Geohydrology and Potential Water-Supply Development on Bumkin, Gallops, Georges, Grape, Lovell, and Peddocks Islands, Eastern Massachusetts

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CONVERSION FACTORS

Multiply	By	To obtain
acre	4,047	square meter
foot (ft)	0.3048	meter
foot per day (ft/d)	0.3048	meter per day
mile (mi)	1.609	kilometer
square mile (mi2)	2.590	square kilometer

In this report the unit of hydraulic conductivity is foot per day (ft/d), the mathematically reduced form of cubic foot per day per square foot $[ft^3/d)/ft^2]$.

VERTICAL DATUM

Sea Level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929--a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.

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By John P. Masterson, Byron D. Stone, *and* Rick R. Rendigs

Abstract

An investigation of the geohydrology and of the potential for water-supply development on several of the Boston Harbor Islands, eastern Massachusetts, was conducted to evaluate the possibility of developing a permanent small-capacity water supply to support recreational activities, such as camping, hiking, and swimming. The Boston Harbor Islands, including Bumkin, Gallops, Georges, Grape, Lovell, and Peddocks Islands are part of a larger group of glacially deposited drumlins, which are composed of thick, dense, homogeneous till in their core that are overlain by a thin layer of stratified-beach deposits. The surficial materials overlie a weathered zone of the metasedimentary Cambridge Argillite in the Boston Harbor area and were deposited by continental ice sheets that covered New England twice during the late Pleistocene Epoch, and by near-shore processes in the Holocene Epoch. The thickness of these materials range from less than 1 to about 300 feet where present.

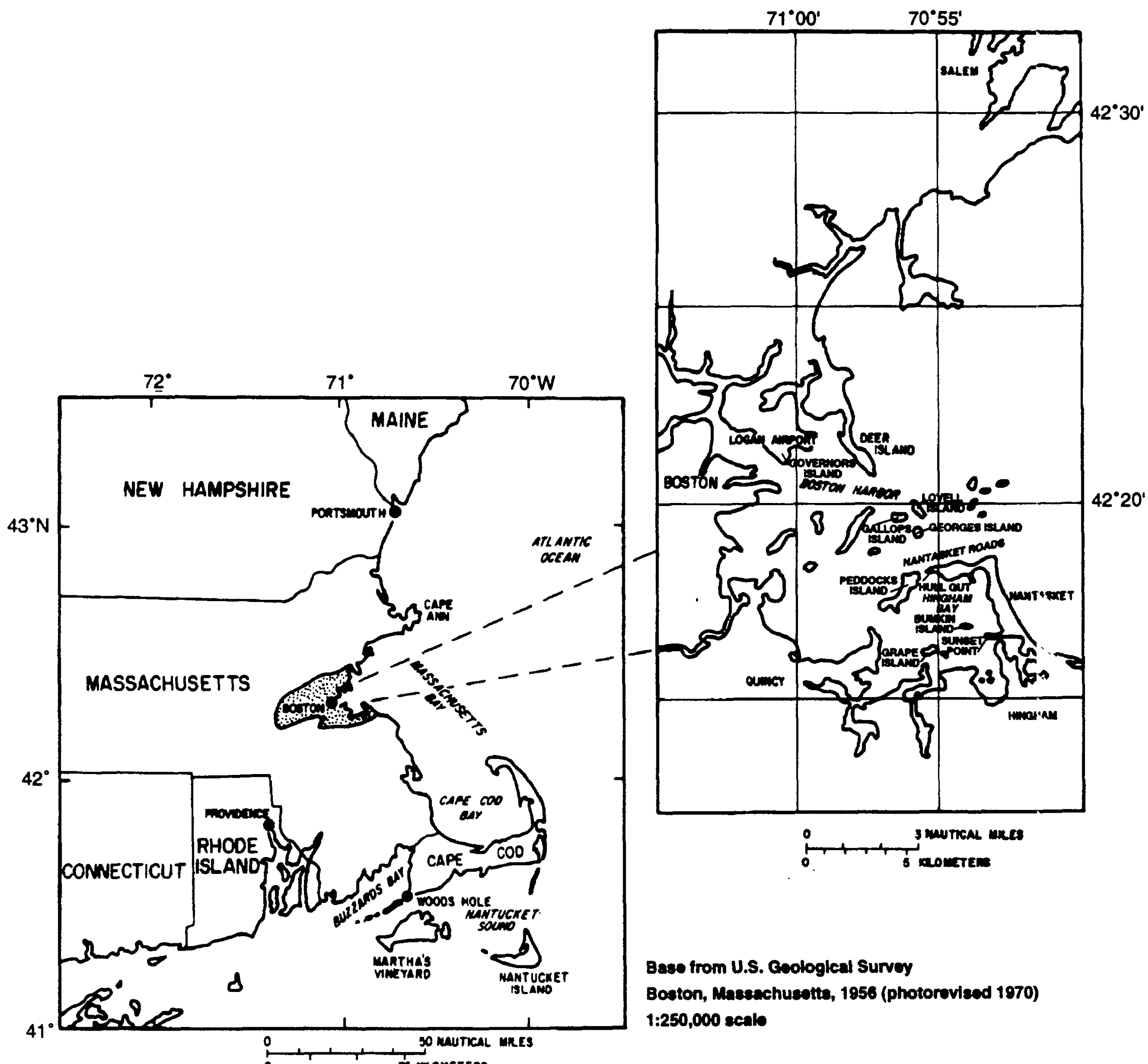
The till was deposited by glacial ice and is characterized as an unsorted matrix of sand, silt, and clay with variable amounts of stones and large boulders. The stratified deposits primarily consist of sorted and layered sand and gravel that accumulated and formed the beaches and tombolos of the harbor islands. These deposits overlie the till at altitudes generally less than 10 feet above sea level.

A cross-sectional, ground-water-flow model was developed to estimate depth to the water table for a hypothetical drumlin-island flow system, which was assumed to be representative of the drumlin islands in Boston Harbor. Areas were identified in each island flow system with the greatest potential for small-capacity water-supply development based on the model-calculated depth to water and surficial geology of the islands. Model-calculated depth to water estimates were used because of the lack of available hydrologic data for the islands. Model results indicate that the simulated depth to water is less than 20 feet within 240 feet from the shore of the hypothetical drumlin-island flow system. This area on the topographic maps of the six Boston Harbor Islands roughly coincides with the high transmissivity zones of stratified-beach deposits and weathered till on the lower slopes of the drumlins where ground-water discharge and surface and subsurface runoff occurs.

INTRODUCTION

The islands in Boston Harbor are in a lowland estuary in the western part of Massachusetts Bay, which constitutes the major commercial waterway for the metropolitan Boston area (fig. 1). The harbor is about 50 mi^2 in area and is dotted with 31 islands that collectively cover about 1,200 acres of land. The islands range in size from less than 1 acre to as large as 214 acres.

The Massachusetts Department of Environmental Management (DEM) and the Metropolitan District Commission (MDC) currently oversee the operation and maintenance of the State parks on several of the 31 Harbor Islands. These agencies are currently evaluating the possibility of developing a permanent small-capacity water supply to support recreational activities such as camping, hiking, and swimming for each of the islands, including Bumkin, Gallops, Georges, Grape, Lovell, and Peddocks.



Base from U.S. Geological Survey
Boston, Massachusetts, 1956 (photorevised 1970)
1:250,000 scale

Figure 1. Location of the Boston Harbor Islands, eastern Massachusetts. (Modified from Rendigs and Oldale, 1990.)

The landforms that dominate these islands are part of a larger group of glacially deposited, elongated asymmetrical hills known as drumlins. The drumlins of the Boston Harbor area are composed of thick, dense, homogeneous till in the core, overlain by thin beach deposits. The potential for water-supply development on these islands is difficult to assess because of the limited extent of the permeable beach deposits, the uncertainty in predicting water-bearing properties of till, and the limited information available on the geohydrology of these islands. The U.S. Geological Survey, in cooperation with the DEM, Office of Water Resources and DEM, Division of Natural Resources, began an investigation in June 1995 to improve the understanding of the geohydrology of the Boston Harbor Islands and to provide a preliminary assessment of potential locations best suited for water-supply development on Bumkin, Gallops, Georges, Grape, Lovell, and Peddocks Islands.

The purpose of this report is to (1) describe the geohydrology of the Boston Harbor Islands including the geologic setting, depositional history, and the geohydrology of a typical drumlin-till island based on a simplified cross-sectional ground-water model; and (2) delineate zones of the greatest water-bearing potential for Bumkin, Gallops, Georges, Grape, Lovell, and Peddocks Islands. The report also includes a discussion of existing dug wells on several of the islands that could potentially be used for water supply.

PHYSIOGRAPHIC SETTING OF THE SIX HARBOR ISLANDS

The Boston Harbor area (fig. 1) is a glacially carved estuarine lowland underlain by relatively nonresistant metasedimentary rocks (argillite, conglomerate). The Boston Harbor islands are composed primarily of glacial materials that directly overlie the bedrock surface. The islands are single or grouped drumlin landforms that are joined by tombolos, which are beaches or sand bars that link one island to another. These drumlins are elongate hills with smooth surface topography, elliptical in plan, and generally oriented southeasterly to easterly. Modern wave erosion has extensively modified the shapes of the drumlin cores of the islands producing steep, bare slopes and cliffs on the sides of the drumlins. Modern beach deposits have accumulated at the ends of the islands and extend as tombolos connecting grouped drumlins as in Peddocks Island.

Bumkin Island

Bumkin Island is in southeastern Hingham Bay. The 35-acre island is a single drumlin that gently rises to an altitude of about 70 ft above sea level. Most of the shoreline is rocky and the northwestern end of the island is eroded with prominent exposures of the till that constitute the drumlin. A long sand bar, which is exposed at low tide, extends to the east almost to Sunset Point in Hull (fig. 1). The island is densely overgrown with sumac, poison ivy, viburnum, wild roses, aspens, and apple trees. Historically, the island was used to support a fishing and farming community. During the late 19th century, a children's hospital was located at the center of the island. During World War II, the U.S. Navy constructed barracks for about 1,300 sailors. The 58-building complex was destroyed by fire in 1945. The island is presently used for hiking, camping, and picnicking (Snowe, 1971).

