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Assessment of Potential Saltwater Encroachment in the Herring River Basin
Cape Cod National Seashore

Natural Resource Report NPS/NRPC/WRD/NRTR—2007/370

ON THE COVER
Aerial photograph of the Herring River basin, looking southeasterly.
Photograph by: Barbara Dougan, Cape Cod National Seashore

Assessment of Potential Saltwater Encroachment in the Herring River Basin
Cape Cod National Seashore

Natural Resource Report NPS/NRPC/WRD/NRTR—2007/370

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Contents

Figures

Page

Executive Summary

This report is the first phase in an assessment of the potential vulnerability to saltwater intrusion of private domestic wells adjacent to the Herring River basin, following restoration of tidal flow in the basin. This assessment should be further refined using information from planned photogrammetric contour mapping and 2-D modeling of the tidal range and salinity. This report identifies those areas and private property parcels within the basin that should be more closely investigated.

Fresh groundwater flow is outward from upland areas toward river valleys and generally upward under the valleys. That is, groundwater from upland areas is flowing toward and discharging into the rivers and creeks. This upward and outward groundwater flow inhibits infiltration of saltwater downward through the sediments. Periods between high tides allow fresh groundwater to partially flush saltwater back out of the sediments. This natural flow of groundwater toward the river channels makes it is unlikely that saltwater will intrude into the fresh groundwater system any appreciable distance. Investigations at other tidal estuaries on Cape Cod have shown that there is generally a freshwater aquifer underlying the saltmarsh sediments.

Even though we do not expect significant saltwater intrusion beyond the saltmarsh sediments, additional analyses were conducted to identify private property parcels that lie within 250 feet of bottomland areas that will potentially be inundated at high tide following restoration of tidal flow in the Herring River basin. These parcels should be examined individually to determine the location of the well on the parcel, the depth of the well, depth of the screened interval, water table elevation, and the conductivity of water from the well. This information will allow a more thorough analysis of the potential for saltwater intrusion at these wells on an individual basis.

Introduction

The dike at the mouth of the Herring River has restricted tidal flow into the river basin since 1909. One of the consequences of restricting tidal flow is that the area has been converted from a salt-marsh environment to a freshwater wetland. Over the course of the many decades since construction of the dike, the near surface aquifer underlying the drainage basin has converted from brackish or salty water to a freshwater aquifer system. The thickness of freshwater in the aquifer underlying the Herring River basin is several tens of feet thick (Masterson, 2004).

Currently, the Town of Wellfleet and the National Park Service are evaluating plans and alternatives to enlarge the opening of the dike to restore tidal flow to the Herring River basin, allowing the area to revert to a saltmarsh ecosystem. With the restoration of tidal flow, there will be a regular influx of saltwater that will gradually infiltrate the surficial sediments, replacing the freshwater in the sediments underlying the area that will be regularly inundated by tidal water. The salinity of the groundwater in the sediments will decrease in the upstream direction proportionate with the salinity of the surface water. Figure 1 shows the approximate extent of the original tidal wetlands. Much, but not all, of this area will be regularly inundated at high tide. Some of the upper reaches of the drainage basin shown in Figure 1 lie at an elevation high enough to place them beyond the range of normal tidal flow.

Spaulding and Grilli (2005) conducted computer modeling to estimate the extent of tidal flooding and salinity distribution for various degrees of opening the dike at the mouth of the Herring River. Figure 2 shows the predicted salinity distribution with a tidal gate opening in the dike 30 meters wide and 3 meters high. An opening of this size will allow essentially unrestricted tidal flow to the basin. Additional photogrammetric contour mapping and 2-D modeling of the tidal range and salinity for the entire drainage basin is planned for 2007 to provide better information about the extent and salinity distribution of restored tidal flow.

One of the concerns of adjacent landowners is the potential for saltwater intrusion from the tidal flow to infiltrate into the aquifer and affect the availability of freshwater for private domestic wells. The assessment of the potential for saltwater intrusion is the primary focus of this report. This report expands the scope of a previous report (Martin, 2004), which looked at the potential for saltwater intrusion in a smaller area, the lower part of the basin, generally downstream of Bound Brook Road. Because current plans are to restore tidal flow to the entire Herring River basin, it is necessary to assess the potential for saltwater intrusion in a larger geographic region.

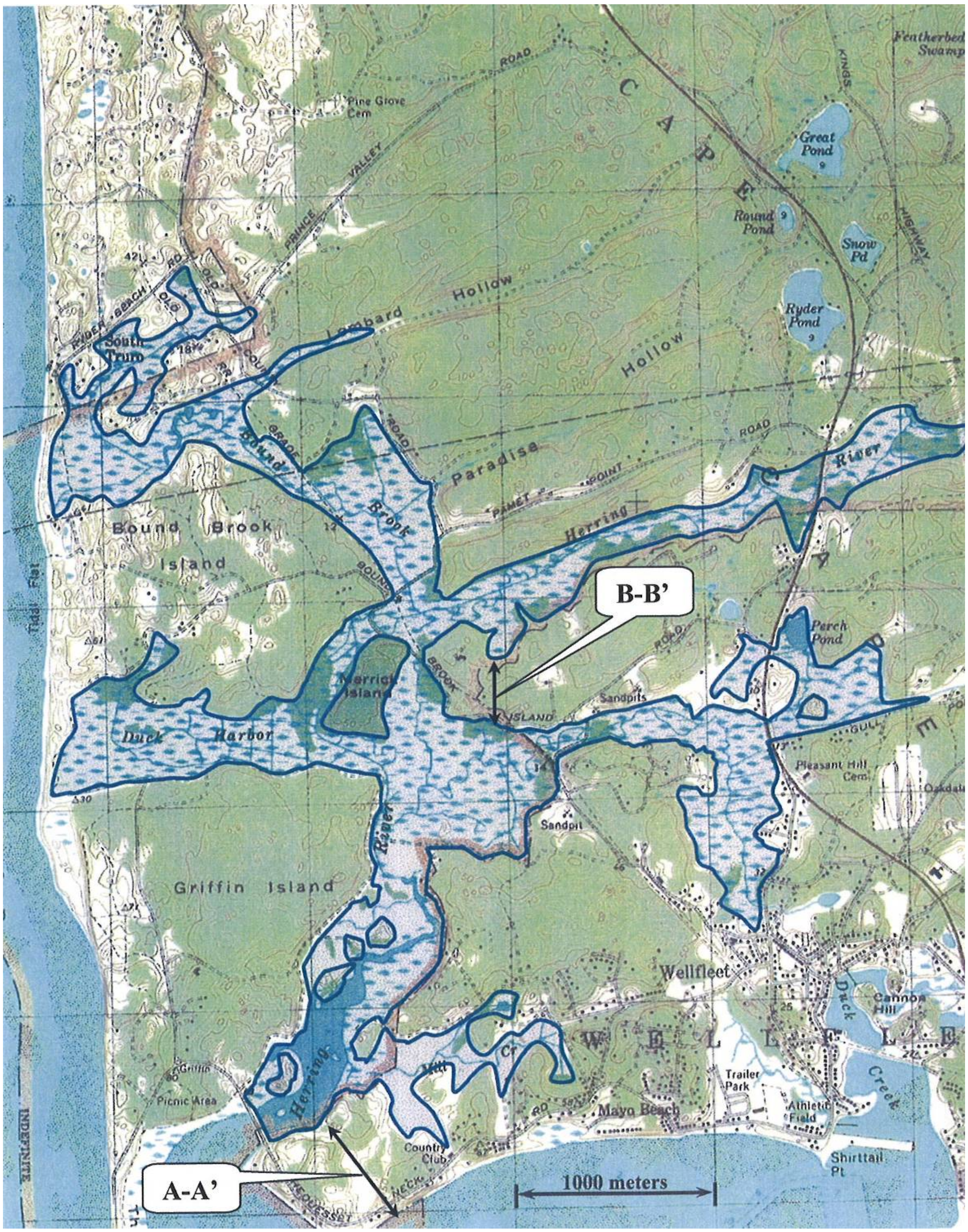


Figure 1. Approximate extent of valley bottom in the Herring River basin that may be subject to tidal flooding (maximum extent of original tidal wetlands).

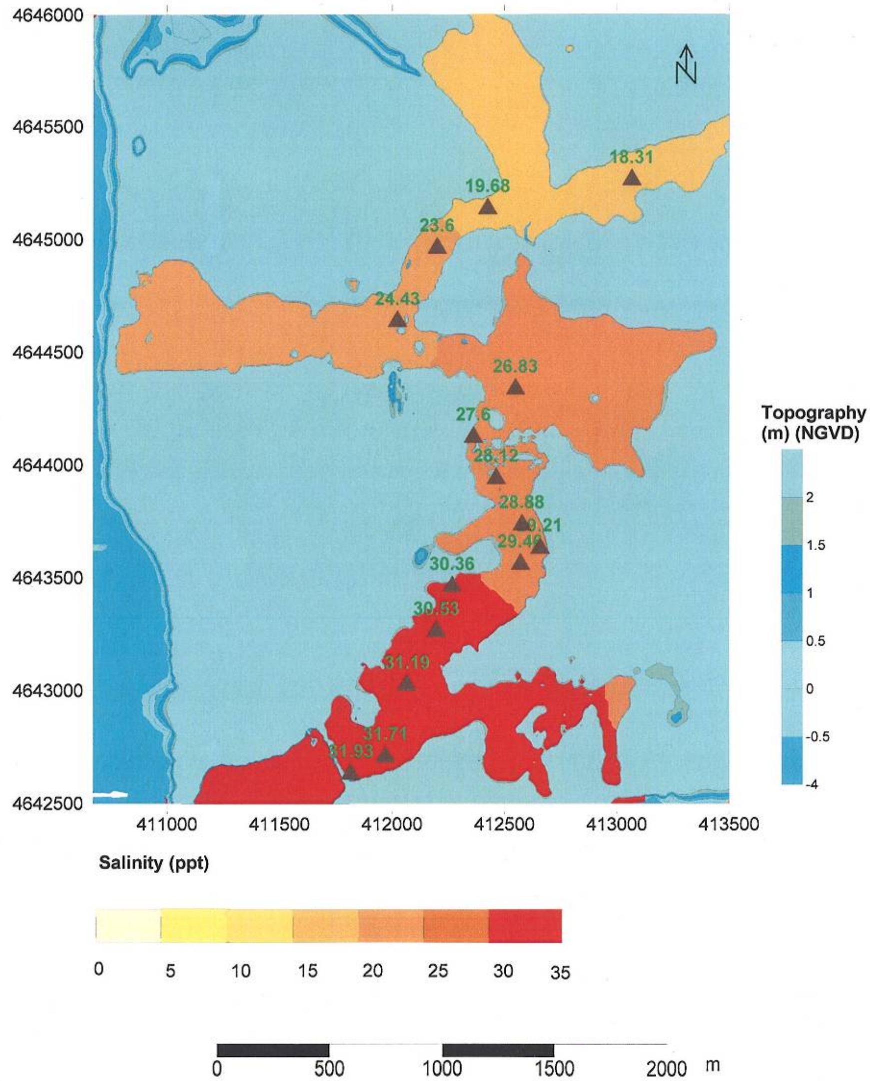


Figure 2. Salinity distribution at high tide. 30 meter wide gate, 3 meter high opening

Results contained in this report, especially the identification of property within 250 feet of tidal areas is preliminary in nature, being based on available data. Additional 2-D modeling of the tidal range and salinity and photogrammetric contour mapping is planned for 2007 and will allow more accurate identification of areas that will be inundated by tidal flow and areas that may be vulnerable to saltwater intrusion. It is believed that the delineation of areas that might potentially be affected by tidal flow, as presented in this report, conservatively overestimates the potential for saltwater intrusion. Additional field investigations in potentially affected areas, as identified in this report, should include locating wells on the property parcels, obtaining well construction data (depth and perforated interval), measuring the conductivity of water from wells, and assessment of the hydrologic and geographic setting of each well. This information will help in the assessment of the potential for saltwater intrusion at each well.

Previous Investigations

Fitterman and others (1989) conducted geophysical surveys on the highlands to the east of the Herring River. They determined that the thickness of the freshwater aquifer was at least 10 meters (30 feet) and that the thickness of the aquifer increased away from the river. They used an analytical equation to evaluate how increased tidal fluctuation in the river would affect the water table adjacent to the stream. They concluded that completely opening the tide gates would have no effect on wells in the highlands east of the river because the mean river level would not change and the area affected by water table fluctuations would be limited to a few tens of meters from the river.

