Attachment M

HDD and Aquifer Memo

Memo

To:	Kenneth Fitzgerald, P.E. Stantec	From:	Donald Moore, P.G. Stantec – Auburn, NH
File:	198804104	Date:	March 27, 2023

Cc:

Reference: **Avangrid Renewables – Commonwealth Wind Project / Analysis of Potential HDD Impacts to Aquifer at Dowses Beach, Barnstable, MA**

Avangrid Renewables requested Stantec evaluate whether the proposed horizontal directional drill (HDD) installation required for the landfall of the Commonwealth Wind Project subsea cables would impact the aquifer at the proposed landing site at Dowses Beach in the Osterville village section of Barnstable, MA. To evaluate this issue, Stantec conducted a desk top review of State and Local resources, including surficial geologic maps, Town zoning maps and ordinances, as well as the draft geotechnical reports in the vicinity of the installation.

In terms of the designation of aquifer, it is important to note that the entire land mass of Cape Code is designated as the Cape Cod Aquifer. It has been determined by the US EPA that the Cape Cod aquifer is the sole or principal source of drinking water for Cape Cod. The boundaries of this aquifer are Cape Cod Canal, Cape Cod Bay, the Atlantic Ocean, Nantucket Sound, and Buzzards Bay. Therefore, Dowses Beach is a part of the Cape Cod Aquifer.

It is also important to note that the term aquifer has various definitions. A simple definition is that an aquifer is a saturated geologic formation capable of transmitting water. The geologic sediments of the Cape are comprised primarily of sands and gravels that were deposited from glacial melt water and are described as Glacial Stratified Deposits. The thickness of these deposits have been determined to range from 200 to over 600 feet in the interior areas of the Cape. The aquifer is 100% recharged from infiltration of rainwater and snow melt. The sediments at Dowses Beach are shown on the attached Geologic Map of the Hyannis Quadrangle as Beach Deposits. These deposits are described as wave-eroded glacial deposits that are sorted, transported, and redeposited to form spits and beaches. This depositional environment or activity occurred after glacial retreat (i.e., Post-Glacial).

A more comprehensive definition is that an aquifer is a subsurface geologic formation that contains sufficient saturated permeable material that can yield significant quantities and qualities of water to wells and springs. Throughout the Cape there are areas where the Glacial Stratified Deposits contain more gravel sized particles and are more transmissive. These areas have typically been developed as public water supply wells and/or well fields.

Important characteristics in determining the yield of an aquifer are hydraulic conductivity, saturated thickness, and transmissivity. Hydraulic conductivity is a measure of the capacity of a porous medium to transmit water. In general, hydraulic conductivity values range from about one to a few hundred feet per day (ft/day) for fine to course sands and from about 1,000 to over 100,000 ft/day for gravels. Saturated thickness is the vertical thickness of the aquifer, typically the distance from the water table to the bottom of the aquifer (usually on bedrock or a confining layer such as till.) Transmissivity, which is a function of hydraulic conductivity and saturated thickness, is a description of the capability of the entire thickness of the aquifer to transmit water.

To further this analysis of aquifer, the attached Zoning Map of the Osterville section of Barnstable shows that Dowses Beach is designated as Aquifer Protection Overlay District (AP), with a note that AP is all other areas not identified as Wellhead or Groundwater Protection Overlay Districts. The underlying zoning district is show as RF-1 (single family residential). This AP zoning is consistent with the description of the Cape Cod Aquifer above.

The zoning map also shows that there are three existing public water supply wells located approximately 1.5 miles to the northwest. These wells, designated as C-O AR #3,4, C-O MC #2, and C-O #10, fall within the Wellhead Protection Overlay District (WP). WP is based on a five-year time of travel to existing, proven future and potential future public supply wells.

Surrounding the WP is the Groundwater Protection Overlay District (GP). The GP is based on Zone II delineations to existing, proven future and potential future public supply wells. A Zone II is defined as "That area of an aquifer which contributes water to a well under the most severe pumping and recharge conditions that can be realistically anticipated (i.e., 180 days of pumping at safe yield, with no recharge from precipitation). It is bounded by the groundwater divides which result from pumping the well and by the contact of the aquifer with less permeable materials such as till or bedrock. In some cases, streams or lakes may act as recharge boundaries. In all cases, Zone IIs shall extend up gradient to its point of intersection with prevailing hydrogeologic boundaries (a groundwater flow divide, a contact with till or bedrock, or a recharge boundary)." Zone IIs have been determined by hydrogeologic modeling and approved by the Massachusetts Department of Environmental Protection's (DEP Drinking Water Program (DWP).

The zoning map shows the area of aquifer contributing water to this well field extends primarily to the northwest. It shows that Dowses Beach is not within the Zone II or GP. In other words, any fresh water located underneath Dowses Beach is not supplying the public wells or the aquifer surrounding and contributing water to the wells.

An analysis of the data presented in the draft geotechnical reports further shows that the sediments underlying Dowses Beach are not comprised of a "sufficient saturated permeable material that can yield significant quantities and qualities of water to wells and springs." Three soil borings were advanced at the Dowses beach location. These include B-OTC1-01, B-JOINT-01, and B-JOINT-02. The boring logs show the subsurface materials are primarily comprised of fine to medium sands. Thin layers of fine to coarse gravels were encountered at B-JOINT-01 (from 7 to 8 feet below ground) and at B-JOINT-02 (from 9.5 to 14.5 and 17.0 to 19.5 feet below ground).

The sieve analyses/gradation curves presented in the reports and utilized for geotechnical purposes can also be used to estimate the hydraulic conductivities of the sediments encountered.

The relationship between conductivity and grain size requires the choice of a representative grain-size diameter (Freeze and Cherry, 1979). A simple, and apparently durable, empirical relation is described by the formula:

$K = A(d_{10})^2$

where:

K: Hydraulic conductivity in cm/s.
d_{10}: The grain-size diameter, in mm, at which 10% by weight of the soil particles are finer and 90% are coarser. The d_{10} value is taken directly from the gradation curves.
A: A constant; for K in cm/s and d_{10} in mm, the coefficient A is equal to 1.0.

As shown in the attached Table 1, the d10 fraction was able to be calculated directly from the majority of gradation curves. A few of the curves were extrapolated as shown to determine the d10 fraction.

The calculated hydraulic conductivities, based on grain-size distribution, are also listed in Table 1. This method calculated conductivities in the sandy sediments from 12 ft/day to 93 ft/day. The calculated conductivity of the gravel sediments encountered in B-Joint-02 was 359 ft/day. These relatively low conductivity values further support the conclusion that the sediments underlying Dowses Beach are not comprised of a “sufficient saturated permeable material that can yield significant quantities and qualities of water to wells and springs.”

In conclusion, the analysis undertaken of the available data indicates that although the sediments underlying Dowses Beach are part of the Cape Cod Aquifer, they are not a contributing part of the aquifer to nearby public water supply wells. Therefore, the proposed HDD work will not negatively impact the nearby wells or the aquifer contributing water to those wells.

Construction of each HDD will entail drilling a series of progressively larger diameter bores to allow a nominal 32-inch High Density Polyethylene (HDPE) casing to be pulled through the alignment. The HDPE casings serve as conduit for landing the subsea cables. A drilling fluid, comprised of a bentonite (non-toxic clay) and water viscous slurry, will cool the drill bit, support the walls of the bore, and transport cuttings out of the bore and into a drilling pit located adjacent to the drill rig in the Dowses Beach Parking lot. The cuttings are removed, and the drilling fluid is recirculated. Earthen berms will be installed around the construction work to contain fluids aboveground. The viscous nature of the fluid inhibits it from migrating from the bore and from the drilling pit into the surrounding sediments. After the HDD is completed, the drilling fluids are pumped from the pit and properly disposed off-Site.

I hope this meets your needs. Please call me at 603-498-3244 if you have any questions.

Sincerely,

STANTEC CONSULTING SERVICES INC.