Gallops Island

Gallops Island, located near the center of Boston Harbor, is a drumlin about 16 acres in size. The crest of the island is at an altitude of about 60 ft above sea level. Exposures along some of the eroded sea cliffs reveal deposits of dense till that are covered by thin, discontinuous sand or sandy gravels. The eastern end of the island consists of recent beach deposits of medium sand. Vegetation on Gallops Island consists of shrubs and trees, and meadow and salt marsh flora. This island has been variously and extensively used as a sand and gravel mine, resort area, quarantine station, and immigration station since the 1830's, and as a radio operators' school during World War II. Since World War II, the island has served as a garbage dump for the city of Boston and is currently used by the public for various recreational activities (Boston Harbor Islands, 1994).

Georges Island

Georges Island is a 28-acre island in the middle of Boston Harbor just north of the Nantasket Roads shipping channel (fig. 1). The maximum altitude of the island is about 40 ft above sea level. Erosion along the east side of the island and on the steep banks of the west side results in exposures of mixed coarse sands, cobbles, and the underlying till. A small rocky beach is adjacent to the boat-docking area on the southwest side of the island. Vegetation is sparse due to the extensive development related to the construction of Fort Warren, which occupies most of the island. During colonial times, the island primarily was used for farming. The island became Federal property in 1825 and was extensively excavated 8 years later during the construction of Fort Warren. The fort was used by the military during the Civil War and World Wars I and II (Boston Harbor Islands Comprehensive Plan, 1973). After World War II, the island was abandoned and designated as a National Historic Site by the U.S. Department of Interior. The Island's fort is visited by an estimated 70,000 persons annually. The island also is used for recreational activities such as swimming, picnicking, and hiking.

Grape Island

Grape Island is a 50-acre island in Hingham Bay in the south end of Boston Harbor (fig. 1). The island consists of a drumlin with a maximum altitude of about 70 ft above sea level on the west, and till-covered bedrock hill on the east. Exposures of sand and gravel can be seen from eroded banks on the west shore. The southeast side of the island consists of tidal marshes and gravel beaches. Outcrops of argillite are exposed on the north and south shorelines. Vegetation consists primarily of grasses, sumac shrubs, raspberries, blackberries, and scattered oak, birch, and aspen trees (Boston Harbor Islands, 1994). Indians extensively farmed the land and clammed on the tidal flats before the arrival of the settlers in the 1630's. The island has not been disturbed by the installation of military or other facilities and currently is used for recreational activities such as hiking, picnicking, and camping (Boston Harbor Islands, 1994).

Lovell Island

Lovell is a 62-acre island that consists of an eroded drumlin in the central part, and tidal flats and beaches on the southern and northern parts (fig. 1). The crest of the drumlin is at an altitude of about 45 ft above sea level. Vegetation consists of pines, aspens, maples, sumac, wild rose, and marsh grasses. Historically, a succession of farms existed during colonial times with the hardwood stand of trees cut for firewood over the years (Boston Harbor Islands, 1994). The island was acquired by the Federal government in the mid-1800's and used as a training station during the Civil War. Fort Standish was established in 1900 and was abandoned after 1946. Presently, the island is used for fishing, picnicking, and swimming (Boston Harbor Islands, 1994).

Peddocks Island

Peddocks Island consists of a group of five drumlins, locally known as heads, connected by sand and gravel bars called tombolos. The island is about 190 acres and has the longest shoreline of all the Boston Harbor Islands. East Head is the largest drumlin on the island and covers about 90 acres. East Head is less than 0.25 mi from Hull across the Hull Gut and has a maximum altitude of 123 ft above sea level (fig. 1). Exposures of discontinuous stratified deposits of sand and gravel are evident along the steep eroded heads of the island. Beach deposits of sand and gravel are found in low-lying areas connecting the island drumlins. A salt marsh lies between West Head and the middle drumlin and a wildlife sanctuary that contains a brackish pond is found on West Head. Abundant tidal flats of sand and cobbles are exposed during low-tide conditions. Vegetation is abundant on Peddocks Island and consists of large stands of maple, aspen, apple, birch, elm, and pine trees. Ground cover consists primarily of viburnum, blackberry, sumac, barberry, poison ivy, and wild rose (Boston Harbor Islands, 1994). The salt marsh area is surrounded by marsh grasses, milkweeds, and cattails. The island was first settled in the 1620's and used for farming and pastureland through the mid-1800's. In 1900, the Federal government built Fort Andrews on East Head (Snowe, 1971). About this time, a summer community was established in the middle of the island that still exists today (1995). Additional permanent structures were emplaced by the military during World Wars I and II and the island was eventually acquired by the State Metropolitan District Commission in 1968. The island is now primarily used for hiking and sightseeing (Boston Harbor Islands, 1994).

GEOHYDROLOGY

Geologic Setting

The surficial materials that overlie the weathered-bedrock surface in the Boston Harbor area were deposited by continental ice sheets that covered New England twice during the late Pleistocene Epoch, and by near-shore processes in the Holocene Epoch. The thickness of these materials, where present, ranges from less than 1 to about 300 ft. The surficial materials constitute all nonlithified Earth materials that commonly are referred to as "unconsolidated" soils in engineering literature. These materials lie below the modern soil at the land surface.

The surficial materials in the Boston Harbor Islands are divided into two broad categories: till and stratified deposits. Till was deposited by glacial ice and is characterized as a nonsorted matrix of sand, silt, and clay with variable amounts of stones and large boulders. Stratified deposits primarily consist of sorted and layered sand and gravel that accumulated and formed the beaches and tombolos of the harbor islands. These deposits overlie the till at altitudes generally less than 10 ft above sea level.

The distribution of surficial materials is shown on the geologic map of the Boston Harbor Islands (fig. 2). These areas are distinguished on the basis of geologic interpretation of aerial photographs, published geologic maps, marine geophysical studies, and field studies.

The six Boston Harbor Islands of the study area contain 10 drumlin landforms. The drumlins are elongate hills with smooth surface topography, elliptical in plan, and generally oriented parallel to ice-movement directions. Nearly 200 drumlins are in the Boston area and they typically range from 0.5 to 1 mi long, 1,500 to 2,000 ft wide, and 100 to 150 ft high. Some island drumlins, such as in Peddocks Island, have steeper long-axis slopes that face toward the southeast ice-flow direction. Some others, such as Grape and Bumpkin Islands, have steeper slopes that face the up-ice northwesterly directions. However, erosional modification of the islands obscures the original form of these slopes.

The drumlins appear to be locally clustered in belts or lines with long-axis orientations ranging from east to southeast (LaForge, 1932; Crosby, 1934). The apparent clustering or alignment of some drumlins (such as in Peddocks Island) may be a function of the topographic relief on the underlying bedrock topography and the direction of ice movement.

EXPLANATION FOR FIGURE 2

DESCRIPTION OF MAP UNITS

Qb	UNDIFFERENTIATED MARINE AND ESTUARINE SEDIMENTS (HOLOCENE)--Recent marine deposits consisting mostly of silty clay to clayey silt sediments, which may locally contain gravel, shell and shell fragments, organic deposits and sand. This unit may be as much as 5 meters thick. Deposits are thought to be locally derived from the winnowing of glacial deposits during the last rise of sea level. These deposits may be locally overlain by estuarine deposits found mostly in quiet water embayment areas
Qt	GLACIAL DRIFT (PLEISTOCENE)--This unit consists primarily of a compact, dense till inferred to have been deposited during the Illinoian stage of glaciation about 80,000 years ago. The upper surface of this unit may show extensive weathering as evidenced from exposures on many of the drumlin islands in the harbor. This unit may locally thin beneath the sea floor where it may be recognized by extensive lag deposits of cobbles and boulders covering the surface of the sea floor
Pz	BEDROCK (PALEOZOIC OR OLDER)--A complex suite of sedimentary and volcanic rocks that were deposited during the Proterozoic and Cambrian. Outcrops along the sea floor, harbor islands, and adjacent shoreline are localized and consist primarily of Cambridge Argillite, which may be cut locally by dikes and sills of diabase
Qt/Pz	UNDIFFERENTIATED GLACIAL DRIFT/BEDROCK--Exposures along the harbor seafloor cannot be differentiated by major seismic reflectors of sidescan sonar patterns
-----	CONTACT--Dashed where approximately located

