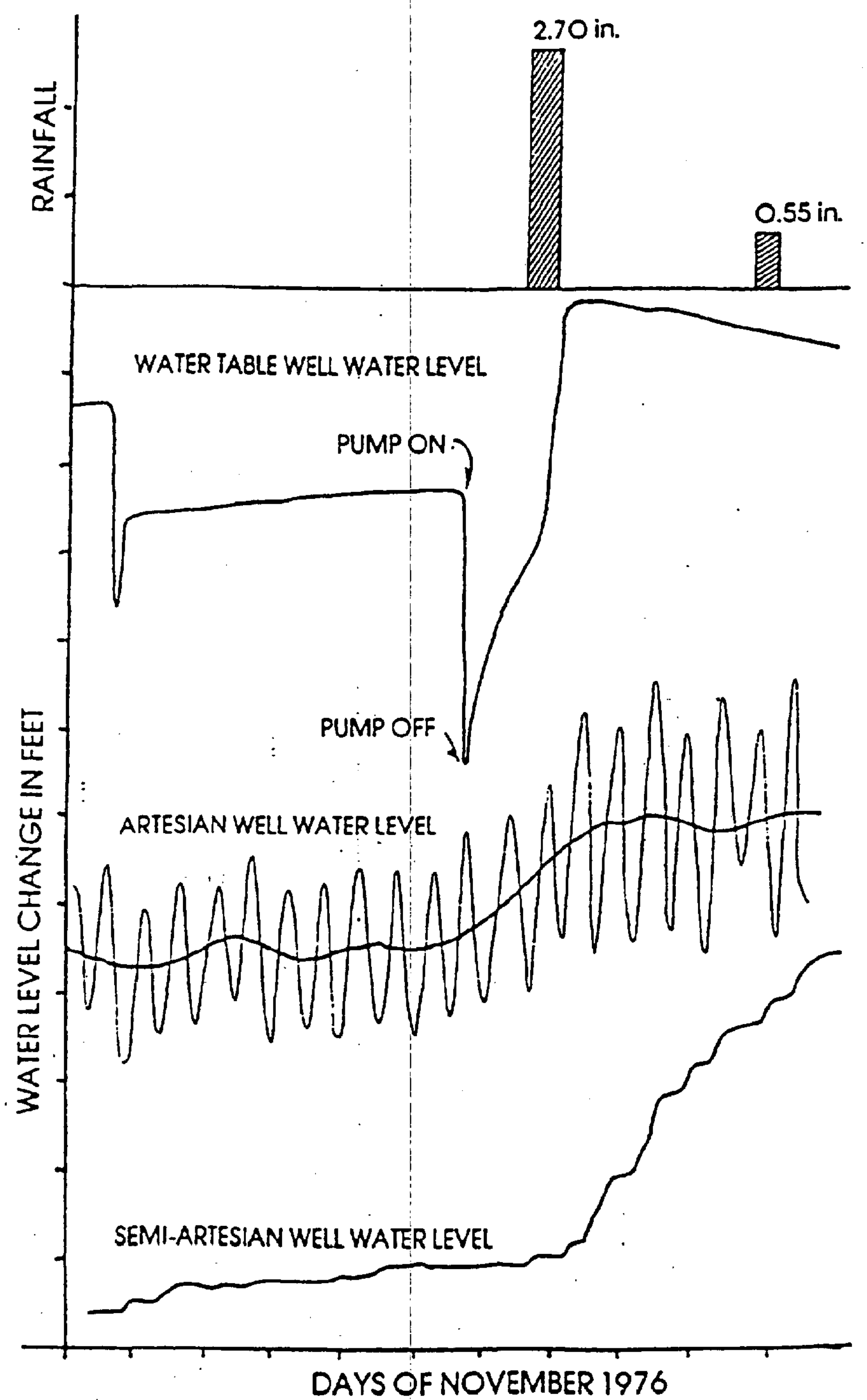
well yield--the maximum rate that water may be pumped from a well, based upon limitations of the aquifer and well construction, and not on the pump; actually well yield is a function of time and will therefore decrease with time if all other factors remain equal and no source of recharge is intercepted