In a subsequent study, Fitterman and Dennehy (1991) installed monitoring wells to verify the results of the geophysical investigation conducted in 1989. They found that the thickness of the freshwater aquifer at four monitoring wells (Figure 3, wells labeled WNW 115-118)) ranged from 18-22 meters (59-73 feet). At two monitoring wells adjacent to the floodplain of the Herring River (WNW-115 & WNW-117), the thickness of the freshwater aquifer was determined to be approximately 65 and 59 feet respectively. Fitterman and Dennehy (1991) assumed that completely opening the tide gates would cause both static-water and high-tide levels in the Herring River to increase by less than 0.5 meter. They then concluded that such a small increase, compared to the large thickness of the freshwater aquifer, makes it unlikely that the thickness of the freshwater aquifer or the position of the fresh/salty groundwater interface would change at wells in the highlands east of the Herring River (although it is unclear how they reached this conclusion). They did acknowledge that wells within the floodplain (land-surface elevation less than 10 feet NGVD) could potentially draw salty water due to infiltration of salt water from the surface or repositioning of the fresh/salty groundwater interface (Fitterman and Dennehy, 1991).

Two additional wells were constructed in September 2003 to allow monitoring in other areas that might be affected by restoration of tidal flow in Herring River and Mill Creek (Wells WNW-133 and WNW-134). The location of these wells is shown on Figure 3.

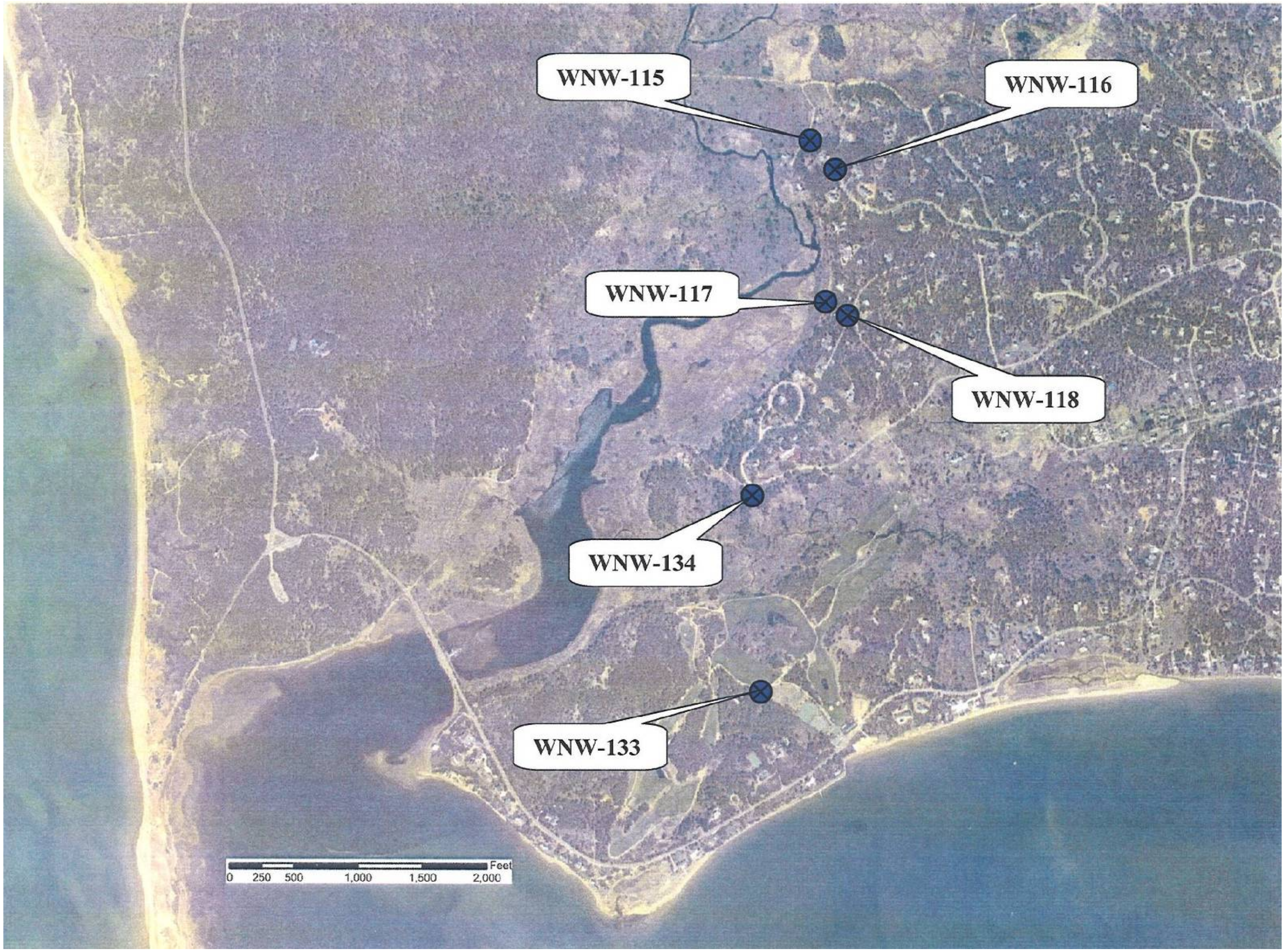


Figure 3. Location of electromagnetic induction monitoring wells in the Herring River basin.

Electromagnetic induction logs measure the electrical conductivity of the aquifer material and water in a radial zone about 0.5-4 feet from the vertical axis of the well. Conductivity of the aquifer is a function of lithology, porosity, moisture content, and the concentration of dissolved solids in the pore fluid. In the monitoring wells on this part of Cape Cod, where the sediment characteristics are fairly constant with depth, most of the response seen on the electromagnetic induction log is due to the concentration of dissolved solids in the groundwater; mostly an increase in salt concentration at the base of the fresh groundwater lens. An electromagnetic induction log for monitoring well WNW-117 is shown in Figure 4

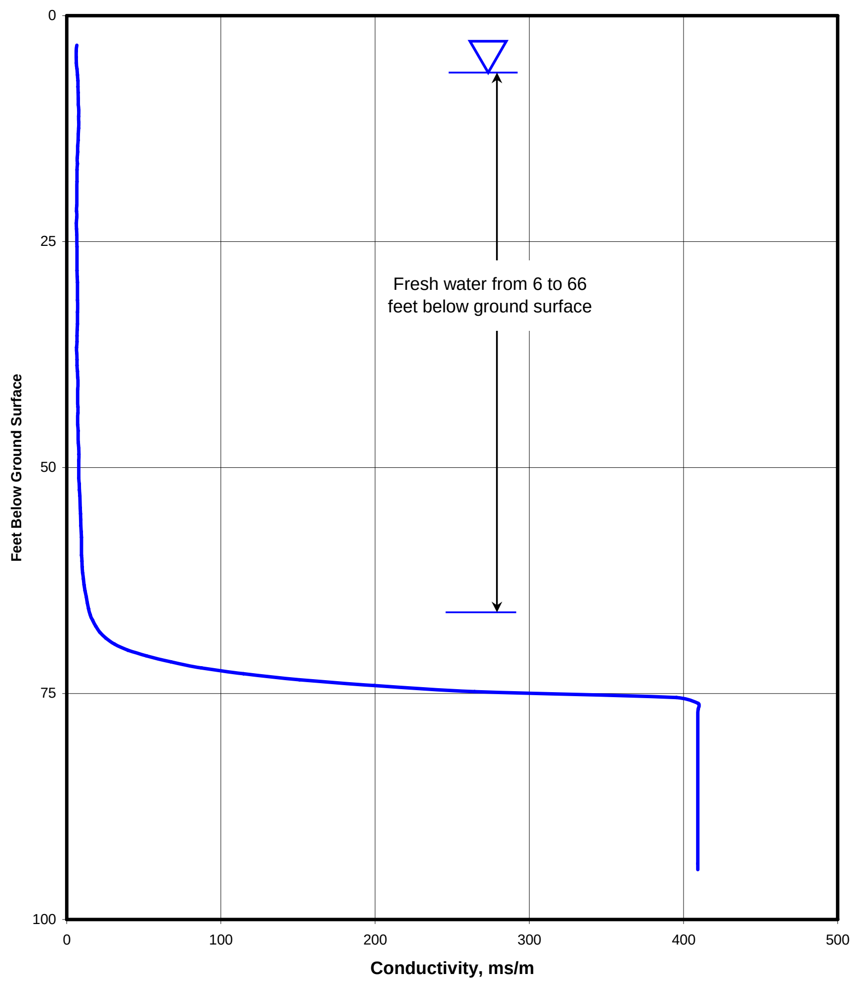


Figure 4. Example of an electromagnetic induction log at well WNW-117.

The USGS conducted computer modeling of the groundwater flow system in the vicinity of the Herring River to assess the potential changes in the fresh/salty groundwater interface that might be expected due to restoration of tidal flow in the Herring River basin (Masterson, 2004). Four scenarios were simulated to assess the potential impacts of restoring tidal flow on the fresh/salty groundwater interface in the vicinity of the Herring River. These simulations were made for a period of 300 years to allow enough time for the groundwater flow system to reach a new equilibrium with respect to changes in the position of the fresh/salty groundwater interface. The four scenarios simulated in the computer model evaluated combinations of increasing the mean water elevation and changing the salinity distribution in the Herring Basin. Only scenario four is discussed here as it most closely reflects current plans for tidal restoration. In scenario four, the mean water elevation in the Herring River Basin was set at 1.5 feet NGVD29, the current mean water elevation measured on the seaward side of the tide-control structure. The salt concentration in the estuary was simulated as decreasing in concentration in the upstream direction as predicted by Spaulding and Grilli (2001). Under this scenario, the freshwater/saltwater interface is predicted to rise between 5and 10 feet in areas of close proximity to the Herring River Basin (Masterson, 2004).

Martin (2004) assessed the potential for saltwater intrusion in areas adjacent to the lower part of the Herring River basin by comparing the area to an oceanic shoreline. If the tidal area was a permanent saltwater body, a freshwater/saltwater interface would develop, as shown in Figure 5. The lighter freshwater floats on top of the more dense saltwater. The freshwater takes the shape of a lens or bubble with an interface or transition zone between the fresh and salty groundwater.

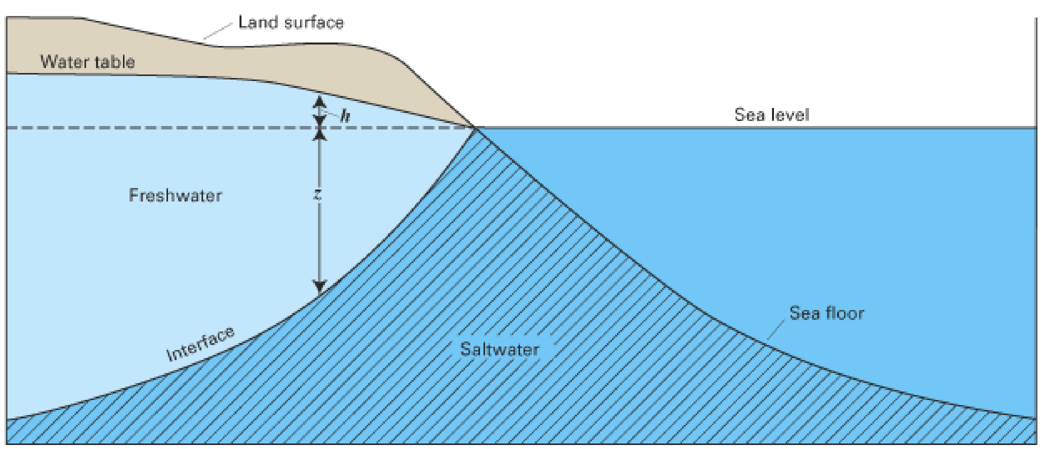


Figure 5. Relationship between fresh and salty groundwater at an ocean shoreline.

Analytical modeling and comparison with nearby areas with similar hydrologic conditions showed that the thickness of the freshwater part of the aquifer would be sufficient to support private, domestic wells at distances of more than about 200-250 feet from the "shoreline."

Comparison to Other Tidal Estuaries

There are several areas on Cape Cod with hydrogeologic environments and freshwater/saltwater conditions that are similar to what might be expected if tidal flow is restored to the Herring River basin. Current conditions in these areas may provide insight into what may occur in the Herring River basin if tidal flow was restored.