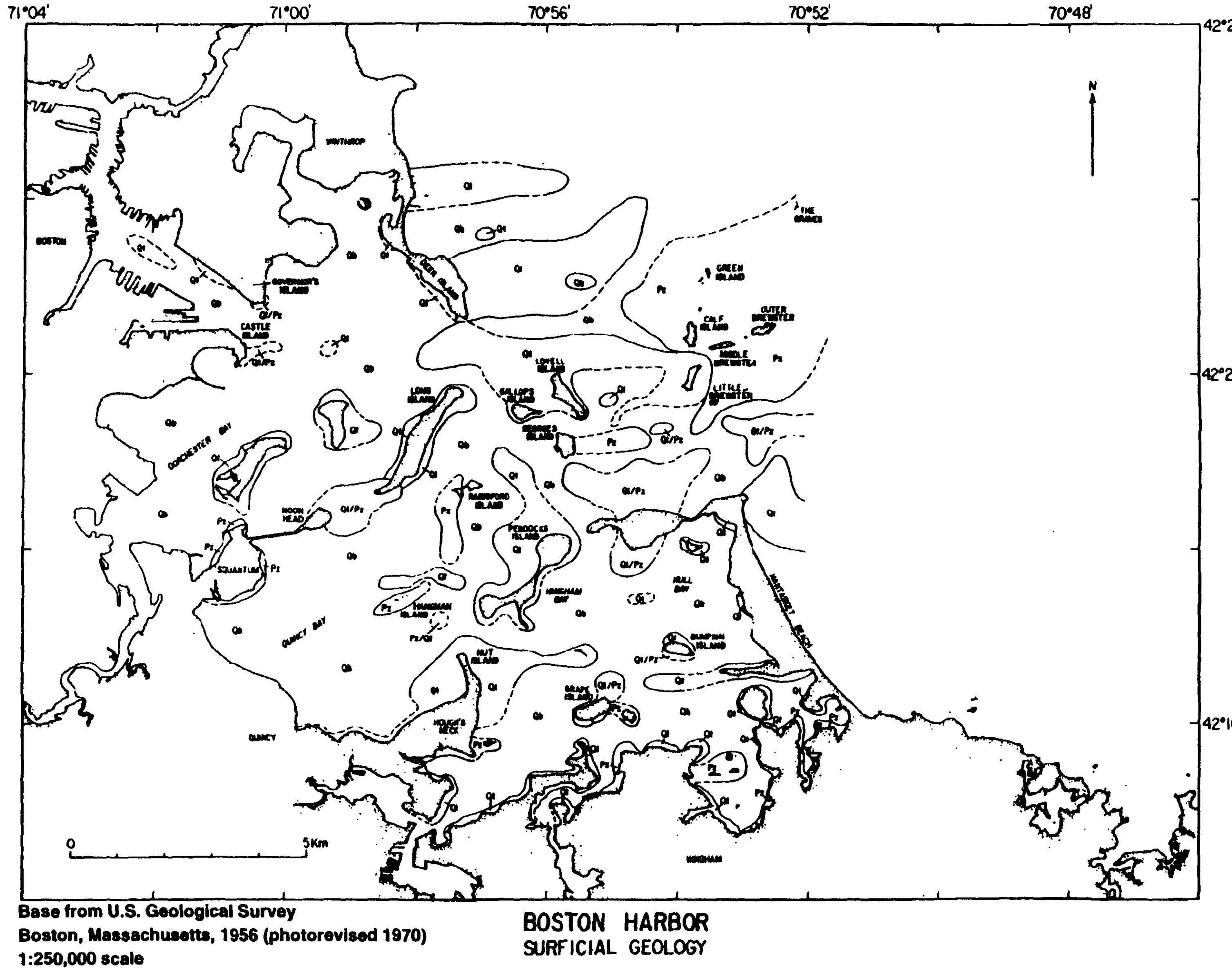


Figure 2. Surficial geology of the Boston Harbor Islands, eastern Massachusetts. (Modified from Rendigs and Oldale, 1990.)

Subsurface geologic data in the region and the deep exposures in the island cliffs confirm that the drumlins contain thick till cores rather than bedrock cores as described for some drumlinoid hills (Flint, 1930). Subsurface data from seismic-refraction studies on Governor's Island drumlin, the present day location of Logan Airport (Lee, 1942) (figs. 3 and 4) confirm the presence of thick, weathered and nonweathered drumlin-till deposits overlying bedrock. Till deposits that constitute the drumlin cores thicken from the outer edge to the center of the drumlins where till thicknesses commonly exceed 100 ft.

The glacial tills in the Boston area that constitute the cores of these drumlins are related to two late Pleistocene continental glaciations (Schafer and Hartshorn, 1965; Stone and Borns, 1986; Weddle and others, 1989). The informal terms "surface till," and "drumlin till," refer to the local stratigraphic superposition of two tills of different glaciations, and to the stratigraphic relation of one to the other.

The surface till consists of relatively sandy or silty till material deposited during the late Wisconsin glaciation about 23,000 to 15,000 years ago (Stone and Borns, 1986). The compact, silty drumlin till, which constitutes the cores of drumlins, was deposited during the late Illinoian glaciation about 180,000 to 165,000 years ago (Fullerton and Richmond, 1986). The surface-till zone overlies a zone of weathered and joint fractured drumlin till, which, in turn, overlies a zone of compact nonweathered drumlin till at depth. The mixed-till zone, which includes the surface till and the weathered part of the lower drumlin till, will herein be referred to as the weathered till zone.

The surface till is discontinuous, probably averages less than 7 ft in thickness, and contains numerous boulders in exposed and submerged areas in Boston Harbor. The surface till is most extensive on eastern Grape Island. A fairly continuous mantle of thick drumlin till, which is beneath the surface till, is draped over rock outcrops and linear topographic features that are oriented parallel to the trend of bedrock structural features (Rendigs and Oldale, 1990). The drumlin till appears to be more continuous than the surface till in submerged areas, and it constitutes the cores of the harbor islands drumlins and submerged drumlins.

The surface till generally is gray below the shallow modern soil, reflecting the unweathered state of minerals in the till matrix. Till-matrix samples from the islands averaged 37 percent sand, 45 percent silt, and 8 percent clay (Newman and others, 1990). By visual estimate, the till contains more than 30 percent gravel by volume, primarily granules, pebbles, and small cobbles of argillite with lesser amounts of crystalline metamorphic rocks. Boulders 3 to 6 ft in length commonly are found in the surface till. The surface till commonly is loose and slightly stratified, locally containing discontinuous beds of sorted and stratified sand. The surface till on the tops of the island drumlins reportedly ranges in thickness from more than 12 ft (Newman and others, 1990) to less than 3 ft.

Nonweathered drumlin till in the core of the harbor drumlins commonly is dark gray. By visual estimate, the till contains less than 25 percent gravel by volume, primarily granules, pebbles, and small cobbles of argillite. Boulders more than 3 ft in length are virtually absent in large exposures of drumlin till; no such large boulders were seen within any exposures of the till in the island drumlins. Gray drumlin till exposed in all deep island cliffs appears structureless and homogeneous.

A weathered zone is developed in the top of the drumlin till, below the thin, bouldery surface till and the modern soil. The weathered zone is oxidized to depths of 10 to more than 20 ft below land surface. Near horizontal fissility (surfaces within the till along which the till matrix parts easily) is well developed in the weathered zone, but is more widely spaced and poorly developed at depth. The fissility is not apparent in lower parts of deep exposures, but dried samples of the till separate along near horizontal fissile surfaces.

Weathering effects are progressive upward through the weathered zone. The blocky structure of the till, formed primarily by subvertical joints and less prominent near horizontal fissility, increases and is more densely developed toward the surface. The degree and darkness of iron and manganese stain on joint faces increase upward. When occurring at a relatively shallow depth, the weathered zone of the drumlin till in the region is the upper part of the C-horizon of a probable well-developed interglacial soil (Pessl and Schafer, 1968; Weddle and others, 1989; Newman and others, 1990); the solum was removed by late Wisconsin glacial erosion.

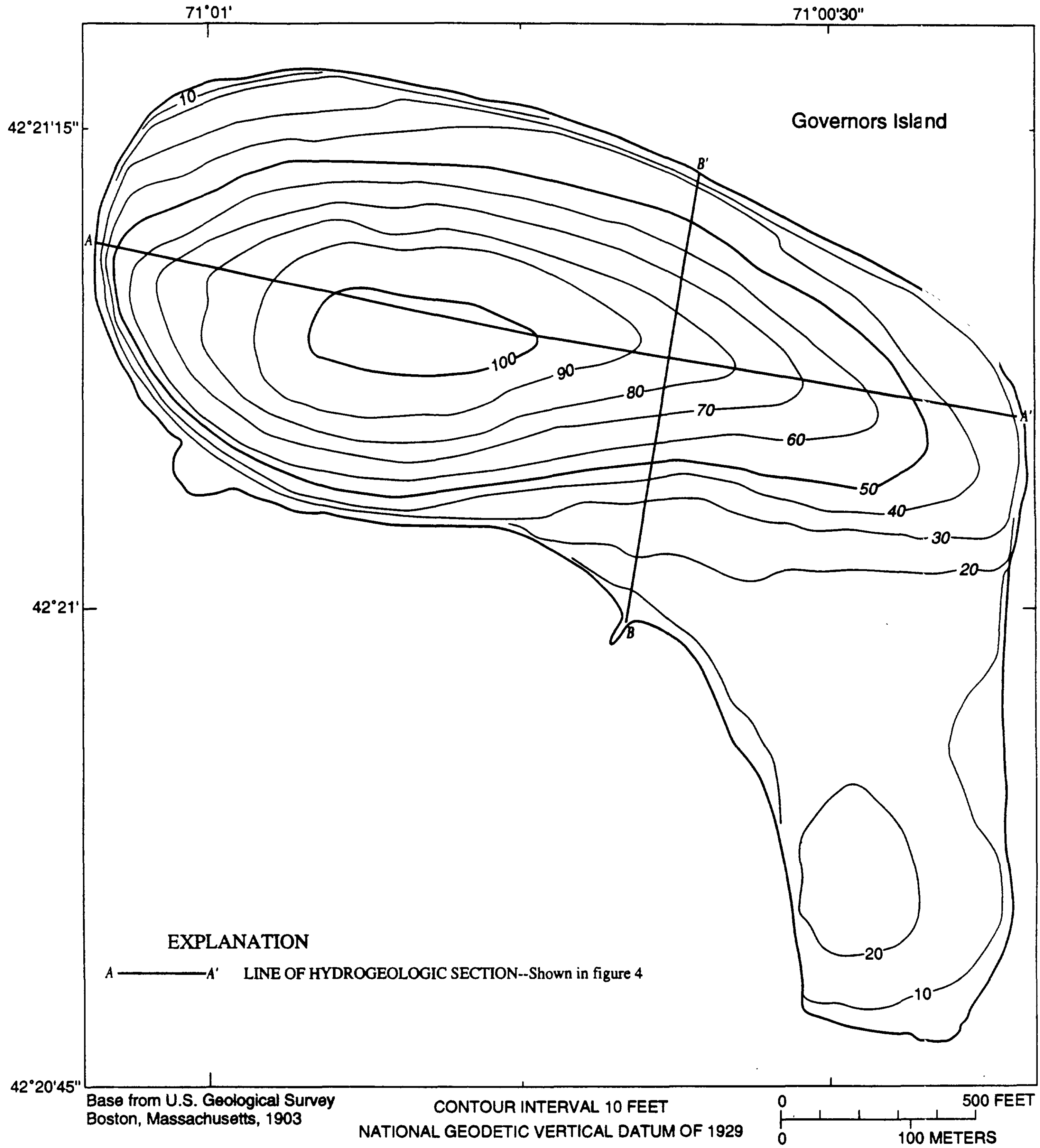


Figure 3. Topography of Governors Island, eastern Massachusetts. (Modified from Lee, 1942.)