Donald F. Moore

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TABLE 1
Sieve Sample/Conductivity Results
Dowses Beach Borings

Location	Type of Test	Material	Sample Depth (ft BLS)	% Gravel	% Sand	% Silt & Clay	d_{10}[1]	Hydraulic Conductivity (K)	
								(cm/sec)[2]	(ft/day)
Shallow Overburden									
B-OTC-01	Sieve Analysis	F - C SAND	5.0 - 7.0	0.7	97.0	2.3	0.1451	2.1E-02	59.7
B-OTC-01	Sieve Analysis	F - M SAND & SILT	11.0 - 13.0	0.0	58.6	41.4	0.0123	1.5E-04	0.4
B-OTC-01	Sieve Analysis	F - M SAND	16.5 - 17.5	0.0	93.6	6.4	0.0887	7.9E-03	22.3
B-OTC-01	Sieve Analysis	SANDY SILT	20.5 - 21	0.0	11.8	88.2	0.0088	7.7E-05	0.2
B-OTC-01	Sieve Analysis	F - M SAND	24.5 - 25	0.1	96.8	3.1	0.1245	1.6E-02	43.9
B-OTC-01	Sieve Analysis	SILT	40 - 42	0.2	25.6	74.2	**0.0060**	3.6E-05	0.1
B-OTC-01	Sieve Analysis	SILT	65 - 67	0.0	29.8	70.2	0.0056	3.1E-05	0.1
B-JOINT-01	Sieve Analysis	F - C SAND	12.5 - 13.5	21.8	73.3	4.9	0.1577	2.5E-02	70.5
B-JOINT-01	Sieve Analysis	F - C SAND	16.5 - 17.0	20.1	72.4	7.5	0.1633	2.7E-02	75.6
B-JOINT-01	Sieve Analysis	F SAND & SILT	24.5 - 25	0.0	56.7	43.3	0.0213	4.5E-04	1.3
B-JOINT-01	Sieve Analysis	F SAND	35 - 37	0.3	84.0	15.7	**0.0650**	4.2E-03	12.0
B-JOINT-01	Sieve Analysis	SILT	50 - 52	0.0	6.5	93.5	0.0069	4.8E-05	0.1
B-JOINT-01	Sieve Analysis	F - M SAND & SILT	53.5 - 54	0.0	50.7	49.3	0.0110	1.2E-04	0.3
B-JOINT-01	Sieve Analysis	F - M SAND	65 - 67	0.4	73.2	26.4	**0.0320**	1.0E-03	2.9

TABLE 1
Sieve Sample/Conductivity Results
Dowses Beach Borings

								Hydraulic Conductivity (K)	
Location	Type of Test	Material	Sample Depth (ft BLS)	% Gravel	% Sand	% Silt & Clay	d_{10}[1]	(cm/sec)[2]	(ft/day)
B-JOINT-02	Sieve Analysis	F - M GRAVEL	8.5 - 9.0	0.0	98.8	1.2	0.1815	3.3E-02	93.4
B-JOINT-02	Sieve Analysis	F - C SAND & GRAVEL	13.5 - 14.0	61.4	36.0	2.6	0.3560	1.3E-01	359.3
B-JOINT-02	Sieve Analysis	F SAND & SILT	23.5 - 24.0	0.0	67.0	33.0	0.0340	1.2E-03	3.3
B-JOINT-02	Sieve Analysis	F - M SAND	28.5 - 29.0	0.0	99.0	1.0	0.1280	1.6E-02	46.4
					AVERAGE SHALLOW OVERBURDEN			1.6.E-02	44.0

1 = d10 values in **bold** derived by extrapolating the gradation curve. High percentage of fines prevents calculation of D10 with this method.

2 = $K = A(d_{10})^2$: (Freeze and Cherry, 1979)
A = 1

DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY

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COMMONWEALTH OF MASSACHUSETTS
DEPARTMENT OF PUBLIC WORKS

GEOLOGIC QUADRANGLE MAP
HYANNIS QUADRANGLE, MASSACHUSETTS
GQ-1158

INTRODUCTION

The Hyannis quadrangle (fig. 1) is underlain by glacial sediments deposited by the last ice sheet to cover southern New England. Deposits associated with the Holocene rise in sea level make up most of the remaining sediments.

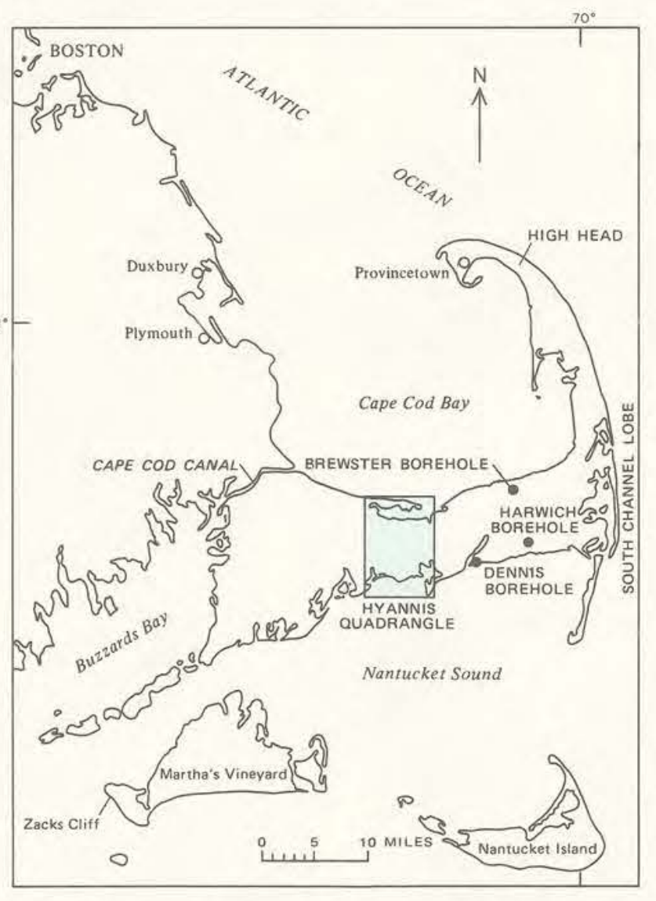

FIGURE 1.—Index map of southeastern Massachusetts showing location of the Hyannis quadrangle and localities and features mentioned in the report.

Subsurface geology is inferred from seismic data (table 1), composition of the drift, and boreholes. The bedrock surface is more than 100 feet below sea level throughout the quadrangle. At Kalmus Park (table 1, site B), bedrock is 525 feet deep, suggesting a bedrock valley. Bedrock lithologies are not known. At Sandy Neck (table 1, site A), however, the 18,000-feet-per-second compressive-wave velocity suggests that bedrock there is probably granitic rock. Trace amounts of glauconite and feldspar in the glacial sands may be derived from preglacial coastal plain sediments of Cretaceous to Pleistocene age, remnants of which may lie beneath the drift.

TABLE 1.—*Seismic data*

		Layer 1		Layer 2		Bedrock
Site	Locality	Thickness (feet)	Velocity (ft/sec)	Thickness (feet)	Velocity (ft/sec)	Velocity (ft/sec)
A	Sandy Neck	310	5,000*	—	—	18,000
B	Kalmus Park	180	5,600*	345	7,650**	21,600***
C	Craigville Beach	362	5,600*	—	—	14,100***

*Interpreted as saturated unconsolidated sediment. Mostly sand with some gravel in the upper part. Possibly silt and clay in the lower part.

**Interpreted as compact basal till.

***Velocity unreliable; line was not reversed.

PLEISTOCENE DEPOSITS

The oldest unconsolidated deposit is represented by layer 2 (table 1), thought to be mostly till (Qt) deposited by the last ice. Sound velocity in this layer is similar to velocities measured on subglacial tills elsewhere in Massachusetts (Oldale and Tuttle, 1965). Layer 2 may also include earlier Pleistocene drifts and possibly preglacial Coastal Plain deposits.

The upper part of layer 1 (table 1) is composed of sandy sediments that make up the surficial deposits. At depth the layer may be clayey silt similar to that encountered in deep boreholes (Koteff and Cotton, 1962, table 3; Maevsky and Drake, 1963).

KAME DEPOSITS

Near the south shore are isolated deposits with surfaces 10 to 50 feet above the surface of the adjacent outwash deposits. They have ice-contact slopes most likely formed before the deposition of the outwash plain. The altitude, the limited areal extent, and the till and large boulders within the deposits indicate that these are kames, possibly formed when the stagnant ice front was slightly south of these features.