Namskaket Marsh straddles the Orleans-Brewster town boundary on Cape Cod Bay (Figure 6) and is a tidally-influenced system. The marsh peat and near-surface sediments that are regularly flooded at high tide contain saline groundwater. Below the marsh sediments, there is fresh groundwater in the sand aquifer. The fresh groundwater is flowing toward, and discharges at, the shoreline of Cape Cod Bay (Figure 7). There is an upward gradient of fresh groundwater flow. Higher water table elevations inland push groundwater toward the creeks, rivers, and the ocean shoreline. This upward flow of fresh groundwater inhibits the infiltration of saltwater downward through the peat sediments at high tide. Additionally, the low permeability of the peat sediments greatly reduces the potential for water movement between the marsh and the underlying sand aquifer. These processes greatly reduce the potential for saltwater intrusion into the aquifer.

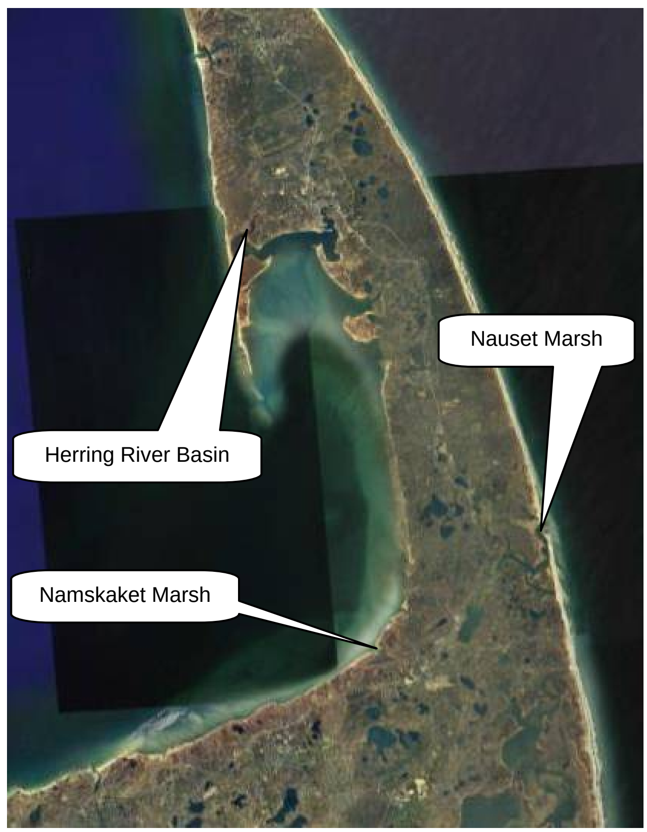


Figure 6. Location of Namskaket Marsh and Nauset Marsh

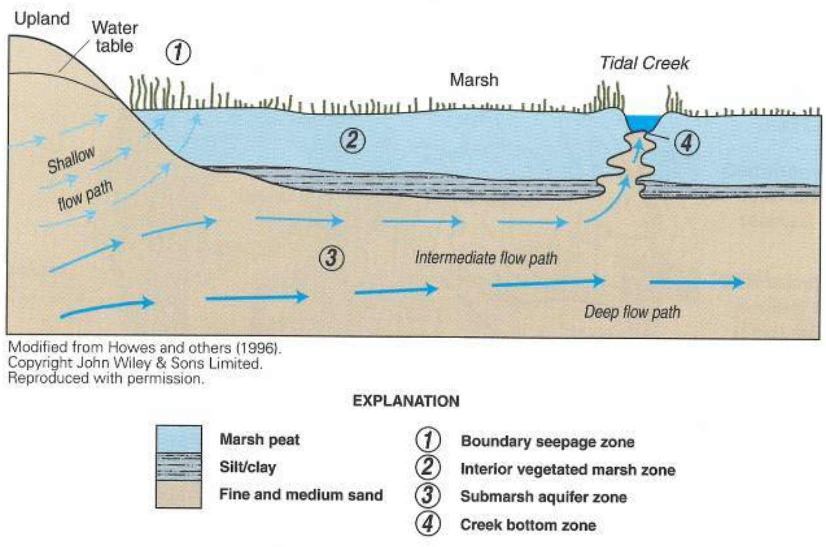


Figure 7. Hydrologic conditions at Namskaket Marsh (from Barlow 2003, Figure 56).

It's likely that the hydrologic system in the upper parts of the Herring River basin will be similar to that shown in Figure 7 after restoration of tidal flow. Groundwater in the near-surface sediments will be salty or brackish and there will be fresh groundwater deeper. The salinity of tidal flow will decrease toward the upper reaches of the estuary, and the hydrology in those areas will be dominated by fresh groundwater. In areas that are underlain by marsh peat and/or silt and clay, the tidal flux of saltwater will be somewhat isolated from the underlying freshwater aquifer.

After restoration of tidal flow, hydrologic conditions in the lower part of the Herring River basin might be similar to those in the Nauset Marsh estuary (Figure 8). The lower part of the basin will be inundated by water having higher salinity and for longer periods of time during each tidal cycle. Therefore, we would expect that the saltwater will penetrate deeper into the sediments and may completely displace the freshwater in the sediments. Portnoy and others (1998) showed that the interface between freshwater and saltwater at the transition between the tidal estuary at Nauset Marsh and adjacent upland areas is essentially identical to the interface at a coastal environment, as shown in Figure 8.

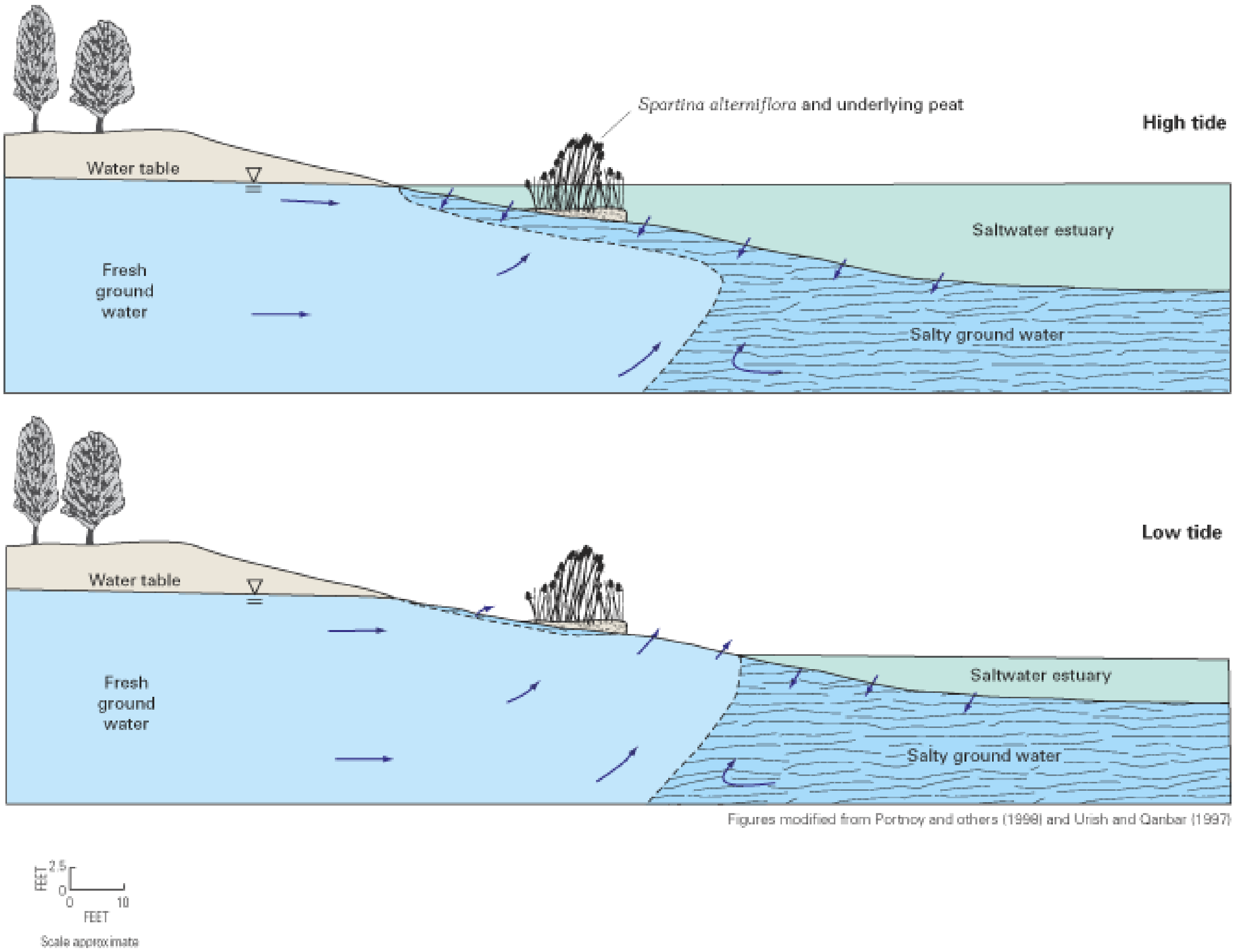


Figure 8. Hydrologic conditions at Nauset Marsh at high and low tide (Barlow, 2003, Figure 62).

Comparison to an Ocean Shoreline

The simplest way to assess a worst-case scenario of the potential for saltwater intrusion in the aquifer adjacent to the Herring River basin is to treat the problem as if it were an ocean shoreline. That is, we assume that the entire Herring River basin is permanently flooded with saltwater. The interface between freshwater underlying the upland areas and the saltwater underlying the tidal areas would then look like Figure 9.

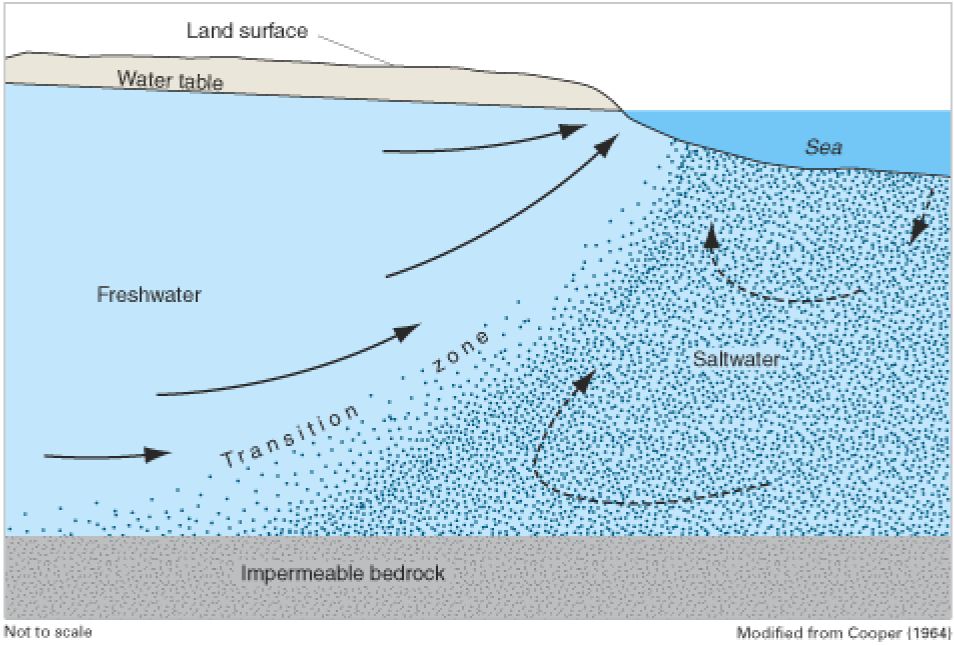


Figure 9. Interface of fresh/salty groundwater at an ocean shoreline (Barlow, 2003, Figure 6)

Many people have investigated the relationship of the fresh/salty groundwater interface in coastal environments over the years. The problem is explained and summarized in Fetter (2001, pp. 327-338). The depth to the interface is approximately 40 times the elevation of the water table above sea level. As shown in Figure 10, z = 40h.