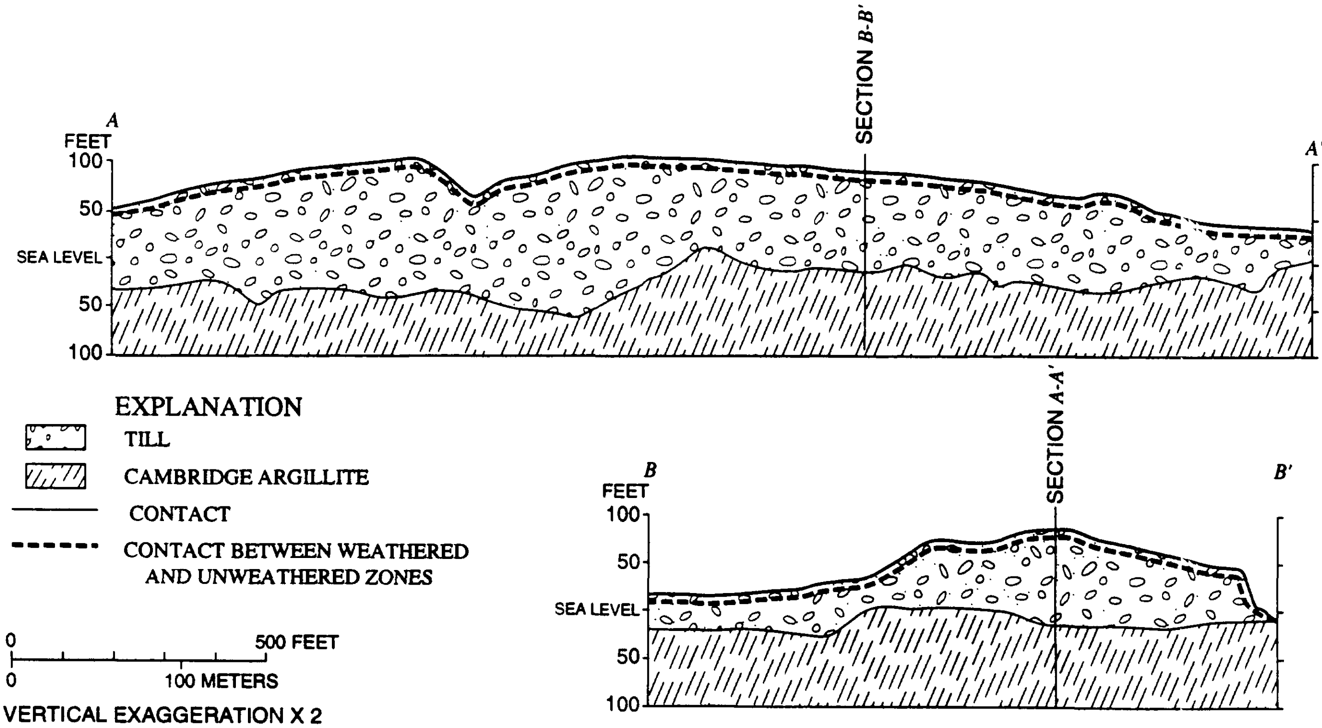


Figure 4. Hydrogeologic sections of Governors Island, eastern Massachusetts. (Modified from Lee, 1942.)

The stratified deposits that underlie the beaches and tombolos of the islands consist of alternating layers of medium to very coarse sand, and gravel with coarse sand matrix. The sand beds commonly range from near horizontal to gently dipping, and contain planar laminations and cross beds. The gravel beds, which consist of pebble to cobble framework with loose matrix sand, generally are near horizontal and commonly contain cross beds. The coarse sand grains and gravel clasts are of argillite and crystalline metamorphic rocks, locally derived from the eroding till slopes on each island. Windblown dune deposits of medium sand locally overlie beach deposits. Fine sand and organic silty deposits are at the base of the ponds and on top of beach deposits in the tidal marsh areas on Peddocks Island. The sand and gravel deposits generally are more than 15 ft thick, extending from near the low-tide zone to storm beach ridges about 10 ft above sea level.

Most of the surficial deposits in the Boston Harbor area (fig. 2) are underlain by Cambridge Argillite, a relatively nonresistant metasedimentary rock. The bedrock forms shallow submerged platforms (fig. 2) that are bounded by northeast-trending faults. Rock ridges extend northeastward across the area in the subsea-bottom and crop out primarily around the outer harbor islands from the Brewster to the Graves Islands. Prominent ridges of resistant rock units extend along northeast trends across the inner harbor at altitudes of 10 to 20 ft below sea level around several of the harbor islands, yet are exposed at only Grape and Bumkin Islands. These bedrock outcrops reveal that a fractured zone exists in the top of bedrock below the till interface and is characterized by subvertical jointing and cleavage. Much of the weathered and hydrothermally altered rock material from most of the Boston area was removed by glacial erosion; however, altered-rock materials are preserved locally beneath glacial landforms such as drumlins (Kaye, 1961). Areas where bedrock is exposed at the surface are delineated on the map showing the geologic setting of the Boston Harbor Islands (fig. 2).

Depositional History of Geologic Units

Boston Harbor lies within a fault-bound structural basin known as the Boston Basin that was formed as the result of extensive faulting of a complex suite of granitic, volcanic, and sedimentary bedrock about

550 million to 1.7 billion years ago (Kaye, 1982; Lenk and others, 1982; Zen, 1985; Goldstein, 1989). Nonmarine clastic sediments were eroded from surrounding highland areas and deposited into this basin. This region was then covered by Paleozoic sediments, which in turn were stripped away by erosion. The region was blanketed by near-shore coastal plain deposits during the Cretaceous and early Tertiary Periods about 50 to 70 million years ago. These coastal-plain deposits were then extensively eroded when this region was exposed about 25 million years ago during the late Tertiary Period in response to a global lowstands of sea level (Vail and others, 1977).

The more recent deposits of the Boston Harbor, including the Boston Harbor Islands, were the result of extensive glaciation during the Pleistocene Epoch, and subsequent marine deposition during the Holocene Epoch. At least two major glaciation events occurred in the Boston Harbor Basin in the late Pleistocene. The first continental glaciation occurred about 180,000 years ago and scoured much of the bedrock and preglacial coastal plain sediments. The ice sheet deposited the dense drumlin till in the cores of the harbor island drumlins as it flowed southeasterly to easterly into the Gulf of Maine Basin. The drumlins of the region developed a deep soil beneath their glacially smoothed surfaces in a prolonged interglacial episode following deglaciation. The depth of soil development indicates the Illinoian age of the till, which correlates with the widespread New England lower till described from sites throughout Connecticut (Melvin and others, 1992), central Massachusetts (Weddle and others, 1989), and from exposures on Nantucket Island (Oldale and Eskenasy, 1983).

The latest continental ice sheet advanced into the region about 25,000 years ago (late Wisconsinan age), scouring off much of the earlier glacial deposits before reaching its maximum southern extent on Martha's Vineyard and Nantucket Island (Oldale, 1988). A thin layer of the surface till was deposited discontinuously on top of the older drumlin till. The ice sheet reshaped the island drumlins as it first flowed southerly in the Boston Basin area during maximum glacial extent, then easterly as the Gulf of Maine Basin was deglaciated. As the ice sheet retreated northward about 18,000 to 15,000 years ago, it deposited submarine sediments of ice-proximal drift including sand, gravel, and till in the Boston area.

After the ice sheet receded northward, sea level rose about 50 ft above the present sea level, which resulted in the deposition of a glaciomarine clay in the topographically low areas in the Boston area. The Earth's crust then rebounded from the removal of the overlying ice sheet and the shoreline receded to almost 150 ft below the present sea level about 11,000 years ago (Oldale and others, 1983).

As the rate of crustal rebound slowed, the Boston Harbor area was submerged from the rising seas that occurred during the Holocene Epoch about 8,000 to 2,500 years ago. As sea level rose, glacial drift deposits were reworked and re-deposited throughout much of the harbor. Beach and tombolo deposits formed around the harbor islands by long-shore transport of sand and gravel from the eroding drumlin cliffs.

Recent deposits of estuarine silts, clays, and amorphous organic matter overlie the re-worked glacial-drift deposits. Much of this sediment that is accumulating in the harbor is derived from erosion of the shorelines of the drumlin landforms that constitute the Boston Harbor Islands and from the erosion of mainland by tidal processes. This sediment is currently being deposited in the quiet-water depositional areas in Boston Harbor such as Quincy, Dorchester, and Hingham Bays.

Hydrologic System

The hydrology of each of the six Boston Harbor Islands is characterized as hydraulically independent freshwater-flow systems that consists of about 10 to 30 ft of weathered till, which contains a dense substratum near land surface that may perch water. This weathered till is underlain by about 20 to 100 ft of dense, homogeneous drumlin till that is in turn underlain by about 5 ft of fractured metasedimentary bedrock. Each island also contains unconsolidated beach-type deposits that surround the till and form the shorelines of the islands. The freshwater-flow systems of each island are laterally separated from one another by the saline Boston Harbor. Each freshwater-flow system is underlain by either bedrock or saltwater.

The sole source of freshwater to each of these island flow systems is the infiltration of precipitation into the soils of each island. The amount of precipitation that actually reaches the saturated zone (recharge) varies spatially and temporally in response to climatic and biologic factors (evapotranspiration), and topographic factors. Recharge rates also are affected by local differences in the infiltration capacity and other hydraulic properties of the materials in the unsaturated zone.

Estimates of recharge rates to the ground-water-flow systems of the Boston Harbor Islands were assumed from previous investigations in similar hydrogeologic settings because of the lack of hydrologic data available for the Harbor Islands. Recharge rates are assumed to range from as high as nearly 2 ft/yr to as low as several inches per year (Peragallo, 1989). The crests of the drumlin islands are assumed to receive most of the recharge because of (1) the infiltration rates and hydraulic conductivity values reported by the Soil Conservation Service for the modern soils on the crests are higher than the soils on the slopes (Peragallo, 1989), (2) the absence of well-developed stream channels indicates that most precipitation available as recharge infiltrates into the thick upper weathered till zones on the crests, and (3) the topography of the top of the crests is less steep than that of the sides, and therefore, the potential for surface and subsurface runoff would be less than the steep-till slopes of the actively eroding sea cliffs that fringe the drumlin islands.