BARNSTABLE OUTWASH-PLAIN DEPOSITS

The pattern of restored contours on the precollapse surface of the Barnstable outwash plain, south of the Sandwich moraine, has the form of the surface of a large outwash fan. The fan apex with an altitude of about 90 feet is located just north of Shallow Pond. From there the Barnstable outwash plain slopes gently south toward Nantucket Sound. Many kettle holes and valleys interrupt the graded surface.

MASHPEE PITTED-PLAIN DEPOSIT

The Mashpee pitted plain, named by Mather and others (1942, p. 1151), is a similar large outwash fan with an altitude at its apex of over 220 feet; the surface slopes at a rate of 15-25 feet per mile south and southeast. Only the eastern edge of this fan is present in the Hyannis quadrangle.

SANDWICH MORAINE DEPOSITS

The Sandwich moraine, mapped by Mather and others (1942, p. 1143), extends into the quadrangle, where it forms a prominent ridge well above the other glacial deposits. On the western part of the moraine, large-scale linear features are roughly parallel, or in a few places roughly normal to, the moraine trend. Parallel-trending features may be push ridges formed by advancing ice or accumulations of drift marking minor ice-front stillstands. Ridges trending roughly normal to the moraine may be ice-channel fillings. Near Mary Dunn Road small festoon-shaped ridges can be seen in aerial photographs. Elsewhere the moraine surface consists mostly of many closed depressions and knobs.

HARWICH OUTWASH-PLAIN DEPOSITS

The ice-contact head of the Harwich outwash plain lies in the vicinity of Cummaquid, Mass. From there the outwash plain slopes southeast through a gap in the Sandwich moraine in the Dennis quadrangle (Oldale, 1974) and then reenters the quadrangle south of the moraine.

GLACIAL-LAKE DEPOSITS

On the basis of borehole data, clayey silt (Ql1) is inferred beneath the outwash plains and possibly even beneath the Sandwich moraine. This unit is believed to have been deposited in a lake dammed by the retreating ice front and by Martha's Vineyard and Nantucket islands.

Younger glacial-lake deposits (Ql2) overlie moraine and Harwich outwash-plain deposits. These lake deposits have maximum altitudes of 50 to 60 feet. The clayey silt was named the Barnstable Series by Shaler (1898, p. 539), who recognized clayey silt in many places along the Cape Cod Bay shore. He assigned the silt to an older glaciation and thought it to be marine. However, as the clayey silt overlies moraine and outwash deposits, it can not be older than the last glaciation. It must, therefore, be a fresh-water deposit, as sea level at that time was far below its present level.

VALLEY-FLOOR DEPOSITS

Valley-floor deposits occupy valleys, called furrows by Mather and others (1942, p. 1160), which are not now being cut in the outwash plains. The valleys are late-glacial features, as the thalwegs are interrupted by kettle holes and late-glacial eolian deposits cap the valley-floor deposits. These valleys probably were eroded when a shallow layer of permanently frozen ground made the outwash impermeable. They are not melt-water carved, as melt water generally flows in sediment-choked braided streams that completely cross the outwash plain.

LATE-GLACIAL EOLIAN DEPOSITS

The glacial deposits are overlain in most places by a wind-deposited mantle 1 to 3 feet thick. The eolian sand, silt, and wind-cut stones are in places mixed by frost action with the underlying coarser glacial deposits, resulting in a till-like texture.

POST-PLEISTOCENE DEPOSITS

MARSH AND SWAMP DEPOSITS

Salt-marsh deposits lie in the drowned parts of valleys, in kettle holes breached by the sea, and in estuaries protected on the seaward side by spits. Thickness is controlled largely by the altitude of the underlying glacial surface. A maximum thickness of about 30 feet was determined for the Great Marshes by Redfield (1965, p. 54). Radiocarbon dates from the base of the salt-water peat in the Great Marshes range from 3,660 ± 250 years B.P. (Before Present) to 1,040 ± years B.P. (Redfield and Rubin, 1962, p. 1731).

Fresh-water marshes and swamps occur mostly where valleys and kettle holes intersect the water table. Locally, these deposits occur at higher altitudes, where till or silt and clay have caused perched water tables.

BEACH DEPOSITS

Wave-eroded glacial deposits are sorted, transported, and redeposited to form spits and beaches. The most extensive beach deposits form Sandy Neck spit. Growth stages of the spit, taken from Redfield (1965, p. 53), are shown on the geologic map.

DUNE DEPOSITS

Dunes are found on spits and on glacial deposits near the shore. Dune deposits commonly range from a few to 30 feet in thickness, but on Sandy Neck they are as much as 65 feet thick. There, roughly parabolic rows of dune crests are separated by blowouts oriented roughly north-south. Blowouts are floored with younger irregularly shaped dunes. Much of the dune area has been eroded by subsequent wind action, exposing dune bedding and, locally, buried soil horizons. Roots, tree stumps, and, in some places, hearth stones and midden debris of Indian origin are associated with these soil horizons. Most slip faces are stabilized by pine and oak forest. Most active slip faces are along the marsh side of Sandy Neck.

QUATERNARY HISTORY

STRATIGRAPHY OF THE GLACIAL DEPOSITS

The inferred stratigraphic relationships are shown on the correlation chart (table 2). The kames are clearly the oldest surficial unit, because their position is well south of the ice-contact heads of the outwash plains and the Sandwich moraine, and because ice must have occupied the area while the kames were deposited. Exact age relationships between the Barnstable outwash-plain deposits and the Mashpee pitted-plain deposits are not clear, but they are probably contemporaneous. The deposits of both are older than the Sandwich moraine. Harwich outwash-plain deposits overlie the moraine and head north of it. Lake deposits overlying the ice-contact head of the Harwich outwash plain along the shore of Cape Cod Bay are the youngest glacial deposits.

PLEISTOCENE HISTORY

The Hyannis quadrangle deposits probably represent the last glaciation (Woodfordian), as only one basal(?) till (Oldale and Tuttle, 1965) is recognized in the subsurface and the surficial deposits are only locally overlain by till. This till can be accounted for either by minor readvances of the last ice or as flowtill. Older Pleistocene events may be represented at depth, as most of the glacial and interglacial stages have been recognized on Martha's Vineyard (Kaye, 1964) and in Boston (Kaye, 1961, p. B75).

During the last advance, the ice overran and incorporated into the glacial drift older glacial deposits and pre-Pleistocene coastal-plain and shelf sediments. The maximum advance of the ice is marked by the terminal moraine on Martha's Vineyard and Nantucket.

The age of the surficial glacial deposits on Cape Cod is established by two radiocarbon dates. A date (15,300 ± 800 years B.P.) from Zacks Cliff, Martha's Vineyard (fig. 1), was derived from leaves in a clay stratigraphically below ablation till and outwash (Kaye, 1964, p. C138; Schafer and Hartshorn, 1965), and indicates that ice occupied Cape Cod at that time. A date on shells from a glaciomarine clay near Boston (Kaye and Barghoorn, 1964, p. 75) shows that the ice had retreated from Cape Cod Bay by 14,250 ± 200 years B.P.

With about 1,000 years for the retreat of the ice from the islands to the Boston area, retreat across the Hyannis quadrangle must have taken only a few hundred years. Even at this rate, retreat was not uniform and major stillstands occurred when the kame, outwash-plain, moraine, and younger lake deposits were formed. Between stillstands retreat must have been very rapid. Glacier retreat was characterized by lobation, and the lobes, from west to east, were the Buzzards Bay lobe, the Cape Cod Bay lobe, and the South Channel lobe (Woodworth and Wigglesworth, 1934, p. 16). Sediments in the Hyannis quadrangle were deposited by the Cape Cod Bay lobe.

Stagnation and downwasting caused the retreat of the ice from Martha's Vineyard and Nantucket. A proglacial lake formed north of the islands, as shown by the thick section of clayey silt in boreholes (fig. 1) (Koteff and Cotton, 1962; Maevsky and Drake, 1963). Large holes formed in stagnant ice when the front was somewhat south of the quadrangle, and stratified drift was deposited in the holes as kames. As the ice continued to retreat, many ice blocks were buried by outwash and eventually melted to form kettle holes. The Mashpee pitted plain and the Barnstable outwash plain were deposited beyond a stagnant ice front, possibly in a position approximated by the Sandwich moraine.