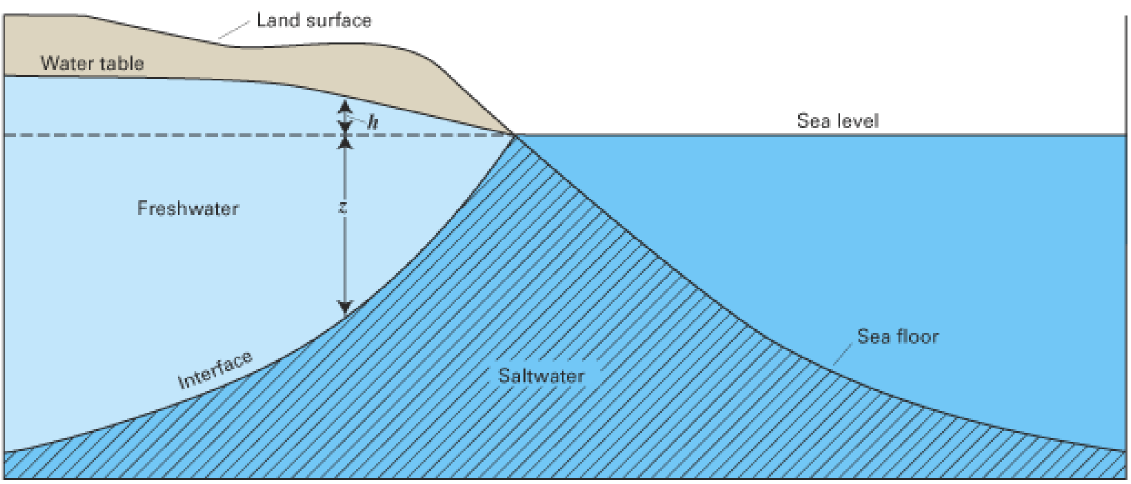


Figure 10. Relationship of water table elevation to depth to fresh/salty groundwater interface (Barlow, 2003, Figure B-1)

The Herring River basin and the probable extent of tidal inundation are shown on Figure 1. To simplify our assessment, we first identify upland areas that are essentially “islands” or “peninsulas” (at least from a hydrologic view) surrounded by saltwater (Figure 1). We select the smallest of these land masses, shown by cross-sections A-A’ (Chequesset Neck) and B-B’ (Coles Neck) on Figure 1. We can then apply the basic principles and equations as described in Fetter (2001) to estimate the thickness of the freshwater in the aquifer at various distances from the “shoreline.” Larger islands or land masses will have a greater thickness of freshwater at the same distances from the shoreline.

Estimating Area of Potential Saltwater Encroachment

For Chequesset Neck (or any infinite-strip or circular island), having a width of 2a, the height of the water table above sea level, h, at any distance, x, from the shoreline can be calculated from

$$h^2 = \frac{w\left(a^2 - (a-x)^2\right)}{K(1+G)}$$ from Fetter, 2001, pp. 335

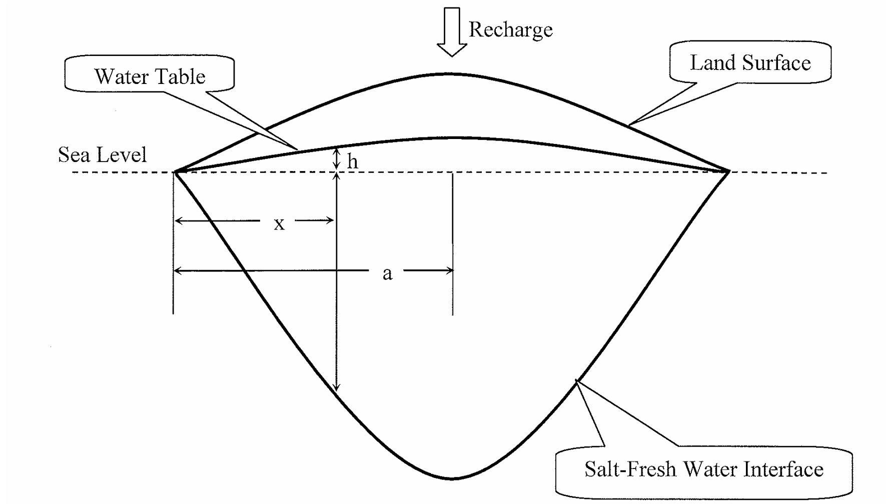
where

- w is the recharge rate to the aquifer (L/T, length/time)
- K is the hydraulic conductivity (L/T, length/time)
- a is the radius of the “island” (L, length)
- G is a ratio of the freshwater density to the difference between the densities of saltwater and freshwater,

$$G = \frac{\rho_w}{\rho_s - \rho_w} = 40$$

ρ_w is the density of freshwater, 1.000 gm/cm^3

ρ_s is the density of salty groundwater, 1.025 gm/cm^3



For average conditions in the Wellfleet area, we can assume that

w = 2 ft/yr

K = 100 ft/d = 36500 ft/yr

a = 1000 ft

The elevation of the water table above mean sea level and the depth to the interface below mean sea level for any distance from the shoreline is computed as follows

Distance from shore (x) feet	Water Table Elevation (h) feet above sea level	Depth to Interface (z) feet below sea level
0	0.00	0.00
25	0.26	10.28
50	0.36	14.44
75	0.44	17.57
100	0.50	20.16
200	0.69	27.75
300	0.83	33.02
400	0.92	36.99
500	1.00	40.05

Graphically, this relationship is shown on Figure 11.

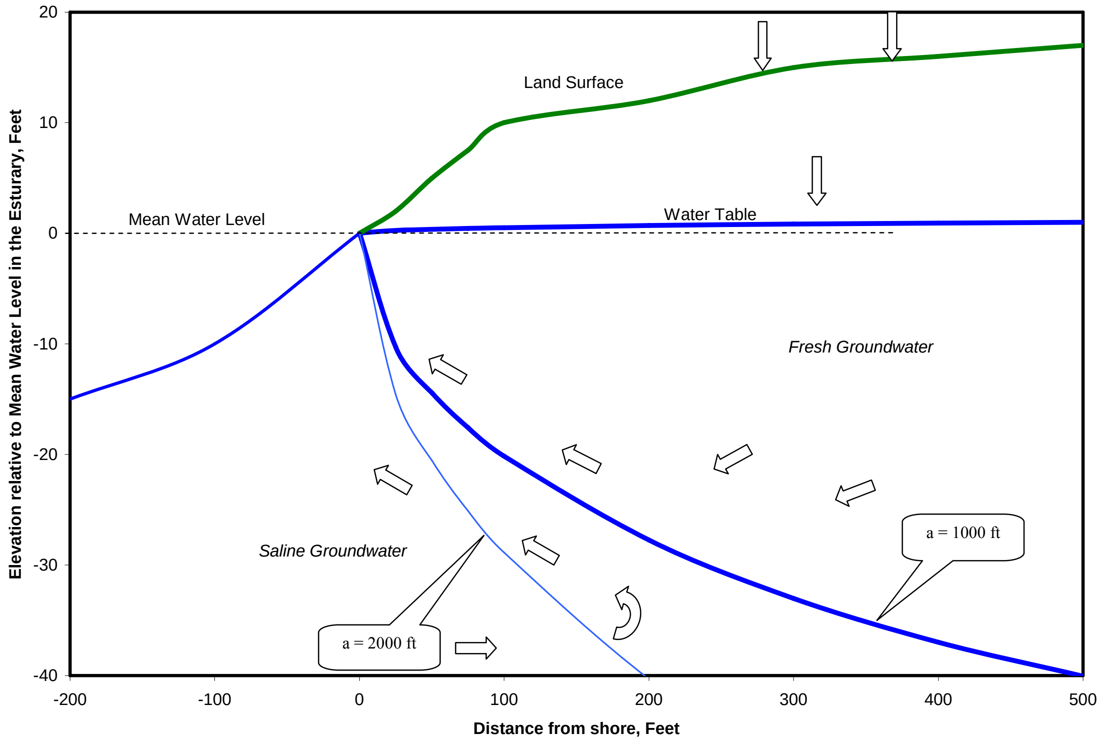


Figure 11. Fresh/salty groundwater interface at a coastal shoreline.

Figure 11 also shows that as the width of the land mass increases (“a” gets larger), the thickness of freshwater near the shoreline increases. This is because as the area of the land mass increases, recharge increases exponentially. The area of a circle is $a = \pi(r)^2$. If the radius of a land mass doubles, the area, and thus the amount of recharge, increases by a factor of 4.

Applying this analysis to the Herring River basin, we see that for even the smallest, most isolated land mass adjacent to the basin, the thickness of the freshwater lens is more than 30 feet at distances greater than 250 feet from the shoreline. This is the “worst-case” scenario and can be used to identify the areas most susceptible to encroachment of saltwater.

Comparison to Similar Hydrogeologic Environments

Another method for assessing the potential for saltwater intrusion is to look at the relationship between the fresh/salty groundwater interface at an ocean shoreline. This represents a worst-case scenario with a permanent saltwater body adjacent to the upland areas, as if the Herring River basin were permanently and continually flooded with saltwater. Comparison can be made to the hydrologic conditions found at existing ocean shorelines at the southern part of Indian Neck and at the homes bordering Wellfleet Harbor along Chequesset Neck Road. These areas have a small size; the groundwater recharge area is limited; and the areas are adjacent to or nearly surrounded by salt water in Wellfleet Bay and by tidal salt marsh. Michaud and Cambareri (2003) show that these areas have local groundwater flow cells that are largely independent of the regional aquifer.

Southern Indian Neck Area

Indian Neck is a peninsula that protrudes into the east side of Wellfleet Harbor (Figure 12). The south part of Indian Neck is topographically and hydrologically isolated from the north part of Indian Neck and the mainland (Figure 13). A large salt marsh east of Indian Neck creates a hydrological separation from the mainland. A smaller salt marsh area separates the north and south parts of Indian Neck, both hydrologically and topographically. There is a narrow, low-lying connection between the north and south parts of Indian Neck, but it is not of sufficient size to be hydrologically significant. Hydrologically, we can think of the southern part of Indian Neck as an island (Figure 13).

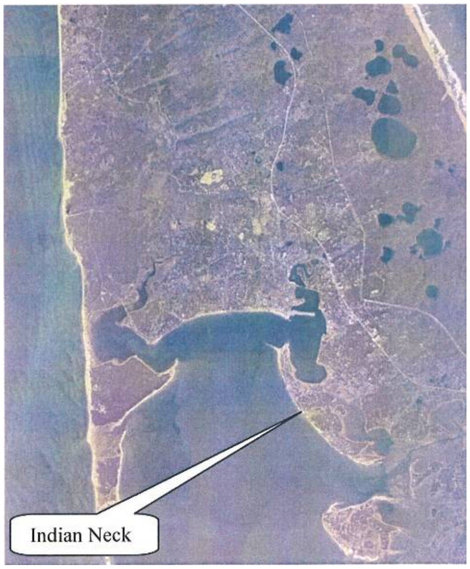


Figure 12. Location of Indian Neck.

The southern part of Indian Neck ranges from about 800-1500 feet wide and is about 3000 feet long. The only source for fresh groundwater underlying the area is infiltration of local recharge from precipitation. There is no inflow of groundwater from adjacent areas. Using the methods presented in Fetter (2001) and previously described in this report, the thickness of the fresh groundwater lens underlying Indian Neck is computed to be about 19 feet in the narrower part of southern Indian Neck and about 35 feet in the wider area of southern Indian Neck. Cross-sections showing these relationships are shown on Figures 14 and 15.

Figure 13. Map of Indian Neck in the eastern part of Wellfleet Harbor.