Ground water moves through the drumlin-island flow systems from areas of high to areas of low water-table altitude. Ground-water flow generally is radial from the center of the island toward the coast. Topographically high areas, such as the crests and upper slopes, are recharge areas with downward vertical gradients. Ground-water discharge typically occurs along the coast and at topographically low areas such as coastal ponds and marshes. Lower-slope areas on the drumlin islands also are discharge areas. Upward gradients were measured beneath the lower slopes of drumlins by Pietras (1981) and Mullaney and others (1992) indicating that these lower slopes are areas of potential ground-water discharge, particularly if the depth to bedrock is shallow. Therefore, the depth to the water table below land surface would most likely be more shallow on the lower slopes of the drumlin islands than on the crests. The presence of ground-water seeps or springs in small depressions in the lower-slope areas during wet periods, when the position of the water table would be highest, would support the assumption that the water table is closer to land surface in the lower-slope areas than at the crests of the drumlins; however, existing hydrologic data from the harbor islands does not support this assumption.

The water-table configuration is assumed to mimic the general shape of the drumlin island, yet the altitude of the water table is lower than land surface. Annual water-table altitudes can fluctuate substantially as a result of seasonal changes in aquifer recharge. The highest water-table altitudes would be expected during the winter and early spring when precipitation rates are high and evapotranspiration rates are low. Fluctuations in the water-table altitude can vary in magnitude within each flow system and are expected to be greater near the center of the island than the coast because a nearly constant sea level has a dampening effect on ground-water levels near the coast.

Hydraulic Properties

Little published data are available on the hydraulic properties that control ground-water flow in surface and drumlin till ground-water-flow systems and information is not available on the hydraulic properties of the Boston Harbor Island aquifers. A compilation of measurements of hydraulic conductivity, porosity, and specific yield for analogous till deposits in southern New England by Melvin and others (1992) shows a wide range in reported values of hydraulic properties of tills. Hydraulic conductivity varies by as much as four orders of magnitude for tills (0.0028 to 65 ft/d). Although this wide range in values does not distinguish between weathered (surface) tills and the underlying drumlin tills, values at the upper end of this range generally are assumed to represent weathered tills. In addition, these values only represent a range in values indicative of the till matrix and do not represent the secondary hydraulic conductivity that may occur due to jointing and fracturing, which may substantially increase the hydraulic conductivity of a till deposit.

The drumlin-till deposits of the Boston Harbor Islands exhibit physical features that could result in hydraulic anisotropy. The compact drumlin tills, for example, have a near horizontal fissility related to grain fabric, which could result in a greater horizontal to vertical hydraulic conductivity ratio. However, vertical fracturing and jointing also is common in these till deposits and would result in preferential vertical flow. Torak (1979) concluded that tills in eastern Connecticut were anisotropic on the basis of laboratory-determined values of horizontal hydraulic conductivity that were about an order of magnitude greater than vertical hydraulic conductivity. A comparison of laboratory-determined values of horizontal and vertical hydraulic conductivity of till samples derived from drumlin tills (Melvin and others, 1992) indicates that the horizontal and vertical hydraulic conductivities were similar.

Data on other hydraulic properties of southern New England tills compiled by Melvin and others (1992) include porosity and specific yield. Porosity ranged from 22 to 41 percent with a median of about 35 percent, whereas specific yield for the same tills ranged from 4 to 31 percent (Melvin and others, 1992).

Flow-Model Analysis

The position of the water table relative to land surface is an extremely important consideration in selecting sites for water-supply development given the difficulties associated with drilling in till material and the maximum depth at which typical low-yield suction ("pitcher") pumps can be productive. However, the depth to water is impossible to estimate on each of the Harbor Islands based on the available hydrologic data. Therefore, a simplified two-dimensional cross-sectional ground-water-flow model was developed to incorporate representative aquifer dimensions, aquifer boundaries, and hydraulic properties of a typical drumlin island to approximate the position of the water table relative to an assumed land surface.

The conceptual model of the typical drumlin-island flow system assumes that the total length of the island is 2,400 ft and the total height is 130 ft. The flow system is bounded laterally by saltwater where the freshwater heads are specified as zero feet. The lower boundary of the model was set at 5 ft below sea level to coincide with the upper contact of unweathered bedrock. The weathered till was assumed to be 30 ft thick at the crest of the drumlin and 10 ft thick on the slopes. The underlying compact drumlin till was assumed to range from about 20 ft thick near the coast to 100 ft thick near the crest of the drumlin. Beach-type deposits on the lower slopes of the drumlin near the coast were assumed to be from 5 to 20-foot thick. A 5-foot-thick zone of weathered bedrock is assumed to exist between the overlying glacial deposits and the underlying metasedimentary bedrock (fig. 5).

The recharge rate used in the cross-sectional flow model was varied spatially to account for changes in the topography of the drumlin. Recharge rates were assumed to be highest (18 in/yr) at the crest of the drumlin and in the lower-slope beach-type deposits. The recharge rates on the upper steep slopes of the drumlin where the potential for surface and subsurface runoff is greatest were set at 6 in/yr, which is consistent with Morrissey (1983) for other New England tills.

The hydraulic properties of a typical drumlin island flow system were estimated from the available data compiled in Melvin and others (1992). These hydraulic properties were assumed to represent typical values of till and weathered rock in New England; however, data were not available specifically for the Harbor Islands. The estimated horizontal hydraulic conductivities were 25 ft/d for the upper, weathered till zone; 75 ft/d for the beach-type deposits; 0.06 ft/d for the compact drumlin-till zone; and 5 ft/d for the underlying weathered-bedrock zone.

The results of the cross-sectional model indicate that nearly all the saturated part of the drumlin-island flow system is in the compact drumlin till, beach-type deposits, and the underlying weathered-bedrock zone (fig. 5). The upper weathered till, where most of the recharge to the flow system is occurring, is predominantly unsaturated, except for the lower-slope zones near the coast. Ground-water flow is predominantly vertical in the drumlin till because of the low horizontal hydraulic conductivity (0.06 ft/d) of these deposits. Ground-water flow is nearly horizontal in the more permeable, underlying weathered rock zone as ground-water discharges toward the beach-type deposits at the coast. At the coast, ground-water flow discharges upward in the beach-type deposits to the surrounding saltwater of the Boston Harbor (fig. 5).

For this investigation, it was assumed that drawing water from a standard "pitcher" pump would be most efficient at a depth to water less than 20 ft below land surface; therefore, the results of the cross-sectional model were used to estimate approximate locations on each island where the depth to water may be less than 20 ft. The calculated depth to water exceeds 20 ft below land surface at distances greater than 240 ft from the coast and the calculated depth to water is as great as 90 ft below land surface near the crest of the drumlin (fig. 5). Areas where the calculated depth to water is less than 20 ft below land surface generally coincide with the high-hydraulic-conductivity zones of beach-type and weathered till deposits on the fringes of each drumlin island. Although the cross-sectional flow model assumes a location of the freshwater-saltwater interface, it is beyond the scope of this investigation to predict the effects of ground-water withdrawals on the position and movement of this interface and whether withdrawals from these areas will be affected from saltwater intrusion.

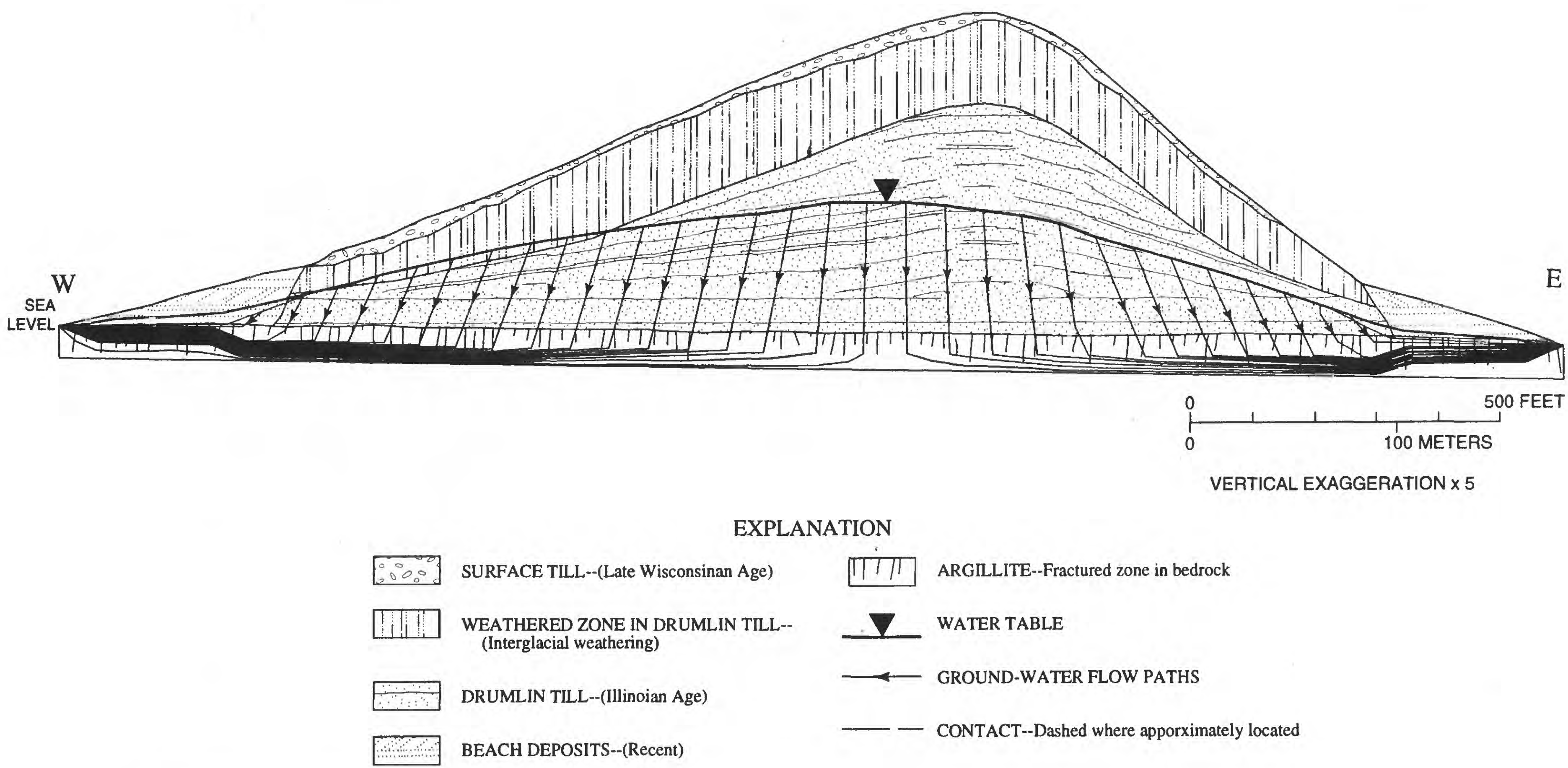


Figure 5. Generalized section of a drumlin island and simulated water table and flow paths.