After the outwash plains formed, a change in the regimen of the glacier resulted in an active ice front with advance essentially balanced by melting, and deposition of the Sandwich moraine took place. At times ice overrode the outwash plains and deformed these deposits. In some places outwash was displaced upward many feet, as suggested by the fine-grained deposits located high on the south-facing slope of the moraine. Glacial till and large boulders were deposited atop the outwash in many places during these advances.

Stagnation followed the formation of the moraine. To the east the ice front retreated a short distance northward before deposition of the Harwich outwash plain took place. In the western part of the quadrangle, the ice may have remained against the Sandwich moraine depositing only a little sediment.

A final stillstand a short distance further north is represented by ice-contact lake deposits. These sediments were deposited in a narrow lake dammed by the moraine and outwash-plain deposits, by high land south of Plymouth (fig. 1) and by the South Channel lobe. Initial lake drainage was probably southwest into Buzzards Bay through a spillway now occupied by Cape Cod Canal (fig. 1). As the ice continued to retreat, the lake greatly increased in size. Deltas on outer Cape Cod (Oldale, 1968) and at Duxbury (fig. 1) (Chute, 1965) were deposited at this time. Final drainage took place when the ice retreated north of High Head (fig. 1).

A periglacial climate and eolian activity followed glacier retreat (Schafer and Hartshorn, 1965, p. 124). Tundra vegetation (Davis, 1967, p. 26) characterized the environment. A permafrost layer prevented water from percolating into the ground, and surface runoff cut the stream valleys. Tundra and possibly permafrost persisted in southern New England until 12,000 years ago (Davis, 1967, p. 26). Eventually a milder climate thawed the permafrost, ending fluvial erosion. The remaining buried ice blocks melted, forming kettle holes and leaving the landscape much as it appears today.

POST-PLEISTOCENE HISTORY

During the maximum glacial advance, sea level was about 400 feet below its present level (Milliman and Emery, 1968, p. 1122). As the glaciers melted, water returned to the oceans and sea level rose. However, in glaciated regions the postglacial change in sea level was not simply upward, for sea level was a result of eustatic rise and crustal rebound. In Boston a late-glacial, relatively high, stand took place around 14,000 years ago. This was followed by a lower-than-present sea level between 12,500 and 10,000 years ago (Kay and Barghoorn, 1964, p. 76). A similar sea-level history probably occurred on Cape Cod, although the late-glacial high remained below present sea level.

Since 10,000 years B.P., relative sea level has risen continuously, but at an ever decreasing rate (Milliman and Emery, 1968, p. 1122). The rate and amount of submergence in the Hyannis quadrangle during the past few thousand years has been determined by Redfield and Rubin (1962, p. 1730). From 3,700 years ago to 2,100 years ago, sea level rose from minus 23 feet relative to present sea level to minus 7 feet. Since 2,100 years ago the rate of sea-level rise has been only one third as much.

As submergence progressed, waves eroded the glacial deposits to form sea cliffs. Eroded material has been transported, sorted, and redeposited by waves and longshore currents to form the beaches, spits, and offshore tidal flats. In areas protected from wave attack, marsh deposits have formed.

The histories of the Great Marshes and Sandy Neck are closely related. The marsh has grown from a few patches of peat, protected by a spit a little over a mile long 3,300 years ago, to a marsh of several square miles behind a spit 6 miles long today (Redfield, 1965).

Sand dunes have formed atop the spits and on the glacial deposits adjacent to the coast. Dunes overlying glacial deposits and smaller spits are probably only a few tens of years old, as they have sparse vegetation and no soil. On Sandy Neck, however, some of the dunes may be as old as the spit, and their history is closely related to the growth of the spit. The bulk of the dunes become progressively younger from west to east, as their formation depended upon the eastward growth of Sandy Neck. Parabolic dune sets appear to mark roughly the former positions of the east end of the spit, as is suggested by the lines showing the formation of the spit taken from Redfield (1965, p. 53). A similar relationship is proposed by Zeigler and others (1965, p. R305) for some of the parabolic dunes on the Provincetown spit. Even though the dunes may range in age from about 3,300 years to modern, they are active along the whole length of the spit today.

Fresh-water swamps and marshes began to form soon after the ice retreated, initially as a result of poor drainage caused by permafrost. Later, as sea level rose, the water table rose, forming shallow ponds in the kettle holes and ground-water streams in the dry valleys. Swamps and marshes began to grow along the shores of these water bodies and eventually filled the bottoms of the kettle holes and furrows locally.

APPLIED GEOLOGY

The glacial deposits make up the major mineral resource and provide an ample source of sand and gravel, as well as large boulders for riprap. Glacial silt and clay were once used to make bricks. Permeable glacial deposits provide abundant ground water. However, any great increase in ground-water usage, a decrease in the recharge, or the discharge of used ground water to the sea by outfalls might lower the water table, dry up swamps and shallow ponds, and reduce the size of deeper ponds. Another potential threat to this resource is contamination of the water supply by improper disposal of waste products.

Major geological hazards are the susceptibility of low-lying nearshore areas to coastal flooding and to wave erosion during northeast storms and hurricanes. Erosion and flooding along the Nantucket Sound shore during the September 1944 hurricane have been described by Chute (1946). Coastal flooding of as much as 10 feet above mean sea level occurred. Shore erosion resulted in retreat of the shoreline by as much as 40 to 50 feet where the prestorm beach was narrow and the sea cliffs were low.

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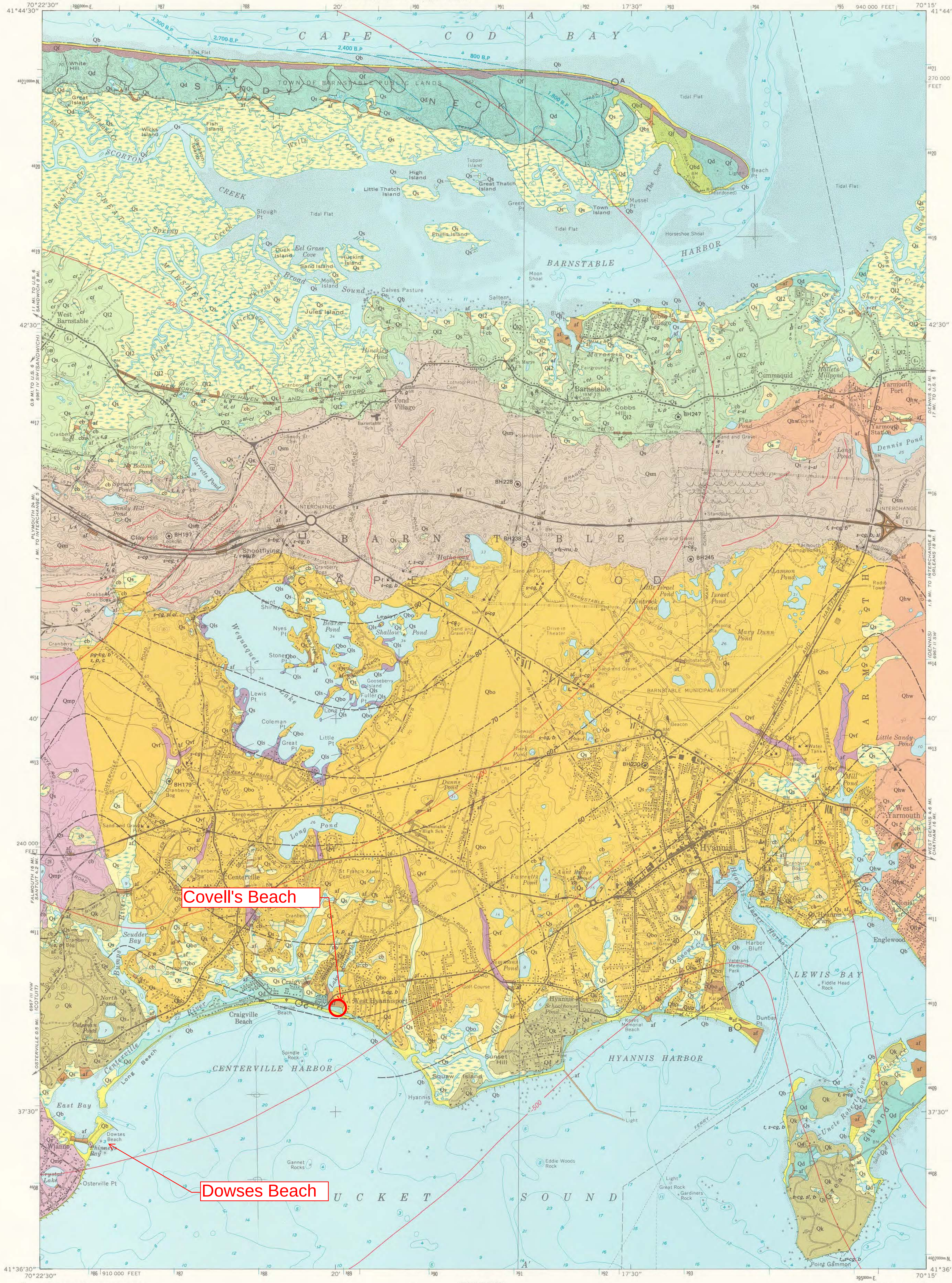
TABLE 2.—*Correlation chart showing stratigraphic relationships of the glacial deposits between the Hyannis quadrangle and adjacent areas of inner Cape Cod*