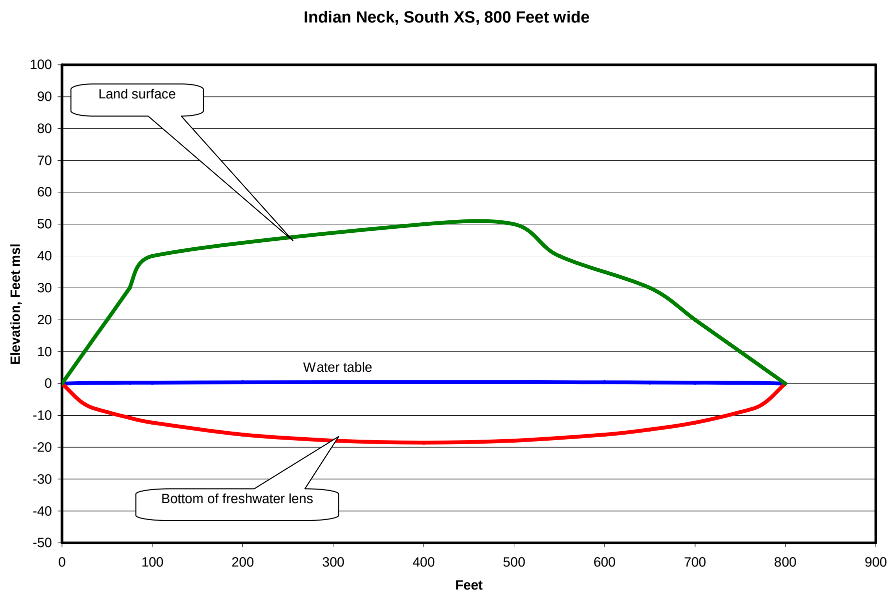


Figure 14. Hydrologic cross-section through the southern part of southern Indian Neck. (800 foot wide section from Figure 13)

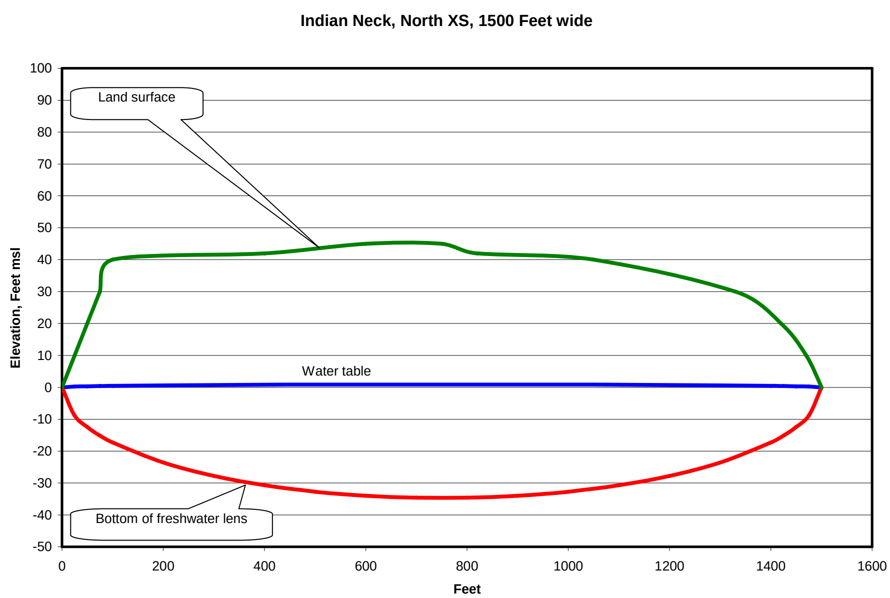


Figure 15. Hydrologic cross-section through the northern part of southern Indian Neck. (800 foot wide section from Figure 13).

Theoretically, there should be enough of a fresh groundwater lens underlying the southern part of Indian Neck to allow construction and pumping of low-yield domestic wells. A well could be constructed by drilling to a few feet below the water table. The screened section of the well casing should not be too close to the freshwater/saltwater interface because that would result in drawing salty groundwater into the well during pumping.

Figure 16 is a parcel map of the southern part of Indian Neck showing the location of water wells (red dots). The blue line is approximately 200 feet from the shoreline.

Figure 16. Location of wells on the southern part of Indian Neck.

As previously discussed, there should be sufficient thickness of fresh groundwater 200-250 feet inland from the shoreline to allow construction of low-yield domestic wells. Many of the wells on Indian Neck are less than 250 feet from the shoreline, indicating that there is fresh groundwater available for wells at this distance from the shoreline. The setback distance for wells from the shoreline is partly dictated by the need to locate the well on the owner's property and also to maintain a 100-foot setback between well locations and septic leachfields.

Well completion and water chemistry reports for the southern part of Indian Neck were obtained from the Wellfleet Board of Health. Basic water chemistry data were available for 24 wells in this area. Specific conductivity of water from these wells was evaluated as an indicator of overall water quality. The specific conductivity of water from two of the wells exceeded 500 umhos/cm. These samples were 660 and 783 umhos/cm, but would still be classified as freshwater (Fetter, 2001). Four other wells in this area produced water with specific conductivity between 450-500 umhos/cm. As a point of comparison, the EPA recommended limit for total dissolved solids in drinking water is 500 mg/l, which is approximately equivalent to a specific conductivity of 800-850 umhos/cm. Fresh groundwater from the Cape Cod aquifer (that is groundwater that is not influenced by intrusion of salt water) generally has a specific conductivity of less than 175 umhos/cm (Frimpter and Gay, 1979)

Examination of well construction and water quality data for the southern part of Indian Neck shows that even a relatively small, hydrologically isolated area will have sufficient groundwater recharge to form a freshwater lens of sufficient size and thickness to supply low-volume, private, domestic wells. Examination of the records shows that there are many wells located within 200-250 feet of Wellfleet Bay that supply good quality water for domestic use.

Homes along Chequesset Neck Road

Data were available for 12 private, domestic wells along Chequesset Neck Road between the golf course entrance and the Herring River dike (Figure 17). The dark line drawn on the map is 250 feet from the shoreline of Wellfleet Harbor. Most of the houses and wells along Chequesset Neck Road are within 250 feet of the ocean, indicating that there is an adequate thickness of fresh groundwater within 250 feet of the shore to allow construction of low-yield, domestic wells. Well locations are partly dictated by lot size. Better quality groundwater could be obtained from wells set back farther from the shoreline.

Figure 17. Location of houses along Chequesset Neck Road adjacent to Wellfleet harbor.

Water quality from these wells is highly variable. Some wells that have very poor water quality are only a short distance from wells having acceptable water quality. In some cases, water quality tests for the same well range from acceptable to very poor. Analysis of the data and well locations revealed that the wells having poor water quality were generally within about 100-150 feet of the bay, very close to the margin of the aquifer. At these locations, the freshwater lens is probably less than 20 feet thick, and it would be quite easy to have the well screened in the transition zone between the salt and fresh groundwater. Pumping even small quantities of water from these wells for domestic uses may cause saltwater upconing into the screened section of the well.

The upland area southwest of the golf course should be of sufficient size to provide enough recharge to sustain a lens of freshwater sufficient to supply low-volume, private, domestic wells. However, homes located on the ocean-side of Chequesset Neck Road may be too close to the edge of the freshwater lens to allow construction of water supply wells without penetrating the transition zone between the fresh and saline groundwater. This problem is a function of proximity to the ocean and should not be affected in any way by reintroduction of tidal flow in Herring River and Mill Creek on the opposite side of the peninsula.

Identification of "At-Risk" Areas

The areas most likely to be susceptible to saltwater encroachment are those locations where private, domestic wells are less than 250 feet from areas that will be inundated by high tides. The distance of 250 feet is likely very conservative. The previous discussion concluded that wells more than 250 feet from an ocean shoreline will probably produce good quality water. The tidally affected areas in the Herring River basin will be inundated by diluted seawater on a cyclical basis. The freshwater/saltwater interface will be dominated by fresh groundwater flow from the upland areas, pushing the interface upward and outward.

Spaulding and Grilli (2001 and 2005) conducted modeling of tidal flow in the Herring River basin for various degrees of opening the dike at the mouth of Herring River. High tide for full restoration of tidal flow would be 1.65 meters (5½ ft) above sea level.

We combine the high tide prediction with the distance of 250 feet from the shoreline to conclude that areas that are more than 250 feet beyond 6 foot elevation contour have almost no risk of being affected by saltwater intrusion (Figure 18). Wells that are within 250 feet of the high tide elevation are identified as being potentially at risk. However, as has been discussed several times earlier in this report, even those wells within 250 feet of the tidal areas have a low-risk of being adversely affected because the fresh groundwater flow is upward and outward and the low permeability sediments underlying the saltmarsh inhibit the infiltration of saltwater into the underlying sand aquifer.

Cape Cod National Seashore
Massachusetts

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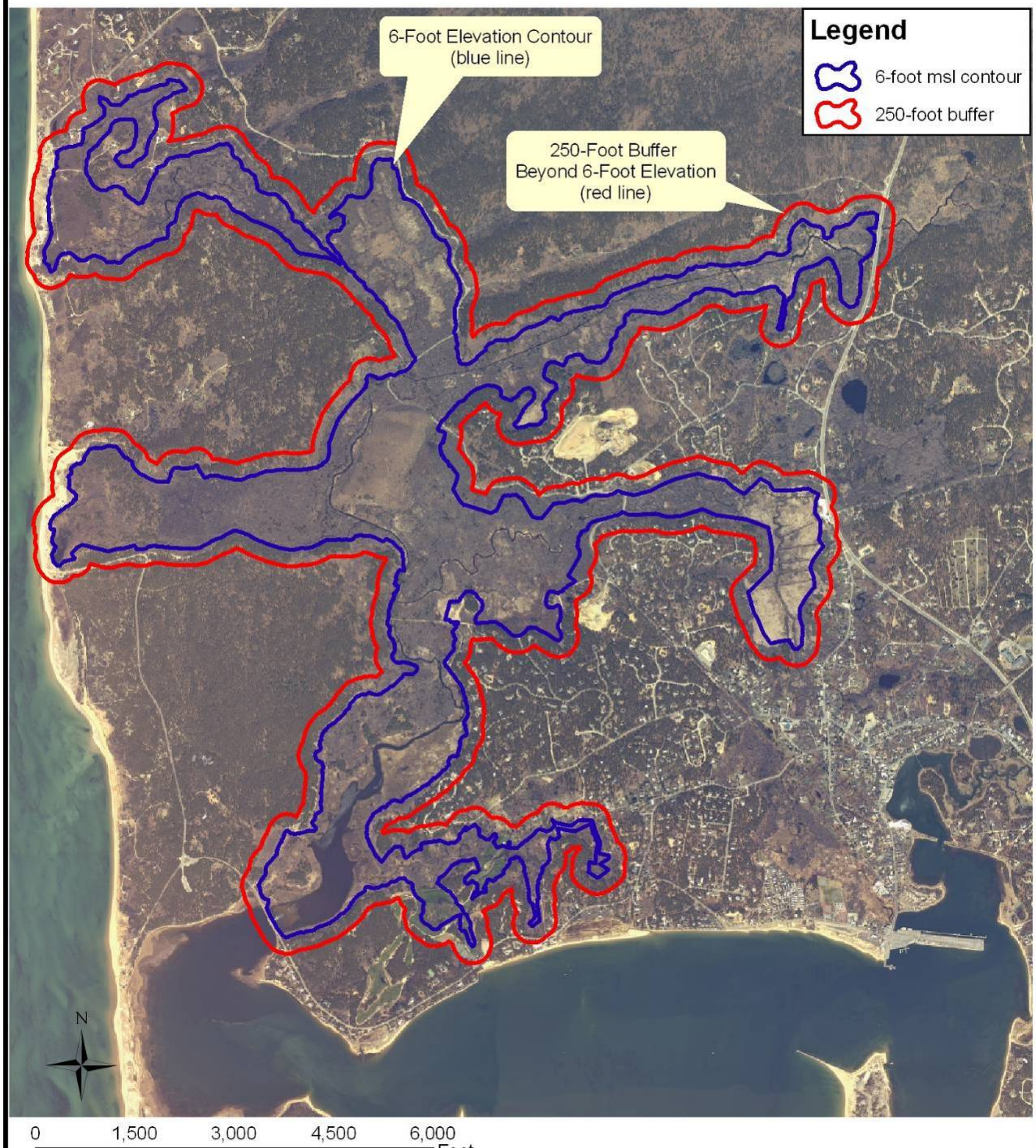
Figure 18. Areas within 250 horizontal feet of the 6-foot elevation contour



Produced by Water Resources Division

March 2007

We would expect that all of the upland areas will continue to have sufficient thickness of freshwater to continue to provide water for low-yield domestic wells in the area. The size and shape of the freshwater lens is controlled by recharge (local infiltration of precipitation) and the permeability of sediments underlying the area. There may be some thinning of the freshwater lens where the upland areas meet the river valley if the groundwater underlying the valley becomes predominantly salty. However, a short distance inland (200-250 feet) the freshwater lens should remain thick enough to provide water for private domestic wells. In the following sections of this report, we look at subareas within the Herring River basin to identify specific parcels of private properties that should be examined more closely to assess the potential threat to individual, potable water wells. The figures accompanying the following discussions of potential impacts for subareas within the Herring River basin are not detailed enough to identify individual parcels, roads, etc. The figures show the general areas where additional information is needed to fully evaluate the potential for saltwater intrusion following tidal restoration.