FIGURE D-1 Response of Wells to Barometric Fluctuations



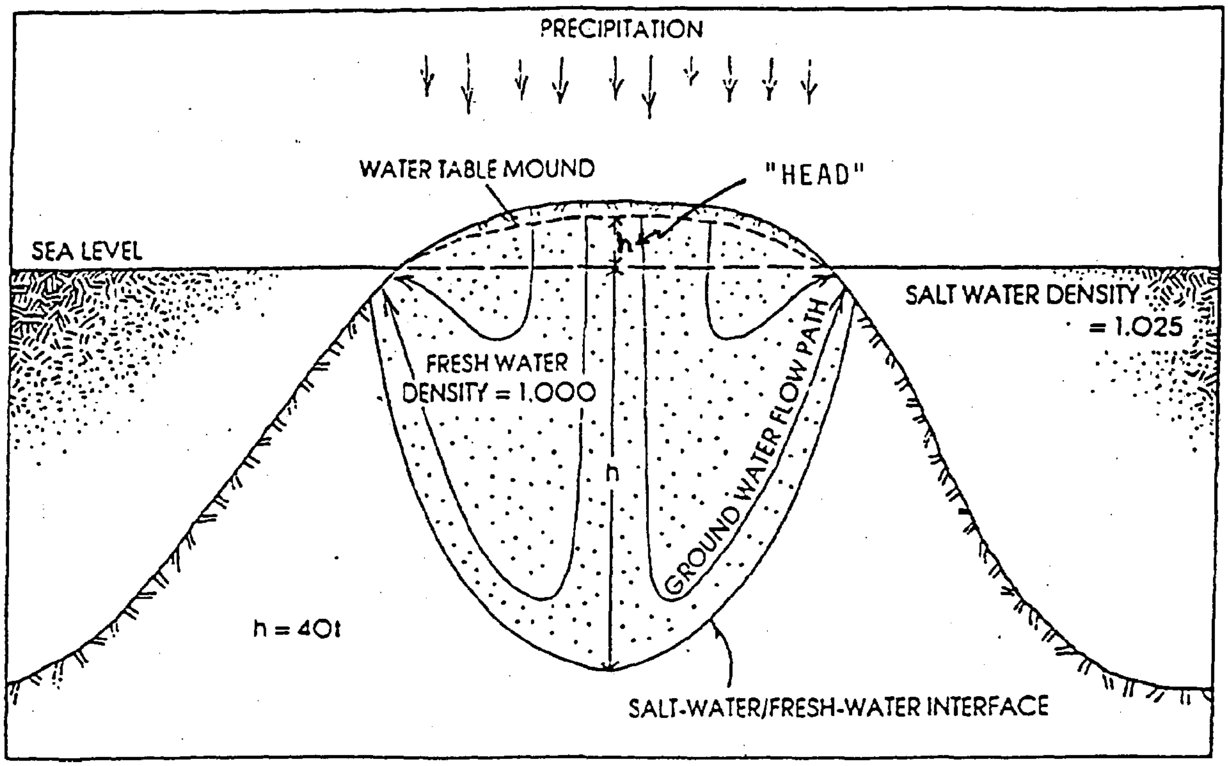

Water-level flucuations in an artesian well that correspond to barometric pressure fluctuations. The barometric efficiency of this well is 52%. (Caswell,1978, Fig. 33, p.41)

FIGURE D-2 Responses of Different Well Types to Precipitation




Water-level records showing the response of three coastal bedrock wells to precipitation and tidal flucuation. The water-level rise in the artesian well starting a few hours before the major storm is caused by the decrease in atmospheric pressure, rather than rain associated with the storm. (Caswell,1978, Fig. 35, p.44)

FIGURE D-3 Response of Ground Water at the Salt-water Interface




Schematic cross section of an oceanic island showing lens of fresh water. The water table mound is maintained by precipitation. (Caswell, 1978, Fig.36, p.46)

Idealized ground water flow near the fresh water/salt water interface. (Caswell, 1978, Fig.37, p. 47)

