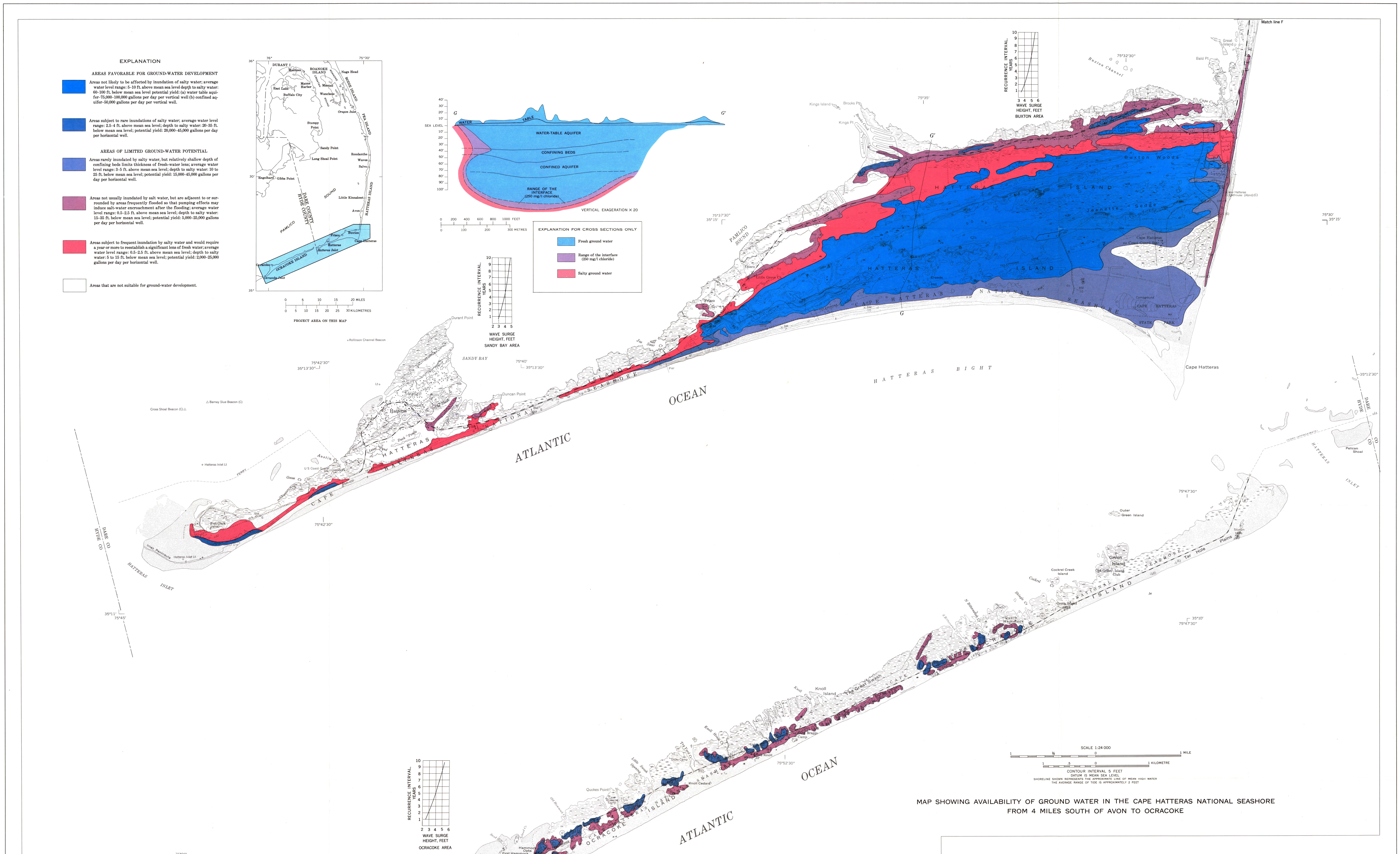
DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY

PREPARED IN COOPERATION WITH THE
U.S. NATIONAL PARK SERVICE

HYDROLOGIC INVESTIGATIONS
ATLAS HA-540 (SHEET 2 OF 2)



The curves may be used to estimate the maximum potential ground-water yield anywhere in the seashore if the height of the water table and the depth to the interface are known. For example, given an initial water level of 2.5 feet, the maximum continuous rate of discharge would be about 17.5 gpm for a 100-day pumping period. At the end of that time, the salt water-fresh water interface would have risen nearly 11.5 feet. The initial depth to the interface will determine whether or not salty water will be drawn into the well under these conditions. Similarly, if the depth to the interface is known to be 10 feet below mean sea level, the maximum discharge would be that which causes a 10-foot rise in the interface, or about 15 gpm at the initial water level of 2.5 feet.