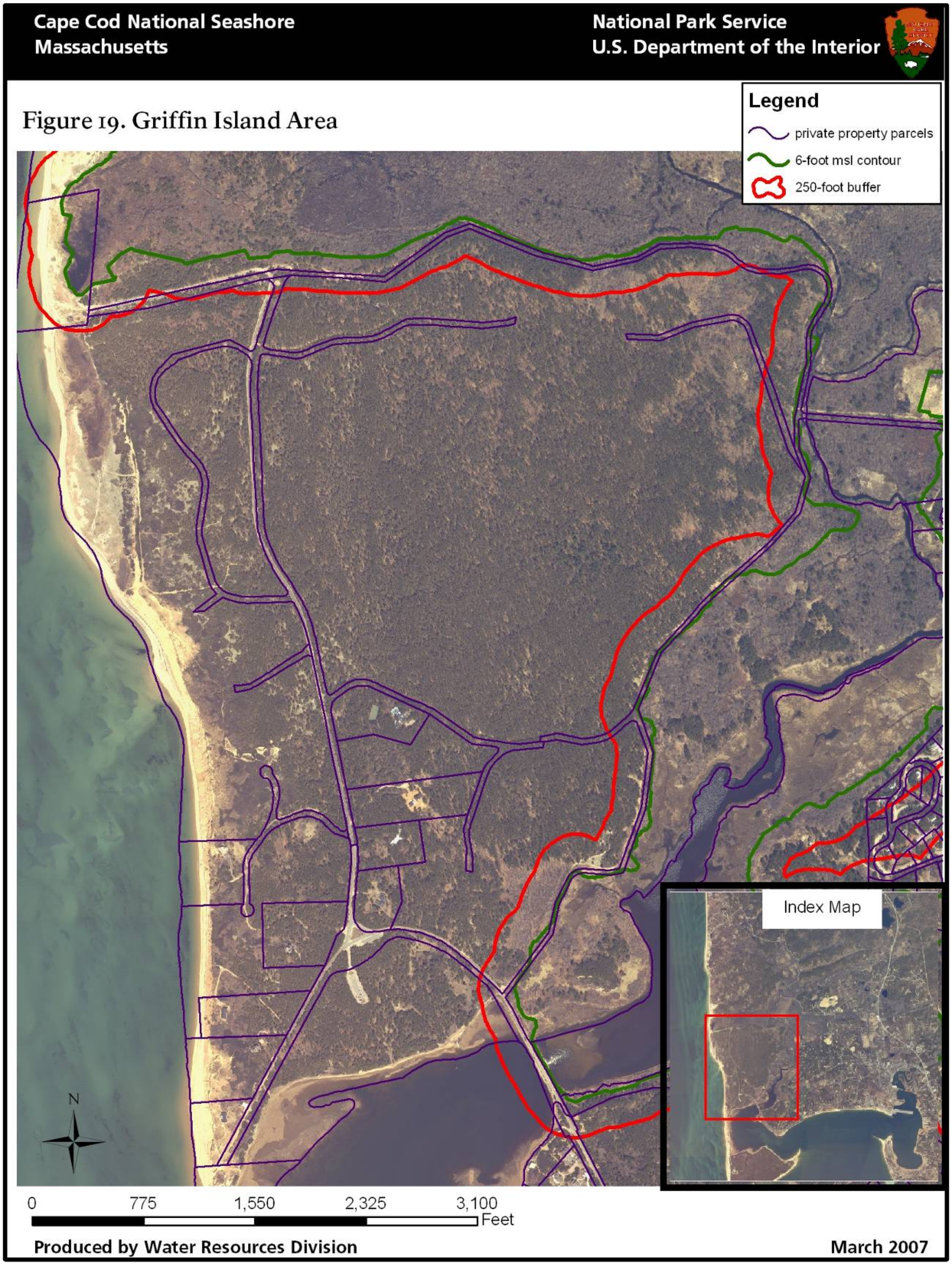
Griffin Island

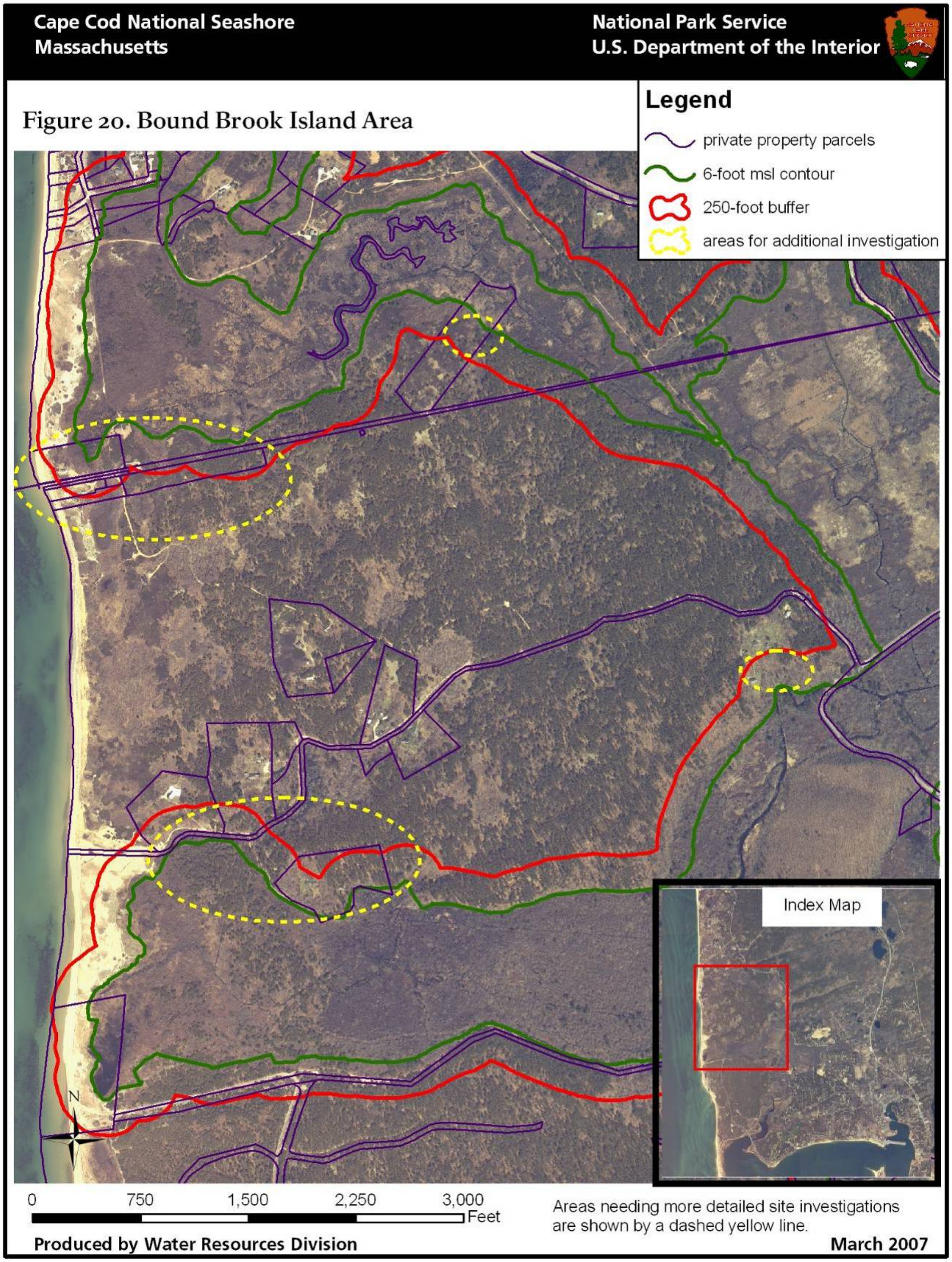
There is no private property on Griffin Island that is within the area (250 horizontal feet from the 6 foot contour) of potential impacts from tidal restoration (Figure 19). The parcel shown on the beach in the northwest corner of Figure 19 is town-owned property at Duck Harbor Beach.

Bound Brook Island

Hydrologically, we can think of Bound Brook Island as a circular island with a diameter of 2500 feet, surrounded by salt water. The “island” is large enough that infiltration of precipitation will sustain its own groundwater mound. In reality, the “island” is not totally hydrologically separated from other areas to the east and northeast on the opposite side of the Herring River valley. Treating it as an island allows analysis of the worst-case situation. Potentially at-risk properties in the area of Bound Brook Island are shown on Figure 20.

There is a small cluster of houses on park service land on the east side of Bound Brook Island, just to the south of Bound Brook Island Road. The location of well(s) providing water for these houses should be identified. The further upland (north and west) the better, as these houses are near the eastern margin of the fresh groundwater mound underlying Bound Brook Island.


Cape Cod National Seashore
Massachusetts
National Park Service
U.S. Department of the Interior
Figure 19. Griffin Island Area
Legend
private property parcels
6-foot msl contour
250-foot buffer
Index Map
N
0
775
1,550
2,325
3,100
Feet
Produced by Water Resources Division
March 2007


Cape Cod National Seashore
Massachusetts
National Park Service
U.S. Department of the Interior
Figure 20. Bound Brook Island Area
Legend
private property parcels
6-foot msl contour
250-foot buffer
areas for additional investigation
Index Map
N
0
750
1,500
2,250
3,000
Feet
Areas needing more detailed site investigations are shown by a dashed yellow line.
Produced by Water Resources Division
March 2007

There are 3-4 houses at the southwestern part of the island that may have wells susceptible to salt water intrusion. The locations of wells at these houses should be identified so that we can make a better assessment of the potential for impact. In particular, the well for parcel 258686 (not identified on the map) may be most susceptible as most of that parcel lies within 250 horizontal feet of the predicted high tide zone.

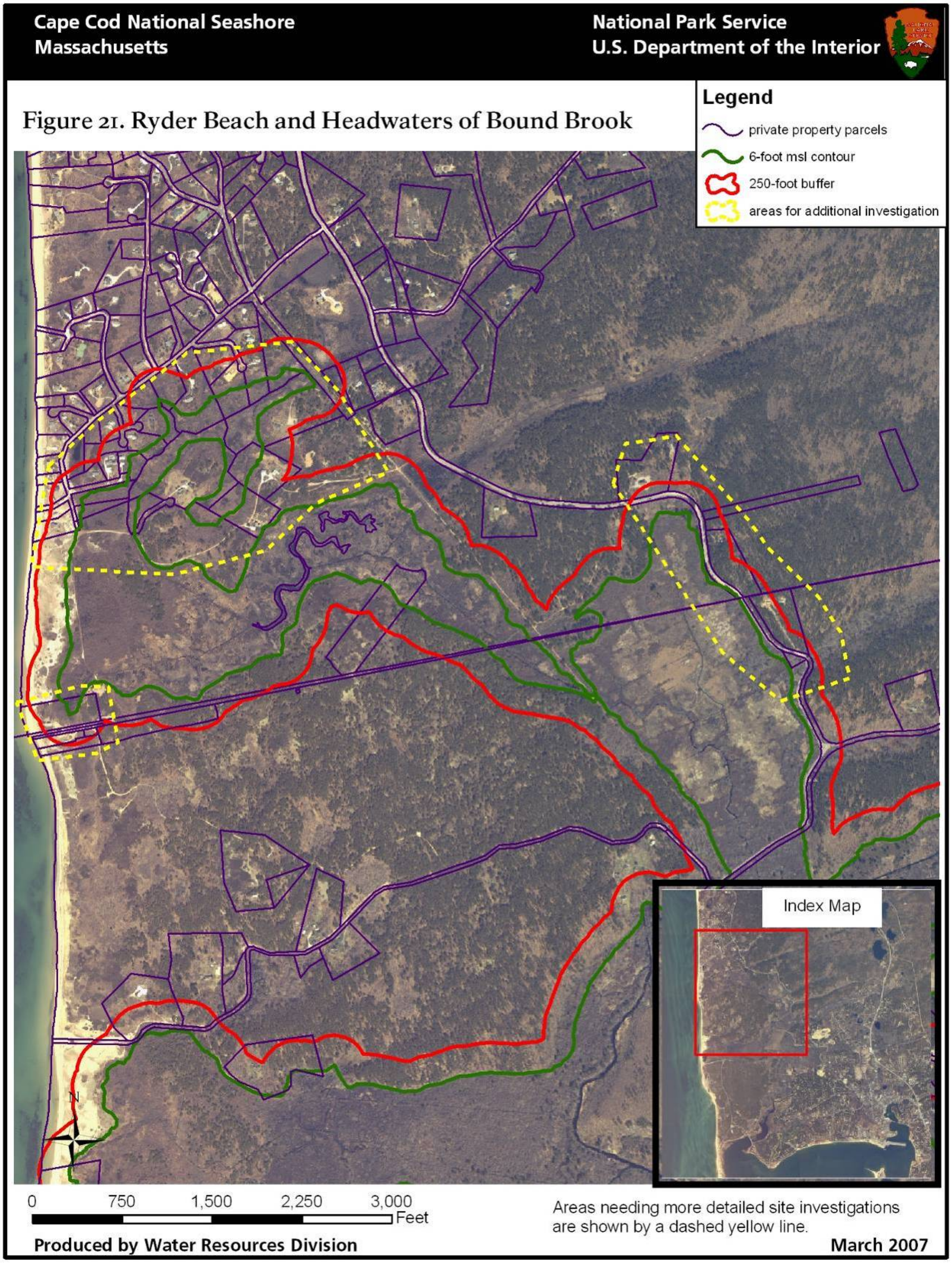
There are several houses at the northwestern part of the island that may have wells susceptible to salt water intrusion. Wells at these houses may be more susceptible due to their proximity to the ocean. We could look at wells for the houses at the southwestern part of Griffin Island as an indication of probable hydrologic conditions that will occur at the northwestern part of Bound Brook Island. Relocation of the wells a few hundred feet to the south and east would remediate the problem if salt water intrusion occurred.