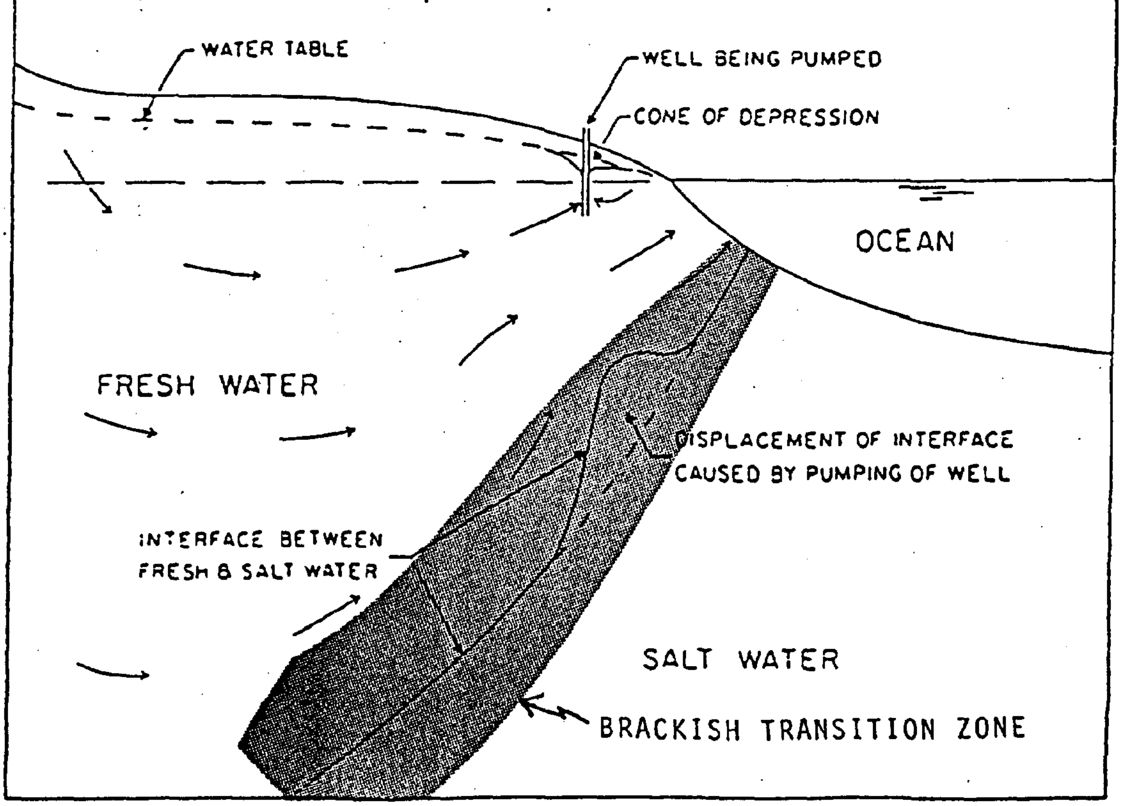
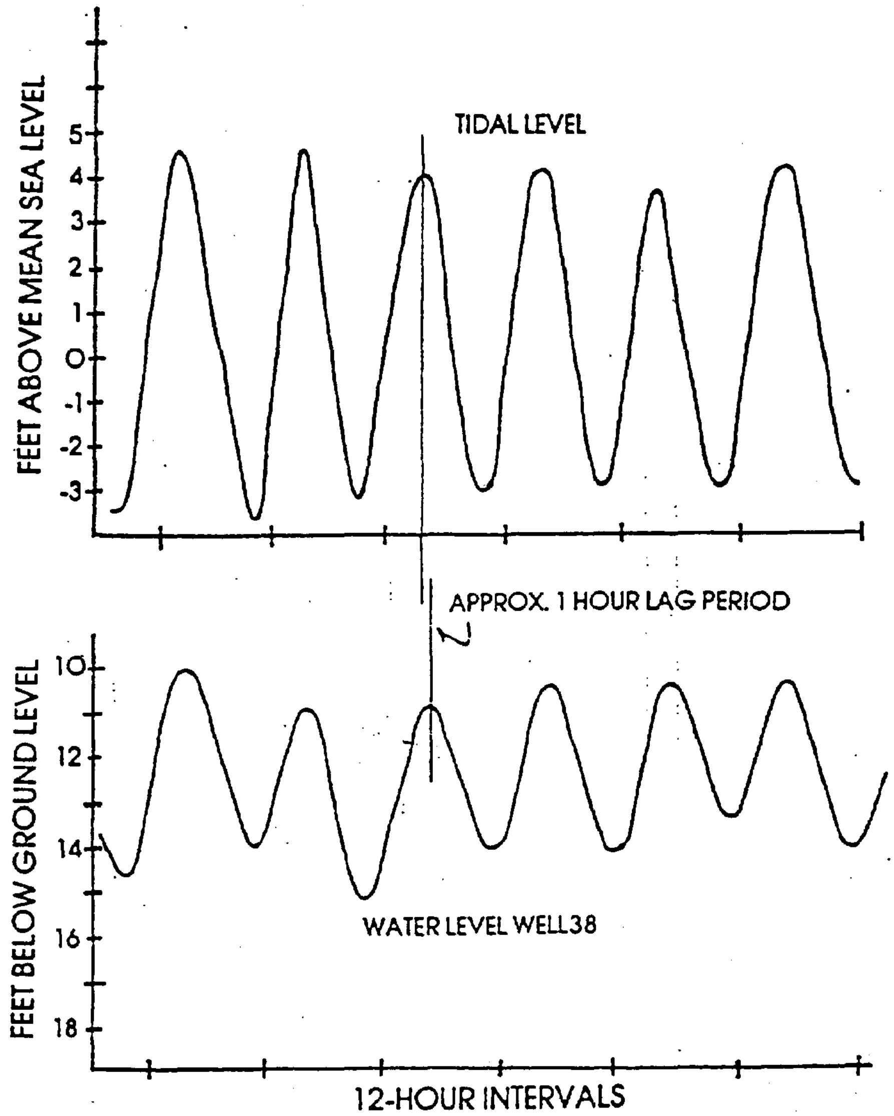