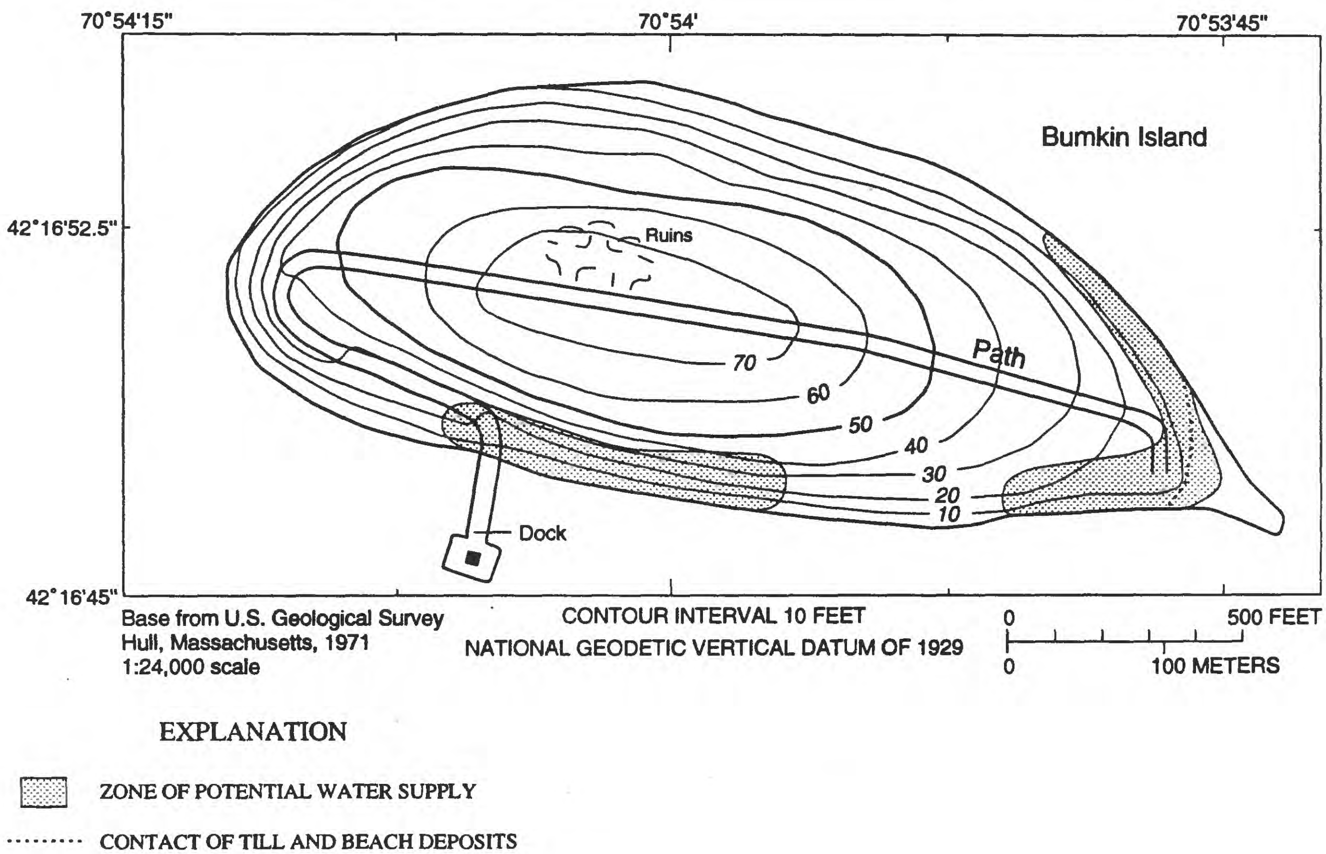
POTENTIAL WATER-SUPPLY DEVELOPMENT

Sources for potential water supply for the Boston Harbor Islands include the development of a supply from the large-diameter dug wells that already exist on several islands and the development of new sources at locations selected as part of this hydrogeologic investigation.

Dug wells were located on four of the six islands of interest. Wells that appeared to be functioning as of July 1995 were located on Georges, Gallops, and Peddocks Islands. However, the wells on Peddocks Island, along the southeastern side of the fourth lobe, were privately owned and, therefore, not accessible to the public. A dug well also was located on Grape Island; however, the well was dry at the time of the investigation (July 1995) and the potential for water supply could not be evaluated. Of the remaining two islands, Lovell Island is reported to have a well on it, but it could not be located; Bumpkin Island does not have any wells.

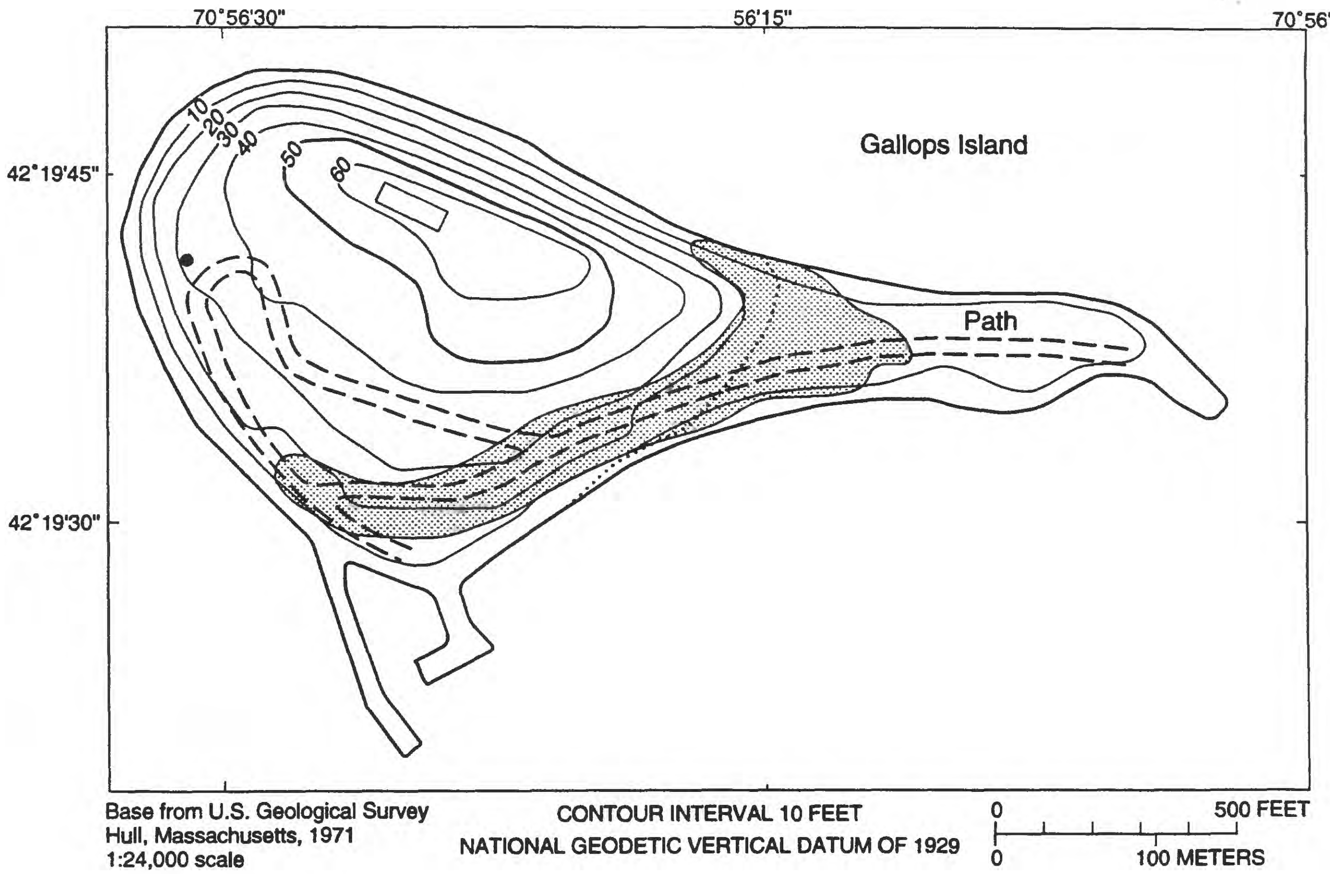
Although functional wells are present on at least one-half of the islands of interest, information is not available on the well design, specific capacity (well discharge per foot of drawdown), or the quality of water for any of the wells. Aquifer tests conducted at each of these wells will determine the well productivity, and water-quality analyses conducted at each of these wells will help determine the potability of the water.