Ryder Beach and Headwaters of Bound Brook

Salt water intrusion in this area should be less of a problem than other areas. This is the very uppermost part of the Herring River basin. The salinity of tidal flow will be decreased this far upstream and the duration of tidal flooding will be less. Fresh groundwater will probably prevail in the sediments underlying the river valley. Nevertheless, we conducted the analysis for potentially susceptible water wells in the same manner, identifying properties within 250 horizontal feet of the predicted high tide elevation. Potentially at-risk properties in this area are shown on Figure 21.

Three houses are located along the east and north side of Old County Road between Paradise Hollow and Lombard Hollow. Wells at these locations will probably be unaffected due to their location in the upper part of the basin and their proximity to large upland areas to the northeast, but we should check the locations of wells on the properties to provide a better estimate of their susceptibility. If necessary, relocation of wells toward the upland side of the property should be sufficient remediation.

Several houses on Ryder Beach, about the southernmost 4-6 houses, may have wells that are susceptible to salt water intrusion. The vulnerability of wells at these houses is highly dependent


Cape Cod National Seashore
Massachusetts
National Park Service
U.S. Department of the Interior
Figure 21. Ryder Beach and Headwaters of Bound Brook
Legend
private property parcels
6-foot msl contour
250-foot buffer
areas for additional investigation
Index Map
N
0
750
1,500
2,250
3,000
Feet
Areas needing more detailed site investigations are shown by a dashed yellow line.
Produced by Water Resources Division
March 2007

on the salinity and duration of tidal flow in that area of the Bound Brook drainage basin lying just east of Ryder Beach.

Wells at several houses south of Ryder Beach Road may be susceptible to salt water intrusion, depending on the salinity and duration of flooding by tidal flow in this area. The most susceptible wells are those at the 4-5 houses located on the "peninsula" protruding into the Bound Brook basin from the northeast.

Herring River South of Pamet Point Road

Salt water intrusion in this area should also be less of a problem than areas further downstream. This is the very uppermost part of the Herring River basin. The salinity of tidal flow will be decreased this far upstream and the duration of tidal flooding will be less. Fresh groundwater will probably prevail in the sediments underlying the river valley. Nevertheless, we conducted the analysis for potentially susceptible water wells in the same manner, identifying properties within 250 horizontal feet of the predicted high tide elevation. Potentially at-risk properties in this area are shown on Figure 22.

There are two properties on the north side of the river that are within 250 feet of the 6-foot contour. Wells at these houses should be unaffected due to the inflow of fresh groundwater from the upland area to the north. Well locations and conductivity of water from the wells should be investigated as a precautionary measure.

There are about a dozen houses on the south side of the river that may have wells susceptible to salt water intrusion. The severity of the threat depends, in part, on the salinity and duration of tidal flooding in the river. Wells in this area should be investigated to determine their location on the property and their proximity to the valley. Wells at these houses will probably be unaffected due to the inflow of fresh groundwater from adjacent upland areas to the south and east.

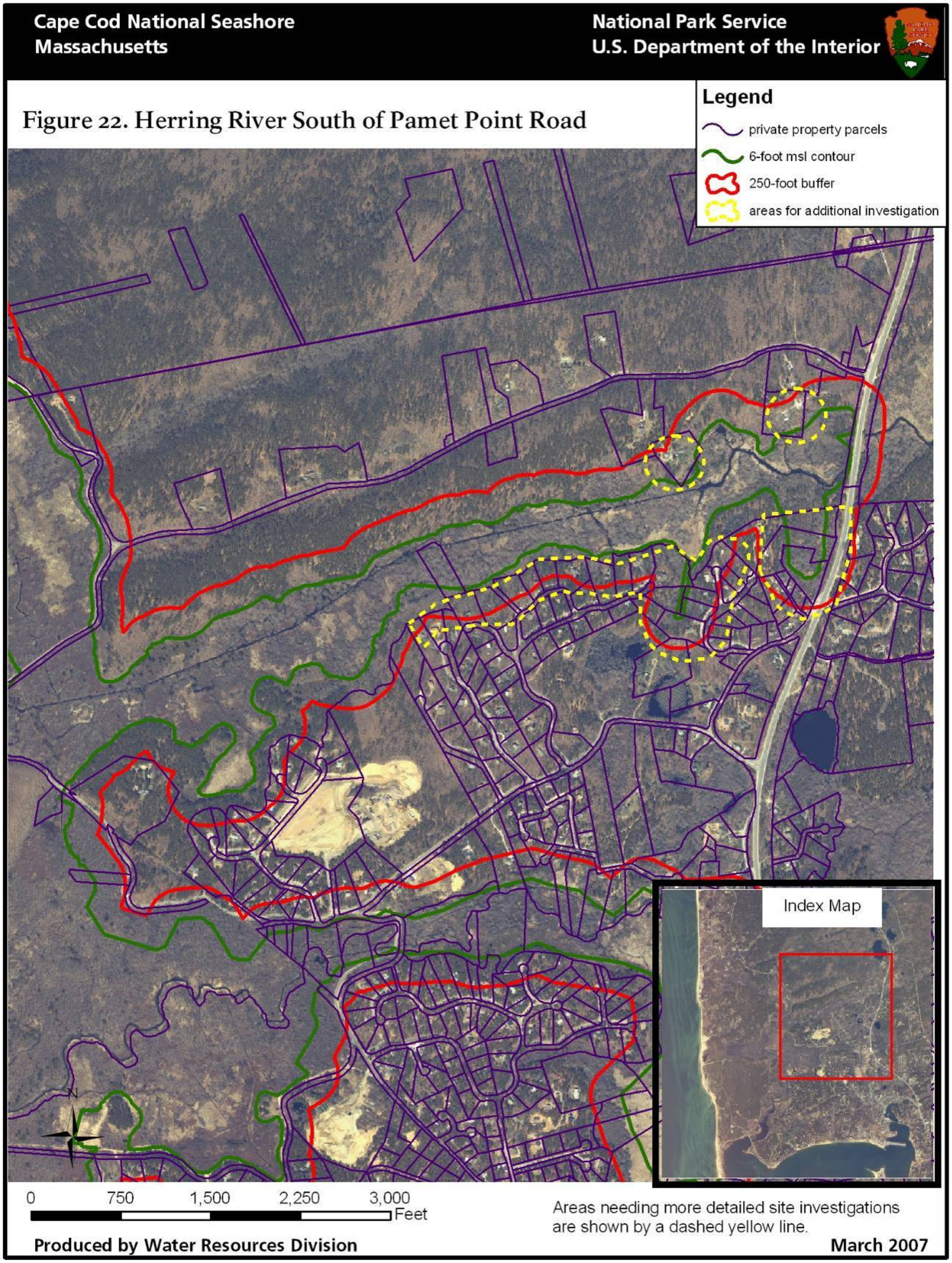


Figure 22. Herring River South of Pamet Point Road

Coles Neck

Most homes on Coles Neck are hooked into a public water supply system. There shouldn't be any wells in this area that could be affected. However, in case there are some private wells in the area, potentially at-risk properties are shown on Figure 23.

The well for the house at the west end of Coles Neck should be investigated (access off of Bound Brook Island Road). There are also several properties on the northwest side of Coles Neck and several along the south side of Coles Neck that should be investigated.

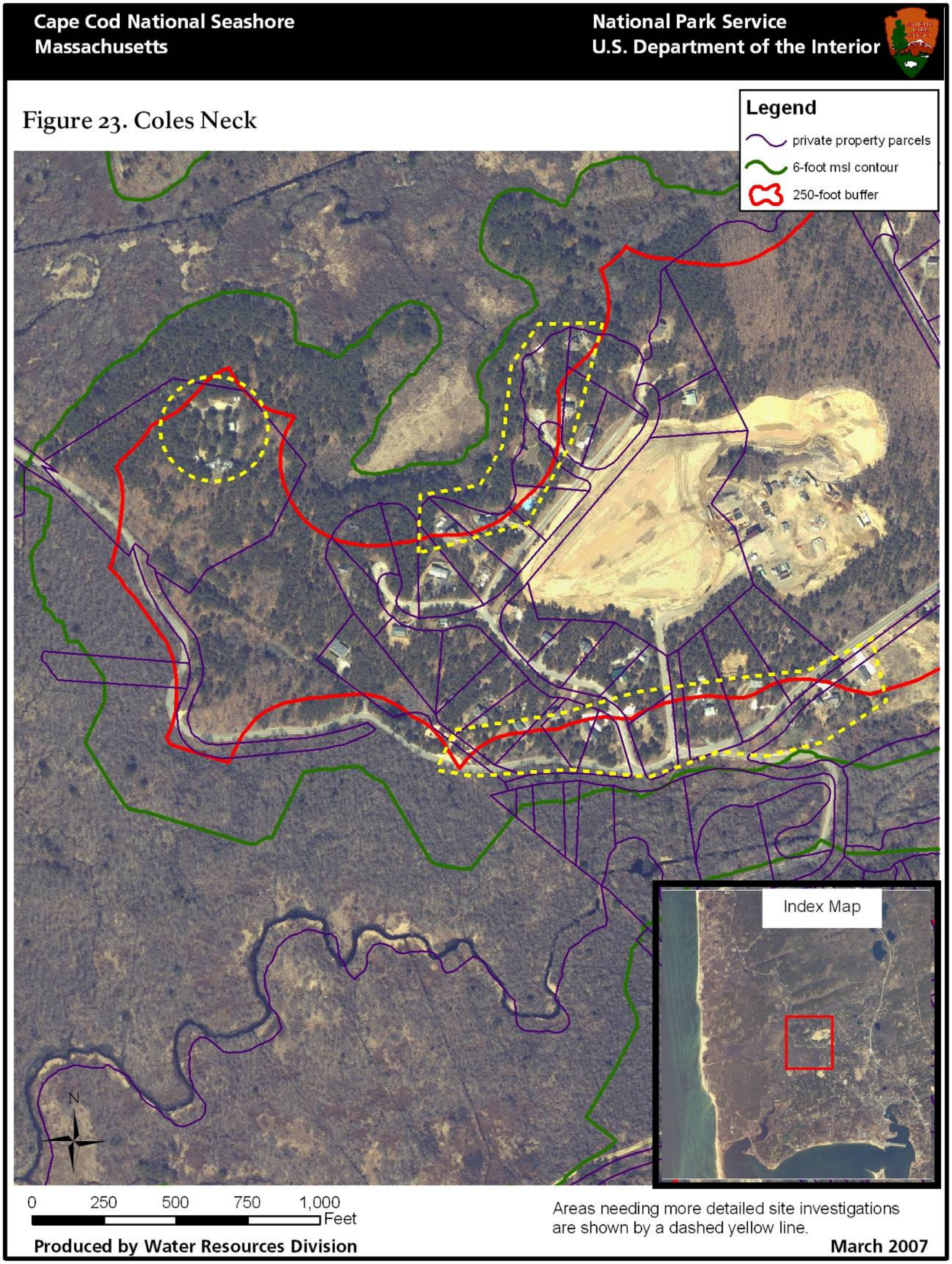
South of Coles Neck, East of Pole Dike Road

There are several properties that may be at risk depending on how much tidal flow is restored upstream of the Pole Dike Road crossing. Potentially at-risk properties are shown on Figure 24. Most likely, the wells at these properties will not be adversely affected because it is an upstream area that will have decreased tidal flow. Most of the wells are probably located near, or beyond, the 250-foot buffer and are adjacent to large, upland land masses with groundwater flowing outward toward the valley.

East Side of Lower Herring River

Wells providing water for houses adjacent to the river valley should be investigated more closely to determine their location on the parcel, and thus their distance from the probable high tide zone. Most of these wells should be unaffected because they are at the margin of the large upland area comprising Wellfleet Center. Larger land masses receive more recharge resulting in a deeper freshwater/saltwater interface at the margins of the freshwater lens. Potentially at-risk properties in this area are shown on Figure 25.