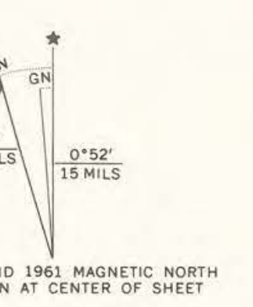
Time units	Surficial deposits		Subsurface deposits
	Hyannis quadrangle	Inner Cape Cod	Inferred
Pleistocene (Woodfordian)	Younger glacial-lake and ice-contact deposits	Lake deposits and lake-bottom deposits (Oldale, 1969a)	
	Harwich outwash-plain deposits	Harwich outwash-plain deposits (Oldale, 1969a)	
		Kame deposits (Oldale, 1974)	
	Sandwich moraine deposits	Sandwich moraine (Mather and others, 1942) Sandwich moraine deposits (Oldale, 1969a)	
		Buzzards Bay moraine (Mather and others, 1942)	
	Barnstable outwash-plain and Mashpee pitted-plain deposits	Mashpee pitted plain (Mather and others, 1942)	
	Kame deposits	Chatham kame deposits (Oldale and Koteff, 1970)	
			Lacustrine clayey silt (Koteff and Cotton, 1962; Maevsky and Drake, 1963)
			Till (Koteff and Cotton, 1962)
Unconformity			Unconformity
Paleozoic and Precambrian			Bedrock, mostly granitic, includes some metasedimentary rock (Oldale, 1969b; Koteff and Cotton, 1962)



Base by U.S. Geological Survey, 1939-61

10,000-foot grid based on Massachusetts coordinate system, mainland zone

1000-meter Universal Transverse Mercator grid ticks, zone 19, shown in blue



UTM GRID AND 1961 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

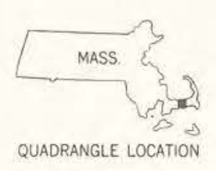
SCALE 1:24 000

1 ½ 0 1 MILE

1000 0 1000 2000 3000 4000 5000 6000 7000 FEET

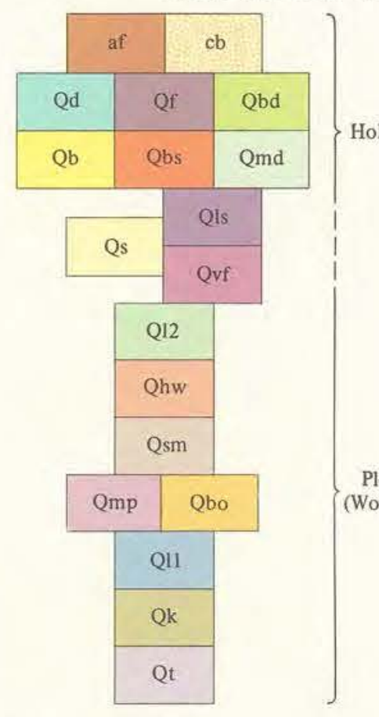
1 .5 0 1 KILOMETER

CONTOUR INTERVAL 10 FEET
DATUM IS MEAN SEA LEVEL
DEPTH CURVES AND SOUNDINGS IN FEET–DATUM IS MEAN LOW WATER
SHORELINE SHOWN REPRESENTS THE APPROXIMATE LINE OF MEAN HIGH WATER
THE MEAN RANGE OF TIDE IS APPROXIMATELY 9.5 FEET
IN CAPE COD BAY AND 3.1 FEET IN NANTUCKET SOUND



QUADRANGLE LOCATION

CORRELATION OF MAP UNITS



DESCRIPTION OF MAP UNITS

A thin surface layer of wind-deposited sand and silt, containing ventifacts and generally mixed with the underlying glacial deposits, is present over much of the glacial drift, but is not shown.