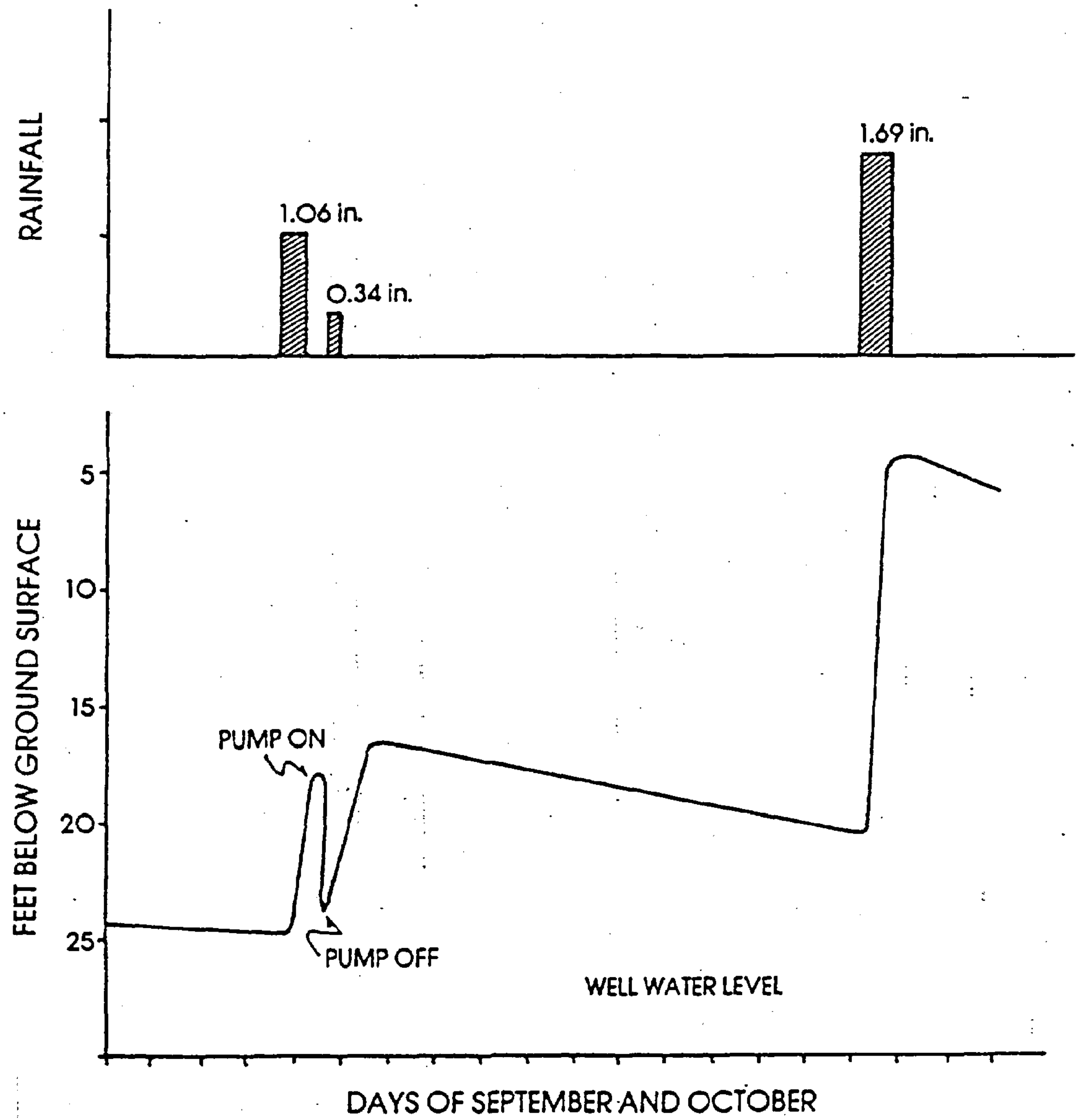