This is the area that was investigated by Fitterman and Dennehy (1991). The monitoring wells in the area (Figure 3) show that the thickness of the freshwater lens is generally greater than 60 feet. There may be some thinning of the freshwater lens by intrusion of saltwater. Computer modeling by Masterson (2004) predicts that the thinning should be no more than 10 feet, leaving at least a 50 foot thickness of freshwater. Martin (2004) predicts that under worst-case simulations of a permanent saltwater body in the river basin, the freshwater aquifer would be 30 feet at a distance of 250 feet from the shoreline.



Cape Cod National Seashore
Massachusetts
National Park Service
U.S. Department of the Interior
Figure 23. Coles Neck
Legend
private property parcels
6-foot msl contour
250-foot buffer
Index Map
N
0 250 500 750 1,000
Feet
Areas needing more detailed site investigations are shown by a dashed yellow line.
Produced by Water Resources Division
March 2007

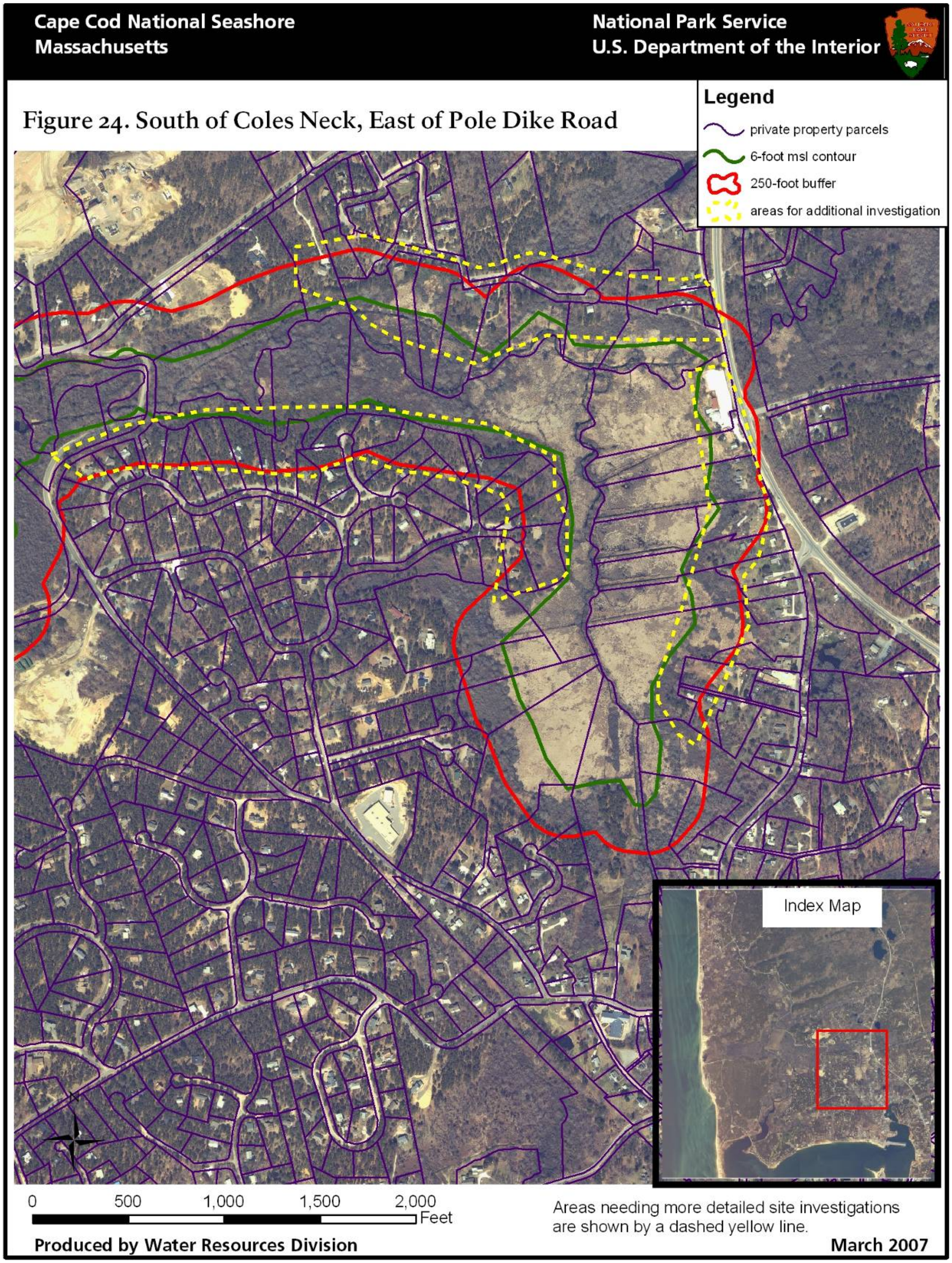
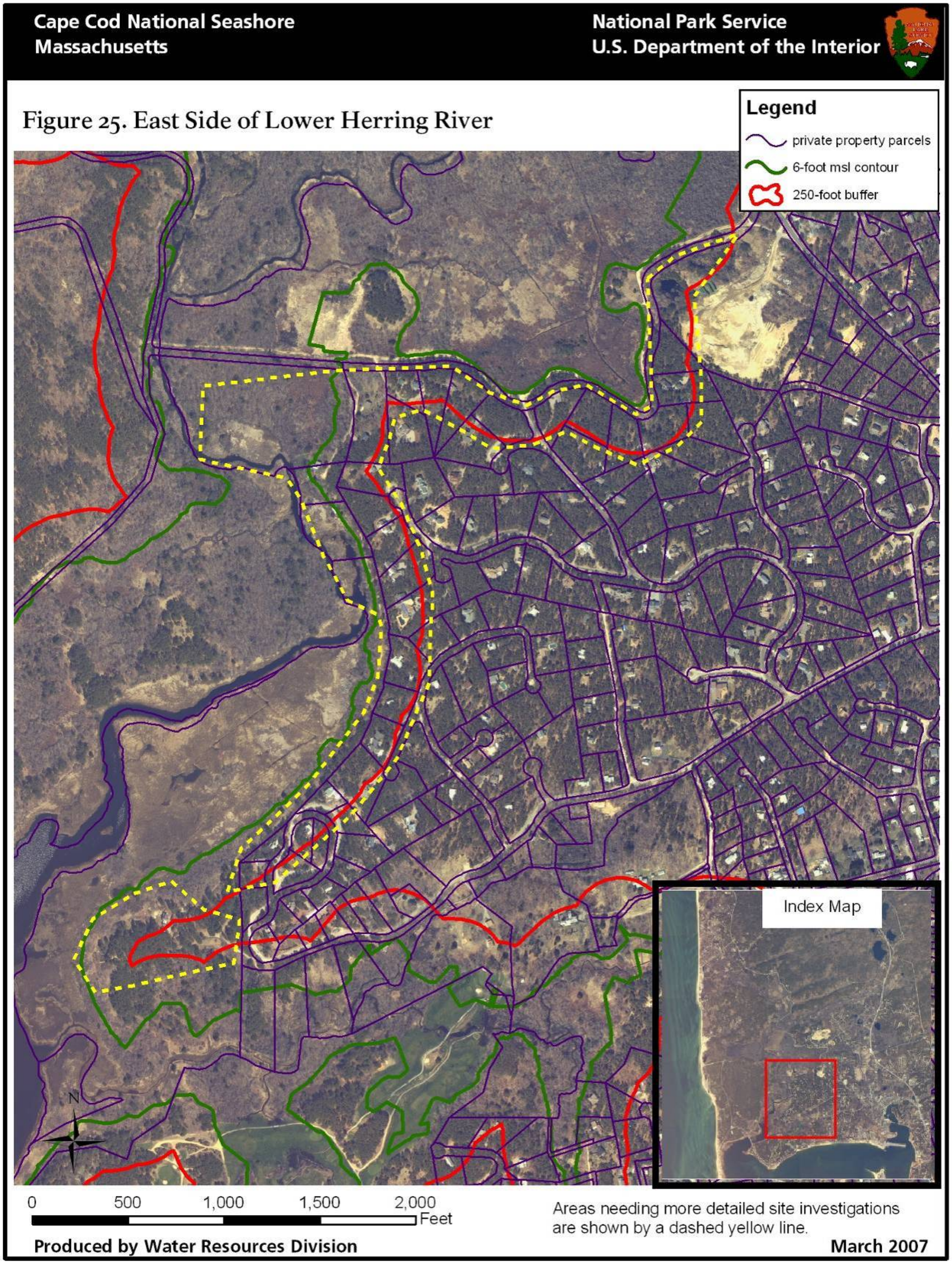


Figure 24. South of Coles Neck, East of Pole Dike Road



Cape Cod National Seashore
Massachusetts
National Park Service
U.S. Department of the Interior
Figure 25. East Side of Lower Herring River
Legend
private property parcels
6-foot msl contour
250-foot buffer
Index Map
N
0
500
1,000
1,500
2,000
Feet
Areas needing more detailed site investigations are shown by a dashed yellow line.
Produced by Water Resources Division
March 2007

A couple of the houses are almost certain to require relocation of the well or import of drinking water to the parcel. These are parcels 264653 and 264654 (not identified on Figure 25), which are immediately to the east of the river and below the 6-foot elevation contour. These parcels are about 300 meters south of Hopkins Drive. NPS is seeking to acquire and terminate residency on one of these properties; disposition of the second property is presently unresolved.

Another location that should be investigated is the house located off the west end of Old Chequesset Neck Road. It's at the end of the peninsula bounded by the Herring River to the northwest and Mill Creek to the south. The parcel number is 268674 (within the dashed yellow oval on Figure 25).

Mill Creek

Wells at 3-4 houses on the south side of Old Chequesset Neck Road may be affected by tidal flooding in the Mill Creek basin. These wells will likely be unaffected because they are at the margin of the large upland area comprising Wellfleet Center. Larger land masses receive more recharge, resulting in a deeper freshwater/saltwater interface at the margins of the freshwater lens. Likewise for wells at parcels in the very upper reaches of Mill Creek (east end of the Mill Creek basin). Fresh groundwater flow from the Wellfleet area will probably protect wells at these parcels. Potentially at-risk properties in this area are shown on Figure 26.

Wells in the area between Mill Creek and Chequesset Neck Road should be investigated more closely, e.g., in the vicinity of Mill Creek Lane. Tidal flow into the Mill Creek Basin will probably limit the freshwater aquifer to a narrow strip between Wellfleet Harbor and the saltmarsh, although the area will be similar in size to the southern Indian Neck area, which has been shown to be large enough to support a freshwater aquifer.


Cape Cod National Seashore
Massachusetts
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Figure 26. Mill Creek
Legend
private property parcels
6-foot msl contour
250-foot buffer
areas for additional investigation
Index Map
N
0
500
1,000
1,500
2,000
Feet
Areas needing more detailed site investigations are shown by a dashed yellow line.
Produced by Water Resources Division
March 2007

Chequesset Neck Road

Wells at parcels along Chequesset Neck Road will not be affected by restoring tidal flow in the Herring River basin. There are no houses located closer than 250 feet to potential tidal zones in the Herring River and Mill Creek drainage basins (Figure 27). These wells are already in close proximity to a permanent body of salt water. Availability of fresh water is governed by local recharge in the adjacent upland areas to the north and northeast. Investigation of water quality at these wells can be used to provide indications of the amount of setback needed to allow construction of a well in the fresh groundwater lens, with minimal influence from the underlying salt water. This information can be used to establish minimum setbacks that will be needed throughout the Herring River basin to protect individual water supply wells.

Well Construction

Well construction and water quality data were obtained for 103 wells in the Herring River Basin. These wells are all on properties that are at least partially within the 10 foot contour line adjacent to the river basin. These wells are potentially susceptible to saltwater encroachment. Well construction data were available for 48 of these wells. Of these 48, 43 penetrate less than 30 feet below the water table and 75% penetrate less than 25 feet below the water table

The sand comprising the Cape Cod aquifer is very permeable. It is not necessary to penetrate deep into the aquifer to obtain enough water for low-yield, domestic wells. In most cases, drilling 10-15 feet below the water table and completing the well with a 2-3 foot screened section is adequate for a domestic well. A low-yield, domestic well constructed in this manner should provide good-quality water where the thickness of the freshwater part of the aquifer exceeds 30 feet.


Cape Cod National Seashore
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Figure 27. Chequesset Neck Road
Legend
private property parcels
6-foot msl contour
250-foot buffer
Index Map
N
0
500
1,000
1,500
2,000
Feet
Areas needing more detailed site investigations are shown by a dashed yellow line.
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March 2007

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NPS D-383, April 2007

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