- **af** ARTIFICIAL FILL AND GRADED AREAS – Mostly locally derived sand, gravel, and boulders
- **cb** CRANBERRY BOG – Generally fresh-water marsh or swamp deposits capped by a top-dressing of sand
- **Qd** DUNE DEPOSITS, UNDIFFERENTIATED (HOLOCENE) – Wind-deposited sand and granules in irregularly shaped dunes or roughly parabolic-shaped dunes. Generally underlain by beach, marsh, or glacial deposits. Planar bedding and eolian crossbedding common. Beds generally an inch to a few inches thick
- **Qf** FOREDUNE DEPOSITS (HOLOCENE) – Wind-deposited sand and granules in a ridge parallel to the shore and seaward of the undifferentiated dune deposits. Underlain by beach or older dune deposits. Planar bedding and eolian crossbedding common. Beds generally an inch to a few inches thick
- **Qbd** BEACH AND DUNE DEPOSITS, UNDIFFERENTIATED (HOLOCENE) – Wind-deposited sand and granules in the form of small isolated dunes, and beach deposits composed of sand and pebbles to small boulders (about 1 ft maximum dimension)
- **Qb** BEACH DEPOSITS (HOLOCENE) – Sand to small boulders (about 1 ft maximum dimension) deposited above sea level as narrow strands or spits. Beach deposits below sea cliffs cut in glacial deposits locally contain large boulders (a few feet to a few tens of feet maximum dimension). Beach deposits mostly planar bedded, some current bedding. Beds generally 1 in. to several inches thick
- **Qbs** STORM-BEACH DEPOSITS (HOLOCENE) – Sand to small boulders (about 1 ft maximum dimension) in the bottom of storm sluices and as overwash fans. The storm sluice (Howard, 1939, p. 405), a flat-floored depression underlain by gravelly sand, near the east end of Sandy Neck was probably cut in the dunes during a major northeast storm. Planar, current, and deltaic bedding common. Beds generally an inch to several inches thick
- **Qmd** MARINE DEPOSITS (HOLOCENE) – Sand, gravel, silt, and clay deposited offshore by waves and currents. Shown only on cross section
- **Qls** LAKE-SHORE DEPOSITS (HOLOCENE AND PLEISTOCENE) – Formed along the shores of ponds and lakes. Includes beaches and small spits composed of well-sorted sand and gravel, lag deposits composed mostly of pebble to cobble gravel as a result of wave winnowing of the glacial deposits, and levee-shaped ridges one to two feet high composed of poorly sorted sand and gravel pushed up by expanding lake ice
- **Qs** MARSH AND SWAMP DEPOSITS (HOLOCENE AND PLEISTOCENE) – Mostly decaying marine-marsh plants mixed with varying amounts of sand, silt, and clay. Underlain by glacial deposits, by marine sand, silt, and clay, or by fresh-water pond and peat deposits; locally overlain by dune and beach deposits. Capped by live marine marsh plants. Includes lesser amounts of fresh-water swamp and marsh deposits
- **Qvf** VALLEY-FLOOR DEPOSITS (HOLOCENE AND PLEISTOCENE) – Sediments deposited in the floors of valleys (furrows) cut into the outwash plains. Mostly gravelly sand and pebble to small-boulder gravel
- **Ql2** YOUNGER GLACIAL-LAKE AND ICE-CONTACT DEPOSITS (PLEISTOCENE) – Associated with a proglacial lake in Cape Cod Bay. Mostly a discontinuous veneer of clay and silt (Barnstable Series of Shaler, 1898) over ice-contact deposits composed of gravelly sand, gravel, till, and large boulders (a few tens of feet maximum dimension). Silt and clay massive to laminated, locally deformed. Sand and gravel planar and current bedded. Beds a foot to a few feet thick
- **Qhw** HARWICH OUTWASH-PLAIN DEPOSITS (PLEISTOCENE) – South of the Sandwich moraine, mostly gravelly sand with some pebble to cobble gravel. North of the Sandwich moraine, ice-contact deposits of the outwash plain include till, silt, clay, and large to very large boulders (a few tens of feet maximum dimension). Sand grains mostly quartz, angular to subround; feldspar and glauconite common accessories. Stones mostly granitic; angular to subround. Deposits generally planar bedded; current bedding and current ripples common. Beds dip gently southward, except locally where collapsed. Beds mostly a foot to several feet thick
- **Qsm** SANDWICH MORAINE DEPOSITS (PLEISTOCENE) – Mostly silty to sandy till and large to very large boulders (a few feet to a few tens of feet maximum dimension). Includes lenses and pockets of stratified clayey silt, sand, and gravel. Two exposures at altitudes of 100 and 120 ft on the south-facing front of the moraine include thin-bedded or laminated clayey silt and very fine sand. The till of the moraine may be a veneer that overlies well-sorted sand and gravel, as suggested by several deeper exposures in the moraine and by the logs from BH197, BH228, BH238, and BH245 (table 3). Sand grains in the moraine angular to subround; glauconite and feldspar common accessories. Stones angular to subround; mostly granitic. Stratified deposits within the moraine generally planar bedded; current bedding and current ripples common. Beds dip gently southward, except where collapsed or deformed locally by ice push. Normal faulting common in collapsed deposits
- **Qmp** MASHPEE PITTED-PLAIN DEPOSITS (PLEISTOCENE) – Mostly gravelly sand with some pebble to small boulder (less than 1 ft maximum dimension) gravel. Sand angular to subround. Pebbles angular to subround, mostly granitic. Beds dip gently southward, locally faulted or more steeply dipping where collapsed. Bedding mostly planar; current bedding and current ripples common. Beds generally 6 in. to a few feet thick
- **Qbo** BARNSTABLE OUTWASH-PLAIN DEPOSITS (PLEISTOCENE) – Mostly gravelly sand with some pebble to small boulder (maximum dimension less than 1 ft) gravel. North part of the outwash plain deposits includes some till, clayey silt, and large boulders (maximum dimension a few feet). Feldspar and glauconite common accessories in the sand. Sand grains mostly angular to subround. Stones generally granitic; angular to subround. Bedding mostly planar; current bedding and current ripples common. Beds generally 6 in. to a few feet thick. Beds dip gently southward, locally faulted or more steeply dipping where collapsed. Outwash sand and gravel may overlie silt and clay as suggested by BH179 (table 3)
- **Qk** KAME DEPOSITS (PLEISTOCENE) – Mostly gravelly sand with some pebble to small boulder (maximum dimension less than 1 ft) gravel. Includes scattered boulders as much as a few tens of feet maximum dimension. On Great Island stratified sand and gravel overlain in many places by brown sandy to silty till or flow till as much as 10 ft thick that contains abundant ventifacts. Sand grains mostly angular to subround. Stones mostly granitic, angular to subround. Sand and gravel planar or current bedded. Beds generally 6 in. to a few feet thick. Beds dip gently southward, locally faulted or more steeply dipping where collapsed
- **Ql1** OLDER GLACIAL-LAKE DEPOSITS (PLEISTOCENE) – Glacial-lake deposits inferred below the sand and gravel of the outwash plains. Shown only on cross section. The inference is based on borehole data from the Harwich quadrangle (Koteff and Cotton, 1962) and the Dennis quadrangle (Maevsky and Drake, 1963), showing thick coarse to clayey silt deposits beneath outwash sand and gravel, and on data from BH179 (table 3) that showed 35 ft of fine sand to clay beneath the sand and gravel of the Barnstable outwash plain
- **Qt** TILL DEPOSITS (PLEISTOCENE) – Inferred from the seismic data at Kalmus Park (table 1, site B), where a seismic layer with a velocity of 7,650 ft/sec is interpreted to represent 345 ft of compact till, and from the Harwich borehole, which showed 116 ft of compact till (Koteff and Cotton, 1962) with a similar seismic velocity (Oldale and Tuttle, 1965, p. D104). In both places the thick accumulation of till is associated with broad deep valleys in the basement surface. Shown only on cross section
- **br** BEDROCK – Metamorphic, igneous, and sedimentary rocks of Precambrian to early Mesozoic(?) age. Shown only on cross section. Altitude of the basement surface inferred from seismic data within and outside the quadrangle (Oldale, 1969b)

Contact – Long dashes where approximately located; short dashes where inferred

Lineament – Axis of major linear feature on the Sandwich moraine. These features include push ridges where ice overrode the outwash plains, accumulations of drift marking former positions of the ice front, and ice-channel fillings

Area of small festoon-shaped parallel ridges – Possibly marking former positions of the ice front on the Sandwich moraine

Lineament formed by dune crests on Sandy Neck

—20— Contour showing the inferred pre-collapse and pre-erosion outwash plain surface – Datum is mean sea level

—-500— Contour showing the altitude, in feet below sea level, of the buried bedrock surface – Datum is mean sea level

⦿ BH247 Location of boreholes described in table 3

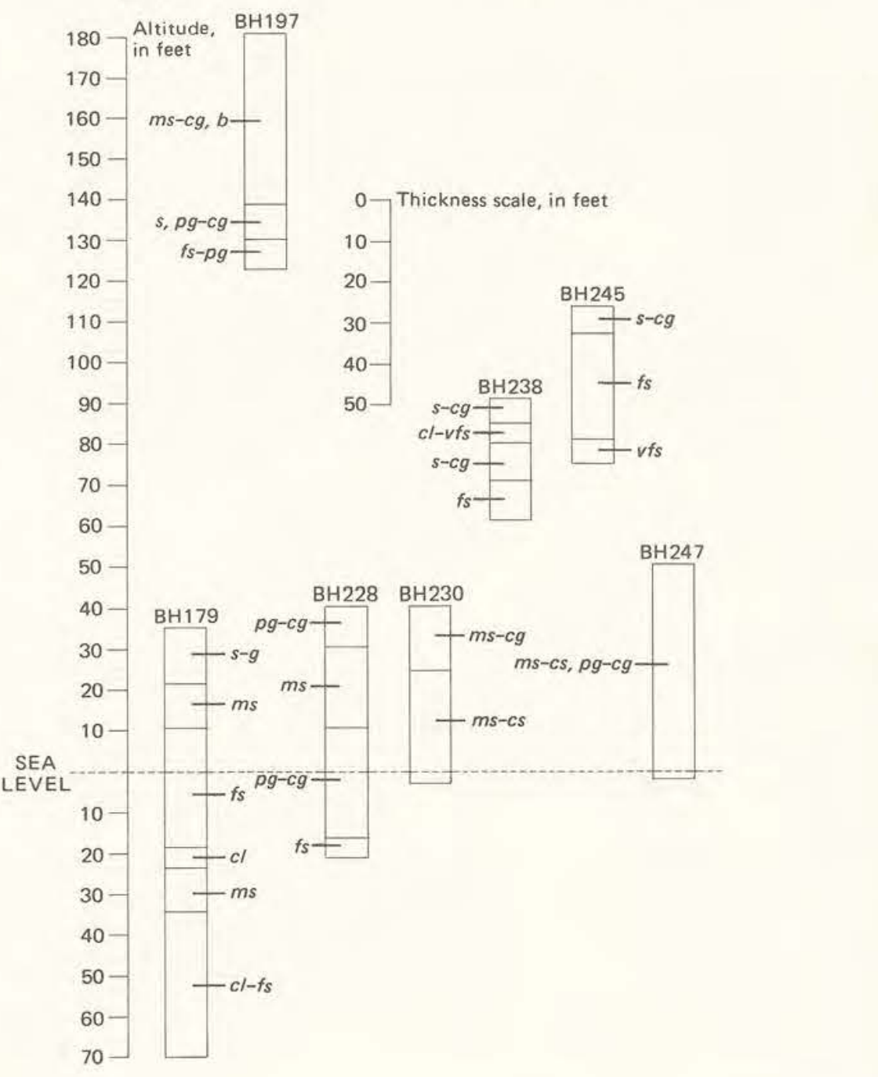
800 B.P
1,800 B.P
2,400 B.P
2,700 B.P.
-X—X-
3,300 B.P
Shoreline of Sandy Neck at various stages in its development – Numbers indicate years before present. From Redfield (1965, p. 53)