FIGURE D-4 Response of Artesian Well to Tidal Fluctuation




Comparison of water-level flucuations in a well on High Head to the tidal cycle. It shows about a one hour lag in its response to the tide. (Caswell,1978, Fig.34, p. 43)

FIGURE D-5 Effect of Well Interference




Effect of well interference. This well is a water table well drilled 100 feet into rock and yields 60 gpm. A similar well is located 300 feet away and was pumped for a short period of time and affected the first well as shown. (Caswell,1978, Fig. 32, p. 40)

APPENDIX E

# APPENDIX E--GROUND WATER AND WELL HYDRAULICS

Caswell, 1978, gives an excellent discussion of ground water and well hydraulics. A few of the most important aspects will be highlighted here.

Water enters the ground surface from precipitation or surface water and enters the aquifer to become ground water. Ground water flows from the higher elevations, or recharge areas, to the lower elevations under the initial influence of gravity. Once ground water enters a confined or artesian aquifer, it moves from one location to another according to the pressure differences, or hydraulic "head" that exist between two locations. The total hydraulic head is composed of elevation head, pressure head, and velocity head. In most ground water problems, velocity head is negligible.

The ground water flow pattern in an aquifer can be described by a flow net. Lines of equal total head are called equipotential lines. Lines which follow the direction of ground water flow are called flow lines. In a homogeneous and isotropic aquifer, flow lines cross equipotential lines at right angles.

The volume rate of ground water flow through an isotropic and homogeneous aquifer is described by Darcy's Law, given in Equation 1, below. This equation states that the rate of flow through a given cross sectional area of aquifer is equal to the aquifer hydraulic conductivity times the slope of the water table (gradient) times the cross sectional area through which the flow is taking place.

$$Q = K(i)A \qquad \text{(Eq. 1)}$$

where
Q = ground water flow in cubic feet per day
K = aquifer hydraulic conductivity in feet per day
i = hydraulic gradient in feet per foot
A = cross sectional area of aquifer, perpendicular to flow direction, in square feet

The seepage velocity or particle velocity is important in analyzing pollutant transport problems. The rate of travel of a conservative pollutant (one not removed by adsorption or chemical reaction) in a homogeneous and isotropic aquifer is given in Equation 2, below.