In addition, water-supply sources could be developed to augment the existing dug wells. Zones with the greatest potential for low-yield water-supply development were selected for each of the six islands. The criteria used for the selection of these zones was based only on the model results and the surficial geology of the islands, and did not account for the water quality. As a result, these zones may be productive in terms of water quantity, yet the quality of the water may be unsuitable for human consumption due to excessive salinity or contamination from past human activities on the islands. The zones with the greatest potential for water supply are typically at the base of the drumlins and coincide with the high-transmissivity zones in stratified-beach and weathered till deposits where the depth to water generally is less than 20 ft and ground-water discharge and surface and subsurface runoff occurs (figs. 6 *A-F*).



A. Bumkin Island

Figure 6. Contact between till and beach deposits and zones of potential water-supply sources for each of the six Boston Harbor Islands, eastern Massachusetts.



EXPLANATION

ZONE OF POTENTIAL WATER SUPPLY

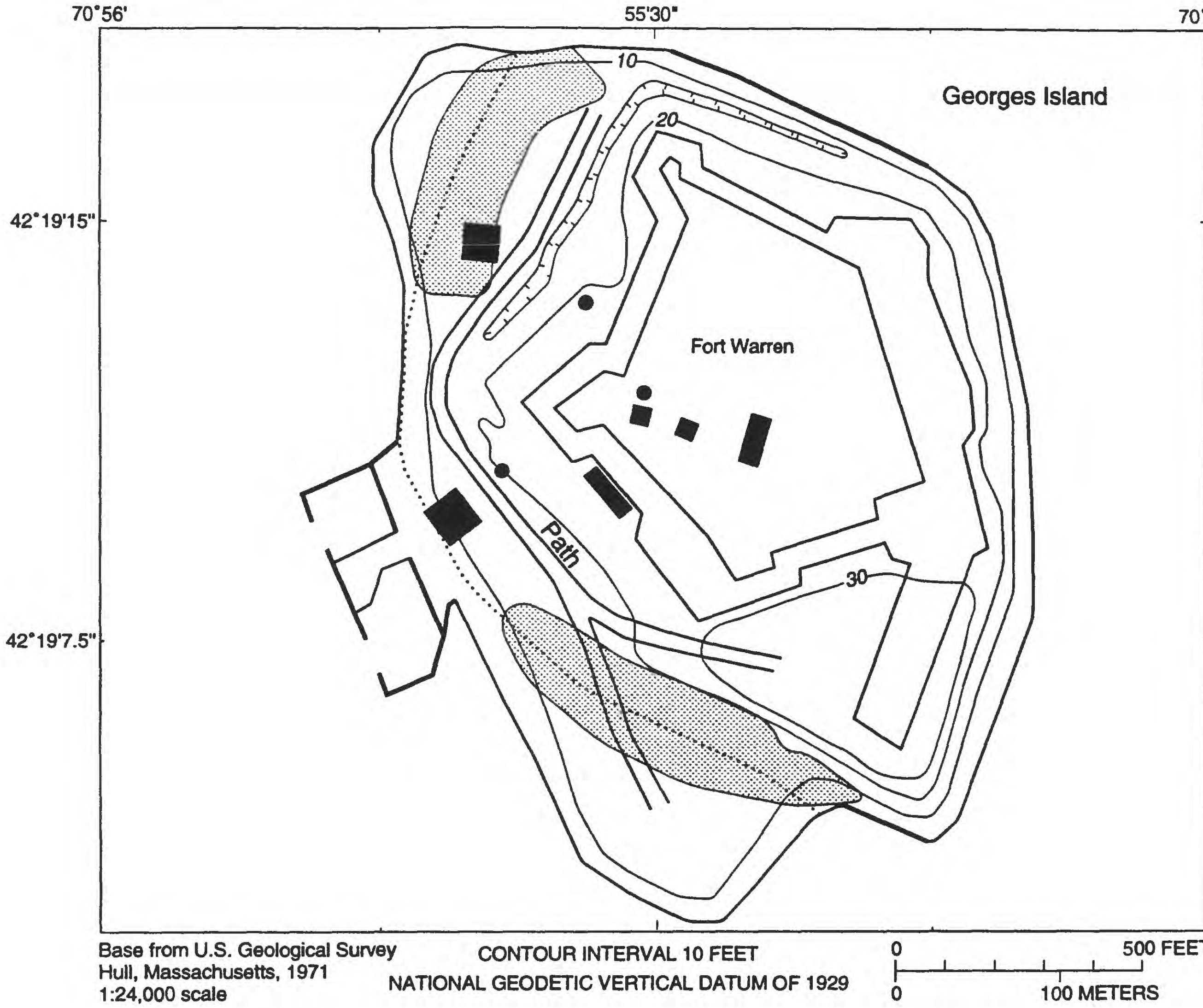
CONTACT OF TILL AND BEACH DEPOSITS

DUG WELL

***B.* Gallops Island**

Figure 6.—*Continued*

Pitcher wells developed in these zones should provide adequate well yields (several gallons per minute) for limited, intermittent water supplies. Aquifer tests would be required to determine whether these zones could support large-capacity water-supply wells. Though obtaining water from the underlying weathered-rock zone may be possible, information is not available on thickness of the freshwater lens or the position of the freshwater-saltwater interface beneath the drumlin islands. Therefore, the effect of a pumping stress on the position and movement of the freshwater-saltwater interface cannot be assumed and as a result, water-supply development in the weathered rock zone is considered less desirable than the overlying beach-type and weathered-till deposits.