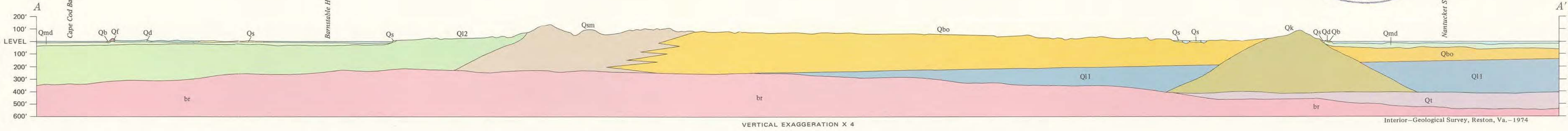
⊙A Seismic station described in table 1

○*cl* Exposure or auger hole

s–cg Pit – Extent of large pits; shown by hachures — Letter symbols on map and in table 3 show texture of deposits: *s*, sand; *vfs*, very fine sand; *fs*, fine sand; *ms*, medium sand; *cs*, coarse sand; *vcs*, very coarse sand; *g*, gravel; *pg*, pebble gravel; *cg*, cobble gravel; *bg*, boulder gravel; *p*, pebbles; *c*, cobbles; *b*, boulders; *sl*, silt; *cl*, clay; *t*, till. Superposition of symbols indicates section, comma reads "and", hyphen reads "to." Where more than one texture is noted, they are listed in order of decreasing abundance

TABLE 3.—*Selected wells and test holes from the Hyannis quadrangle. Data from Maevksy and Drake (1963). For meaning of texture symbols, see map explanation.*