$$V = \frac{K(i)}{n_e} \qquad \text{(Eq. 2)}$$

where
V = velocity of pollutant travel by convection in feet per day
K = aquifer hydraulic conductivity in feet per day
i = hydraulic gradient in feet per foot

$n_e$ = effective porosity of the aquifer

The yield of a well placed in a homogeneous aquifer can be estimated by Equation 3, taken from Lohman, 1972. The specific capacity of a well is the yield of the well per foot of drawdown. Equation 3 shows how this yield is a function of other physical and time parameters for a 100% efficient well.

$$\frac{Q}{s_w} = \frac{4(3.14)T}{2.3\log_{10}\left(2.25Tt\left(\frac{1}{r^2S}\right)\right)} \qquad \text{(Eq. 3)}$$

where
Q = well pumping rate
$s_w$ = well drawdown
T = aquifer transmissivity, which is equal to aquifer thickness multiplied by hydraulic conductivity
t = elapsed time since beginning of pumping
r = radius of well being pumped
S = storativity (see Eq. 4)

The term storativity is defined in the Glossary. The storativity of an aquifer affects the shape and extent of the cone of depression created by a pumping well. The storativity of an unconfined sand and gravel aquifer is approximately equal to specific yield or 0.1 to 0.3. For an artesian sand and gravel aquifer, the storativity is approximately equal to 0.000001 times the aquifer thickness in feet. For an artesian aquifer in bedrock, the following Equation 4 can be used to estimate storativity (Lohman, 1972).

$$S = 0.434(n)b\left(\frac{E_s + E_w}{E_w E_s}\right) \qquad \text{(Eq. 4)}$$

where
n = porosity
b = aquifer thickness in feet
$E_w$ = compressibility of water = 300,000 pounds per square inch
$E_s$ = bulk modulus of elasticity of the solid skeleton of the bedrock in pounds per square inch

For a typical highly artesian crystalline rock such as a mica schist, the storativity would be 0.000001 to 0.0000001.

The radius of influence of a well is of some interest, particularly in problems involving well interference and pollutant transport studies. The radius of influence of a well is obviously affected by local precipitation recharge in the case of a water table well, and by impervious boundaries in the case of artesian aquifers. Equations 5 and 6 are taken from Bear, 1979, and should only be taken as approximations.

$$R = 1.9\left(\frac{HKt}{n_e}\right)^{0.5} \quad \text{(Eq. 5)}$$

$$R = 3000 s_w K^{0.5} \quad \text{(Eq. 6)}$$

where
for phreatic aquifers:
$R$ = radius of influence of well in meters
$H$ = initial saturated thickness of the aquifer, in meters
$K$ = hydraulic conductivity of aquifer in meters per second
$t$ = time in seconds since beginning of pumping
$n_e$ = specific yield
$s_w$ = drawdown in pumping well, in meters

for confined aquifers:
$H$ = aquifer's thickness, b, in meters
$n_e$ should be replaced by storativity, S
all other variables remain the same

To determine the drawdown at some intermediate distance between a pumping well and the radius of influence, the following Equation 7 can be used if the aquifer is reasonably homogeneous, isotropic, and extensive and if the well has been pumped long enough to develop a steady state condition. The equation is taken from Lohman, 1972.

$$\log_e \frac{r_2}{r_1} = \frac{-2(3.1416)K(h_2^2 - h_1^2)}{Q} \quad \text{(Eq. 7)}$$

where
$Q$ = pumping rate in well
$K$ = hydraulic conductivity
$r_1$ = well radius
$r_2$ = radial distance to point of interest
$h_1$ = difference between original aquifer thickness and drawdown at well
$h_2$ = difference between original aquifer thickness and drawdown at point of interest

To determine the approximate depth below Mean Sea Level that the salt-water interface occurs in a coastal area, the Ghyben-Herzberg principle can be used. This principle really only applies in locations where steady state conditions have developed and the fresh water/salt water interface in the aquifer can be modeled as a "sharp interface". Nevertheless, the principle, expressed in Equation 8 is useful as a first approximation.

$$d = 40h \quad \text{(Eq. 8)}$$

where

$d$ = depth below Mean Sea Level to salt water interface
$h$ = height of static water level above Mean Sea Level