EXPLANATION

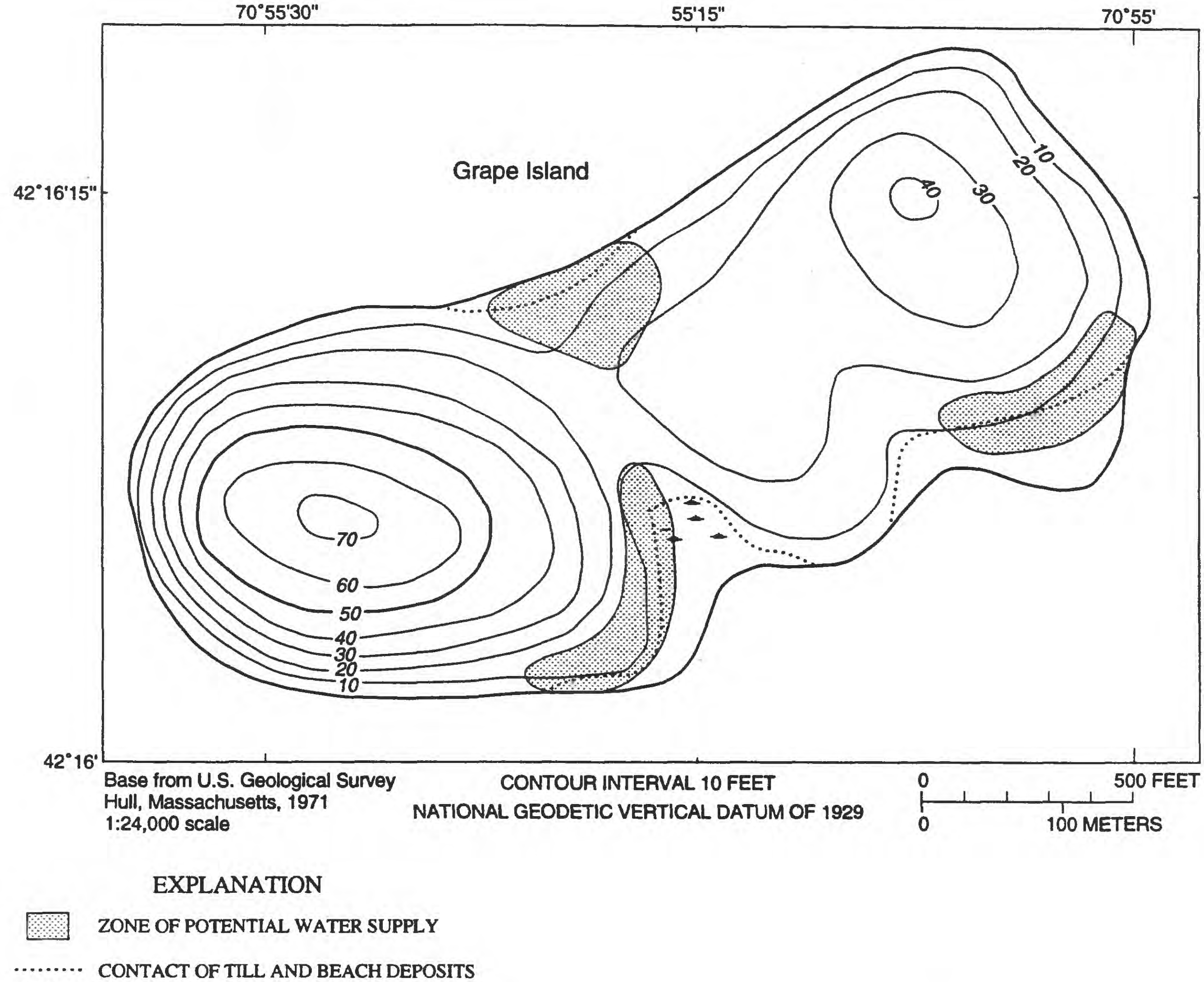
ZONE OF POTENTIAL WATER SUPPLY

CONTACT OF TILL AND BEACH DEPOSITS

DUG WELL

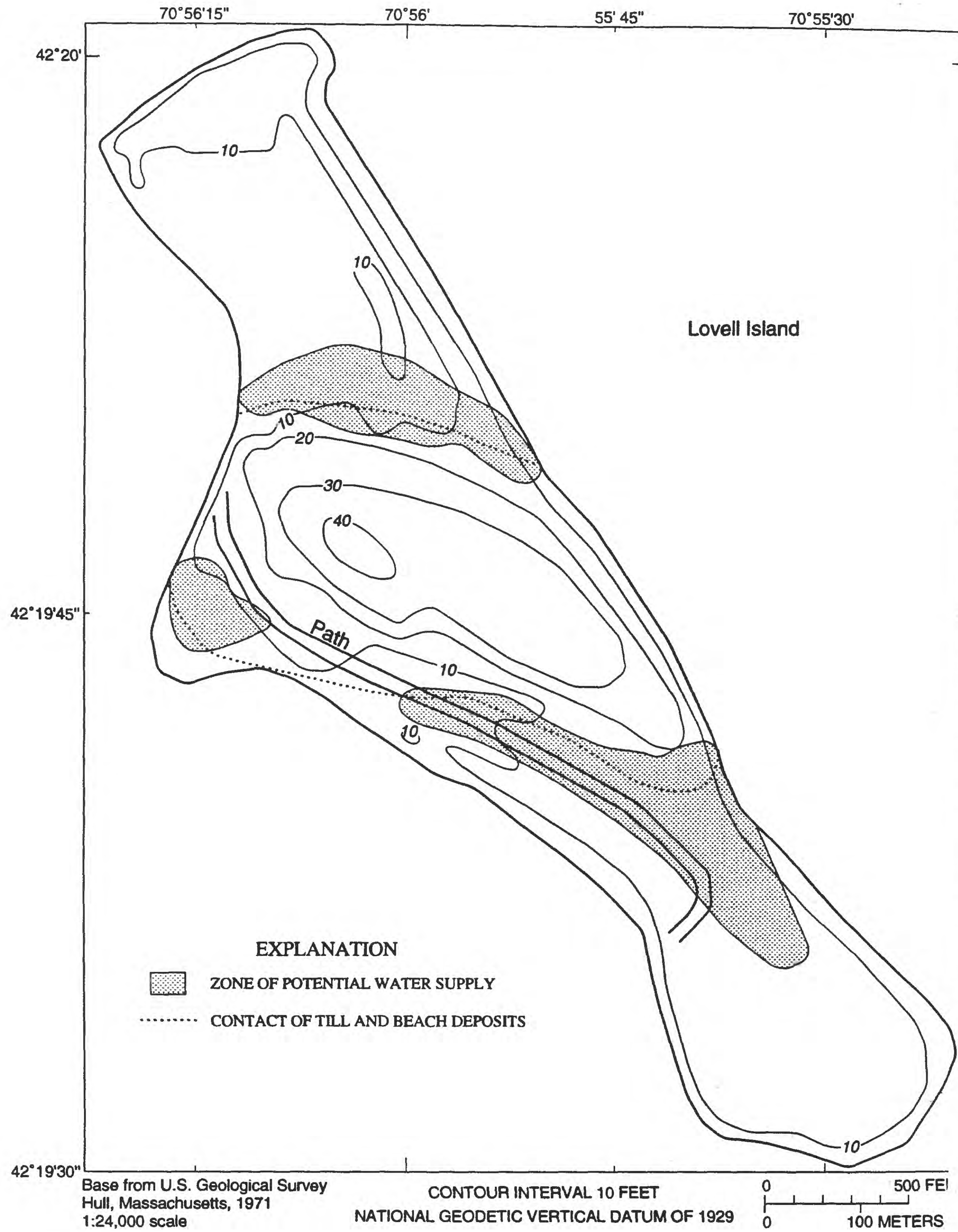
***C.* Georges Island**

Figure 6.—*Continued*



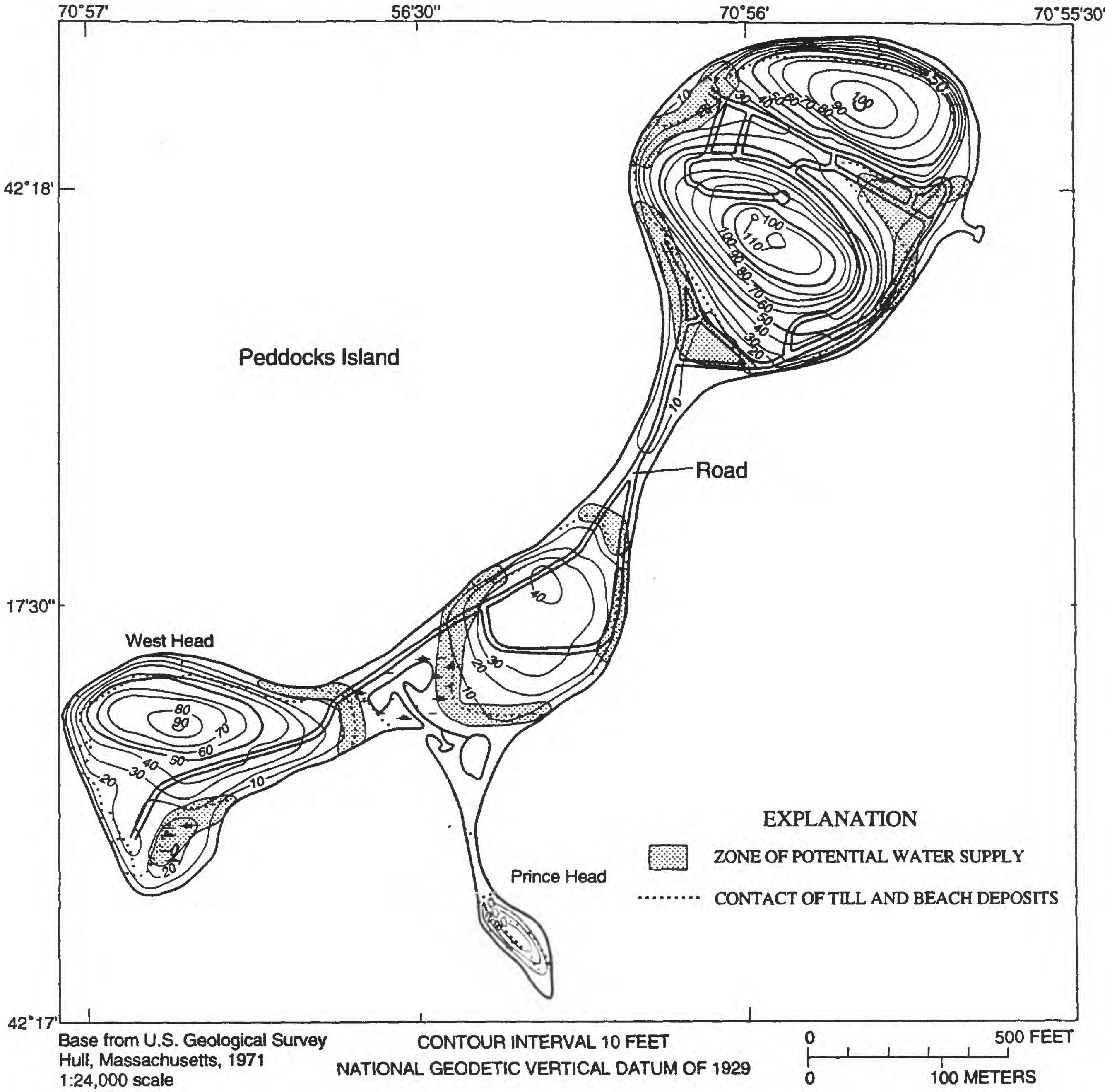
***D.* Grape Island**

Figure 6.—*Continued*



***E.* Lovell Island**

Figure 6.—*Continued*



F. Peddocks Island

Figure 6.—*Continued*

SUMMARY AND CONCLUSIONS

The Boston Harbor Islands are part of a larger group of glacially deposited drumlins, which are composed of thick, dense, homogeneous till in the core that are overlain by a thin layer of stratified beach deposits. The Massachusetts Department of Environmental Management and the Metropolitan District Commission currently oversee the operation and maintenance of the State parks on 6 of these 31 islands that are in the Boston Harbor. These agencies are currently evaluating the possibility of developing a permanent small-capacity water supply to support recreational activities, such as camping, hiking, and swimming for each of these islands including Bumkin, Gallops, Georges, Grape, Lovell, and Peddocks Islands.

The Boston Harbor Islands have been variously and extensively utilized since the 1600's. The islands were originally used to support fishing and farming communities during colonial times. During the 19th century, the islands were used for military installations, hospitals, sand and gravel mines, quarantine stations, and immigration stations. During the early 20th century, the islands have been used for schools, hospitals, and garbage dumps. The islands currently are used by the public for various recreational activities.

The surficial materials that overlie the weathered-bedrock surface in the Boston Harbor area were deposited by continental ice sheets that covered New England twice during the late Pleistocene Epoch, and by near-shore processes in the Holocene Epoch. The thickness of these materials where present range from less than 1 to about 300 ft. The surficial materials are divided into two broad categories: till and stratified deposits. Till was deposited by glacial ice and is characterized as a nonsorted matrix of sand, silt, and clay with variable amounts of stones and large boulders. Stratified deposits primarily consist of sorted and layered sand and gravel that accumulated and formed the beaches and tombolos of the harbor islands. These deposits overlie the till at altitudes generally less than 10 ft above sea level.

A cross-sectional ground-water-flow model was developed for a hypothetical drumlin-island flow system, which was assumed to be representative of the drumlin islands in the Boston Harbor. The results of the cross-sectional model indicate that nearly all the saturated part of the drumlin- island flow system is in the compact drumlin till, beach-type deposits, and the underlying weathered-bedrock zone. The upper weathered till, where most of the recharge to the flow system is occurring, is predominantly unsaturated except for the lower-slope zones near the coast. Ground-water flow is predominantly vertical in the drumlin till due to the low hydraulic conductivity (0.06 ft/d). Ground-water flow is nearly horizontal in the more permeable, underlying weathered rock zone as ground-water discharges toward the beach-type deposits at the coast. At the coast, ground-water flow discharges upward in the beach-type deposits to the surrounding saltwater of the Boston Harbor.

Areas in each island flow system with the greatest potential for small-capacity water-supply development were identified on the basis of model-calculated depth to water and the surficial geology of the islands. The model results indicate that the simulated depth to water is less than 20 ft below land surface within 240 feet from the shore. This area roughly coincides with the high transmissivity zones of the stratified-beach deposits and the lower slope zone of the weathered till where ground-water discharge, and surface and subsurface runoff occurs.

Although functional wells already exist on at least one-half of the islands of interest, information does not exist on the well design, specific capacity (well discharge per foot of drawdown), or the quality of water for any of the wells. Aquifer tests conducted on each of these wells would provide information on the well productivity, and water-quality analyses conducted at each of these wells would assist in determining the potability of the water in these wells.

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