VERTICAL EXAGGERATION X 4

Interior—Geological Survey, Reston, Va.—1974

GEOLOGIC MAP OF THE HYANNIS QUADRANGLE, BARNSTABLE COUNTY, CAPE COD, MASSACHUSETTS

By

Robert N. Oldale

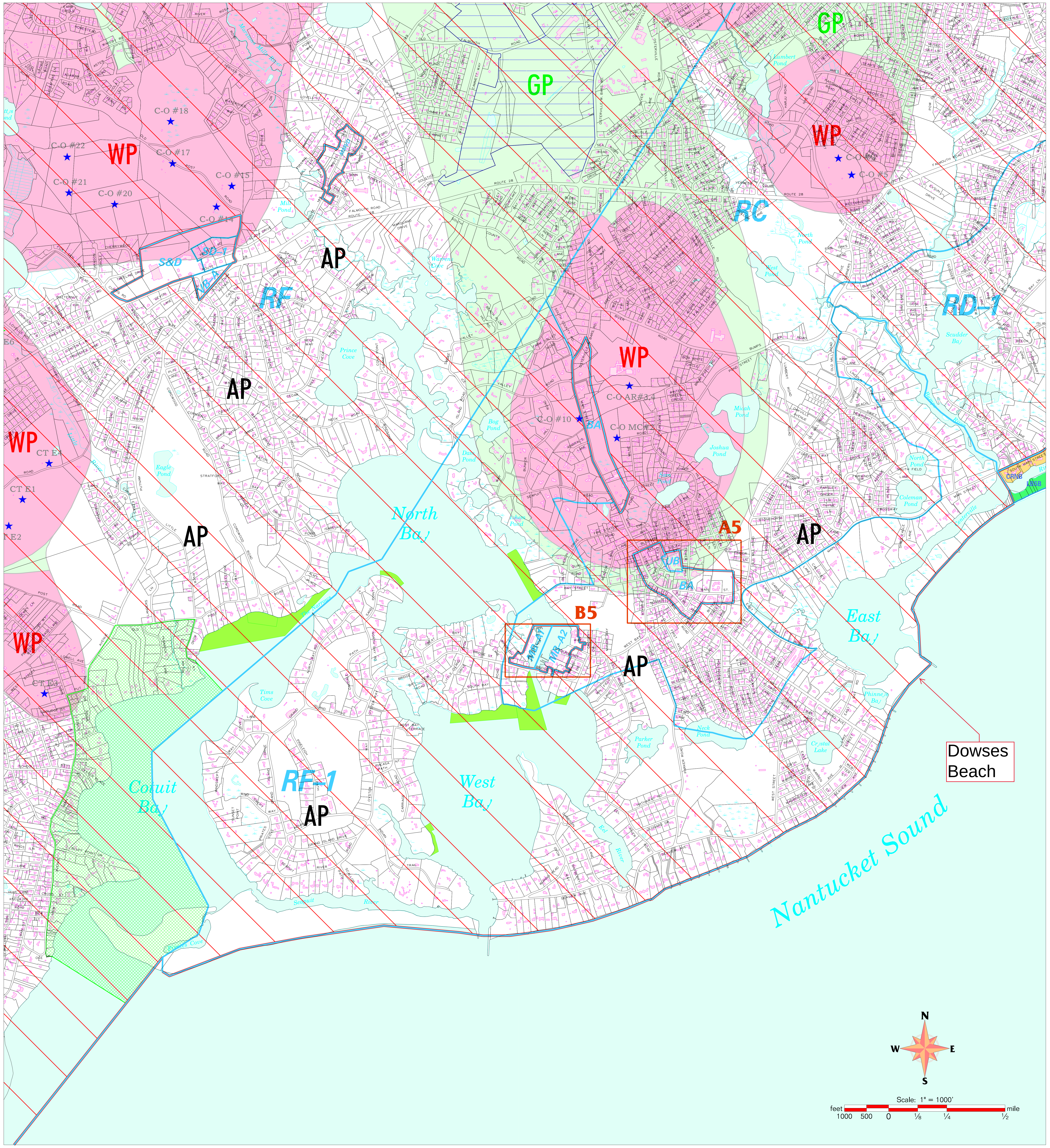
1974

For sale by U.S. Geological Survey, Reston, Va. 22092, price $1.00

ZONING MAP of the TOWN OF BARNSTABLE, MASSACHUSETTS

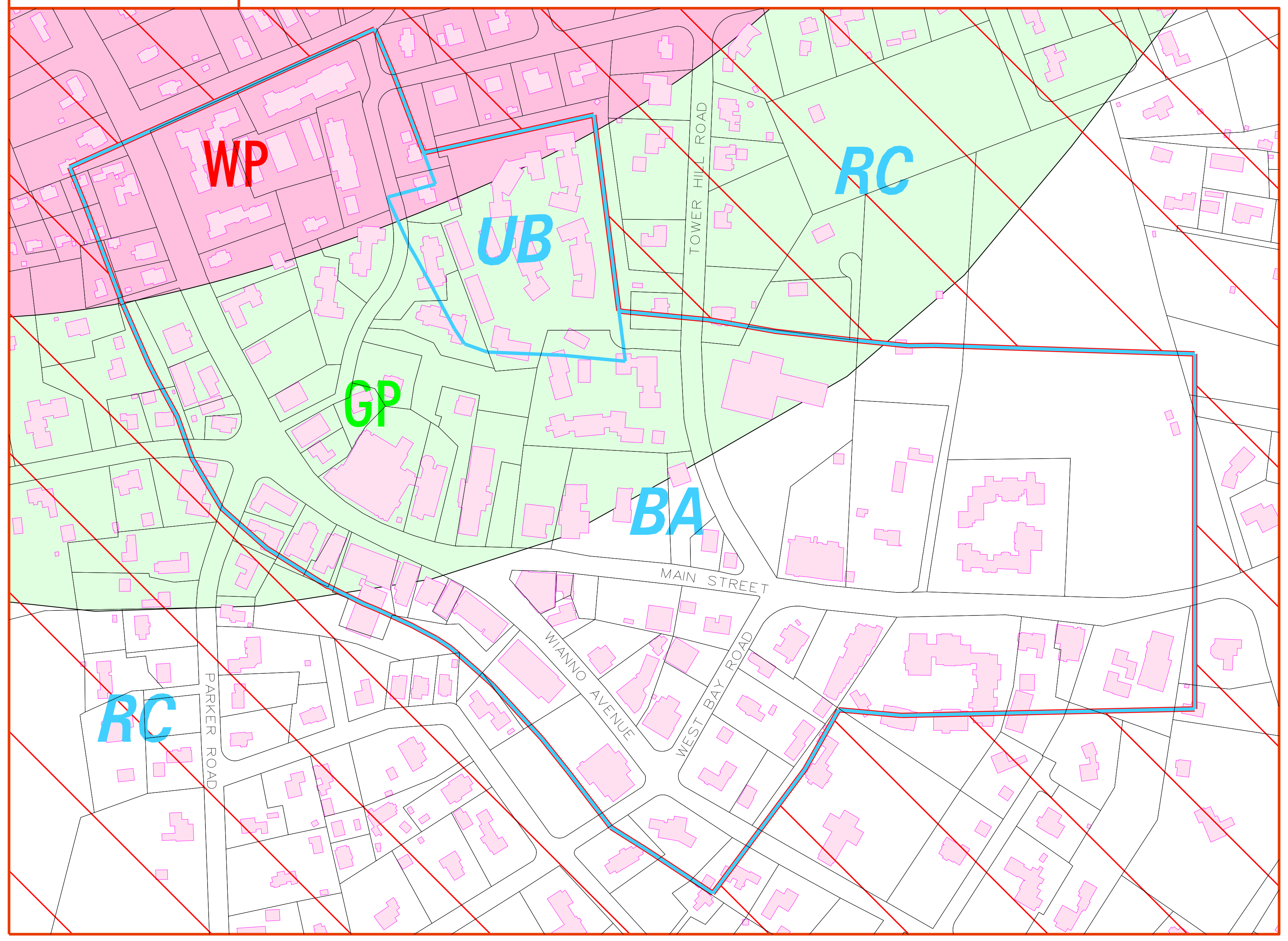
LAST AMENDED FEBRUARY 28, 2019

OSTERVILLE - SHEET 5 OF 7



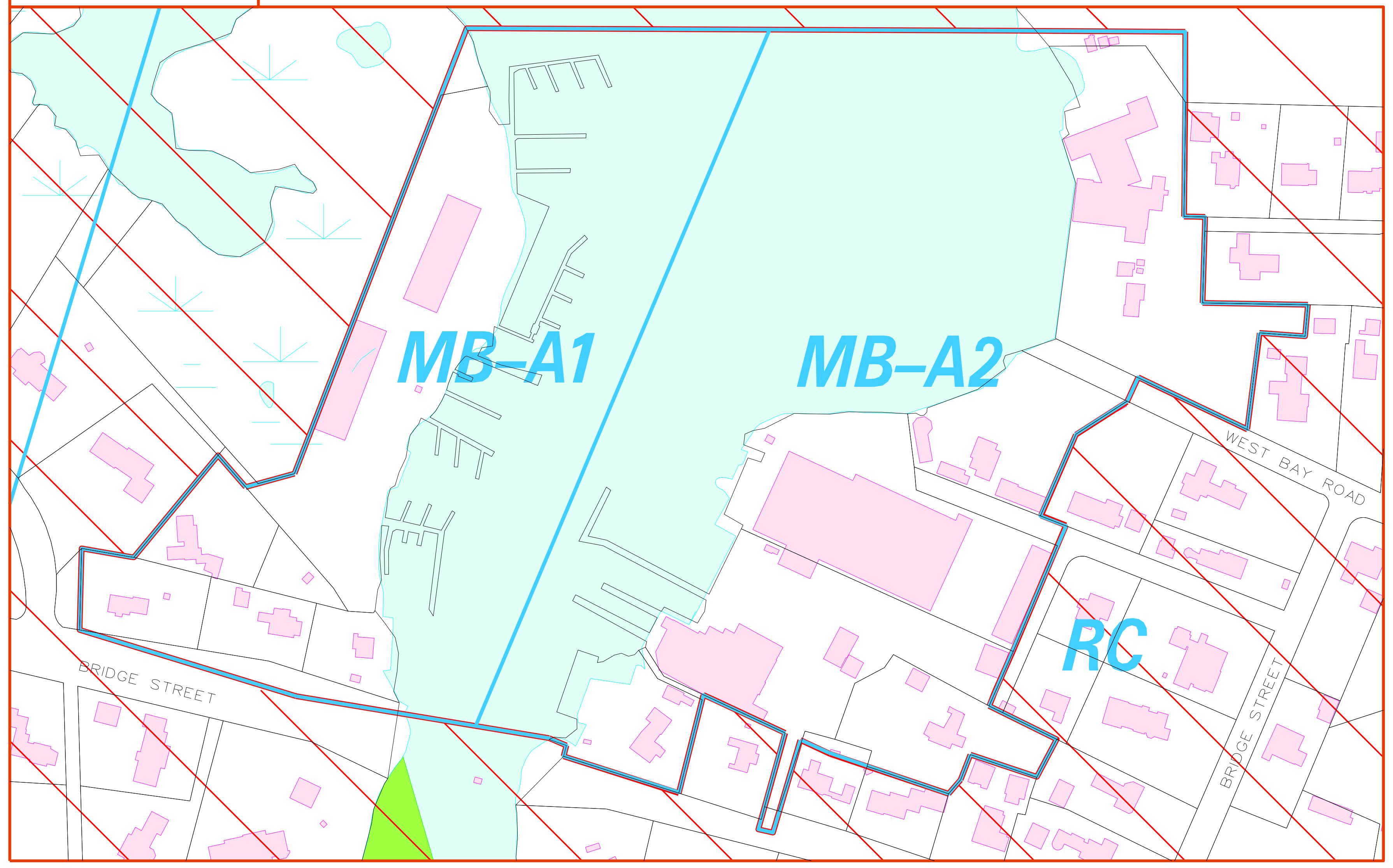
INSET A5

INSET SCALE: 1"=200'



INSET B5

INSET SCALE: 1"=150'



Map Legend

HB	Zoning District		
WP	Wellhead Protection Overlay District	★ C-O #12	Existing Public Well Site
GP	Groundwater Protection Overlay District	★ C-O #18	Proven Future Public Well Site
AP	Aquifer Protection Overlay District All other areas not identified as Wellhead or Groundwater Protection Overlay Districts	★ C-O #20	Proposed Future Public Well Site
▨	Adult Use Overlay District	—	Parcel Lines (FY 2019)
▨	Dock and Pier Overlay District	◆	Buildings
▨	Former Grade 5 School Planned Unit Development Overlay District	┼┼┼	Railroad Track
▨	Medical Services Overlay District	— · · — · ·	Town Boundary Line
▨	Resource Protection Overlay District	⁂	Marsh Area
▨	Shopping Center Redevelopment Overlay District	—	Stream / Edge of Water
▥	Senior Continuing Care Retirement Community - SCCRCOD 2008-1	▨	Cranberry Bog
🟩	Recreational Shellfish Area and Shellfish Relay Area Dock & Pier Overlay District		
▤	Ground Mounted Solar Photovoltaic Overlay District		
CV	Craigville Village Neighborhood Overlay		
LBSB	Long / Short Beach Neighborhood Overlay		
CB	Craigville Beach Neighborhood Overlay		
CRNB	Centerville River North Bank Neighborhood Overlay		

SEE TEXT OF ZONING ORDINANCE FOR COMPLETE INFORMATION ON BULK REGULATIONS.

Where a zoning district boundary is located at the edge of a water body, that zone that applies to the land shall apply to structures and uses such as piers and commercial boating operations to the extent of the territorial jurisdiction of the town.

Where zoning district boundaries are located along the edge of a roadway and a distance is shown from such point to another zoning boundary, such distance and points shall be from the edge of the road layout. The ultimate location of such point shall be determined by survey as the line shown on this map is considered an approximation.

TOWN OF BARNSTABLE G.I.S. UNIT FILE: ostzone.dgn J.A.B. 7-9-2019