Some aquifers are called "leaky" or "semi-artesian" aquifers because they are confined by aquitards and the aquifer's storativity has a value intermediate between that which would apply for either an unconfined aquifer or an artesian aquifer. The rate of water transfer between the two aquifers separated by an aquitard can be calculated by Equation 9.

$$Q = \frac{K'A}{B'}(h_t - h_b) \qquad \text{(Eq. 9)}$$

where
$Q$ = rate of water transfer
$K'$ = vertical hydraulic conductivity of aquitard
$B'$ = thickness of aquitard
$A$ = cross sectional area, normal to flow, over which the flow takes place
$h_t$ = total head at top of aquitard
$h_b$ = total head at bottom of aquitard

## APPENDIX F

# APPENDIX F

## SPECIFICATIONS FOR ABANDONING A DRILLED WELL

Prior to abandoning a drilled well by discontinued usage, the following procedure shall be followed for grouting the well:

A. Gages on grout lines shall be of the nonclogging type, or clogging shall be prevented by using gage savers.

B. Grout pumps of the positive displacement type having a capacity of not less than 40 gpm at a discharge pressure of 25 psi shall be used. Centrifugal-type pumps may be used only if approved.

C. A suitable grout mixer of the mechanical or venturi type will be required to obtain a thoroughly mixed, uniform, highly plastic grout mixture. A holdover tank equipped with a mechanical agitator will be required to keep the grout in uniform suspension. Precaution must be taken to avoid clogging or failure of the pump to pump the grout down the hole through the grout tube. Hand mixing of grout will be permitted only upon specific approval in each case.

D. The grout mix shall consist of Portland cement, pulverized bentonite, and water in proportions as directed. Portland cement shall conform to the requirements of ASTM Designation C150 for Type I or Type II cement with the exception that manufacturer's certification will be as required by the Engineer. Cement shall be furnished in 94-lb sacks and shall be stored and protected to prevent contamination, exposure, and formation of lumps. Bentonite shall be a natural Wyoming sodium bentonite containing no additive, ground to pass a 200 mesh sieve. Bentonite shall be furnished in sacks and shall be free of lumps and foreign matter. Water shall be clean and free from injurious amounts of oil, acid, organic matter, salt, or other deleterious substances.

E. The grout mix ratio (water/cement) will be expressed in gallons of water per 94-lb sack of cement. The water/cement ratio will be varied as directed, generally ranging between 7:1 and 18:1.

   (These ratios correspond to water/cement rations of 0.6 to 1.6 lb/lb.) All grout shall contain one to three pounds of pulverized bentonite per 94-lb sack of cement, as directed. The method of adding and mixing bentonite must result in uniform and thorough dispersion of that grout. <u>A smooth slurry shall first be prepared by mixing about one pound of bentonite per sack of cement with the water and then adding the cement. The remainder of bentonite shall then be added after the cement.</u> The grout shall be thoroughly mixed to produce a uniform, highly plastic mixture. Changes in the water/cement and bentonite/cement ratios beyond the limits shown must be specifically approved. Calcium chloride or other admixture approved by the Engineer may be added to the grout mixture to shorten the time required for the grout to set up.

F. Fill the borehole with clean sand or gravel (max. stone size 1.5") to within 50' of ground surface.

G. The holes will be grouted over the full diameter from the top of the sand or gravel fill in the borehole in a continuous operation to the top of the well casing which shall be cut off one foot below existing ground. The volume of grout to be mixed shall not be less than the calculated volume of that portion of the hole to be grouted. The grout will be tremied down the hole through a tube or pipe extending to within two (2) ft of the bottom of the borehole under a pressure of not more than 35 psi (or be approved) at the gage, until the grout level in the casing is at least level with the ground surface. The casing shall then be withdrawn to the required depth and grout added to the borehole in increments such that the grout level never drops below the upper limit of grouting as specified. The tremie pipe may then be withdrawn while pumping grout to maintain the grout level at the top of the borehole.

NOAA COASTAL SERVICES CENTER LIBRARY
3 6668 00000 6496