A study by Kriz (1972) was conducted using a Hele-Shaw analog model to predict maximum safe pumping rates from a horizontal gallery on long oceanic islands such as the Outer Banks. Direct comparison between the results of this study and the modeling study is difficult because the necessary assumptions required were different, notably the hydraulic conductivity of the aquifer. Also, the yield values in the model study were calculated for continuous pumping conditions with provision for periodic recharge to the system, whereas for this study the yield values were calculated on the basis of no recharge during a 100-day pumping period. However, by extending some of the model data and extrapolating some values, results seem to be comparable.

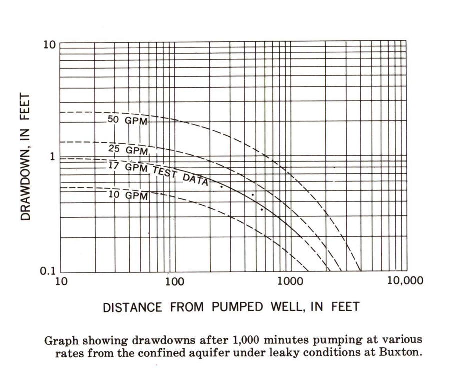
If more than one horizontal well system are to be constructed in a given area of the seashore, the effects of mutual drawdown interference must be considered. Because relatively small drawdowns produce significant rises of the interface, the additive effects of overlapping drawdowns is of critical importance. The rise in the interface at a point, whether caused by drawdowns of a single well or multiple wells may be determined from the graph showing the relation between head change and depth of the interface. Thus, it is important to estimate at what distances mutual drawdown interference between pumping horizontal wells will be negligible.

Hantush and Papadopulos (1962) have shown that beyond a distance equal to five times the length of a horizontal well the flow towards the well is essentially radial and may be treated as flow towards a vertical well. Calculations on this basis indicate that at pumping rates of 25 gpm or less drawdowns are negligible beyond 500 feet from a 100-foot horizontal well. Thus, such wells may be spaced 1,000 feet apart without excessive interference.

The most hydraulically efficient means of recovering the maximum amount of ground water in the seashore is by use of a horizontal well system. The maximum potential yield of a 100-foot horizontal well may be calculated using an average height for the water table of 3 feet. The maximum rate of discharge for a 100-day period would be 22 gpm, producing a total of about 3.2 million gallons. Assuming a radius of maximum influence from the pumping of about 1,000 feet, the amount of fresh ground water recoverable in the 100 days would be equivalent to about 28 million gallons per square mile, or nearly 10 percent of the annual recharge to the aquifer system. By comparison, the total amount of water used at all the campgrounds in the seashore in 1970 was about 15 million gallons.

On the larger land masses at Buxton and on Bodie Island, the hydraulic efficiency of horizontal well systems is not necessary because the fresh water lens is thicker and the presence of confining beds hamper the upward movement of salty water due to pumping. (See geohydrologic sections *A-A'*, sheet 1 and *G-G'*, sheet 2.) In these areas the total availability of fresh ground water is greater because supplies may be developed not only from the water-table aquifer, but also from the deeper aquifer below the first series of confining beds.

Development of water supplies from the deeper aquifer has its chief advantage in that the aquifer is less susceptible to surface pollution, however, these aquifers are confined and drawdowns due to pumping affect larger areas. A distance-drawdown graph for the confined aquifer at Buxton shows that at various rates of pumping over 10 gpm measurable drawdown effects would extend to over 5,000 feet after nearly a day. For this reason large water supplies under continuous pumping conditions cannot be developed from the deeper aquifers except by spreading wells over a large area to reduce the effects of mutual drawdown interference. Large supplies of water can be more feasibly obtained from the shallower, unconfined aquifer.



Graph showing drawdown after 1,000 minutes pumping at various rates from the confined aquifer under leaky conditions at Buxton.

For the well systems being operated at Buxton and Bodie Island, no problems with salt-water contamination have yet been detected under their present operating conditions (15–20 gpm per well for 1 to 2 hours per day). It is estimated that individual well yields as much as 50,000 gallons per day at rates not exceeding 50 gpm could be planned for intermittent operation without a serious salt-water encroachment problem. However, as with well fields at other sites in the seashore, samples of water from the wells should be obtained periodically for chloride analysis to determine if significant rises in the interface are occurring.

QUALITY OF WATER

Fresh water on the Outer Banks is of generally good quality with only a few problems associated with local conditions. The chemical compositions of typical fresh waters from the water-table aquifer in a narrow island section and the confined aquifer at Buxton may be compared in the chemical analyses table. Residence time of the water in an aquifer is a major factor that determines the amount of dissolved minerals in the water; the longer the water stays in the system, the more mineralized it generally becomes. A few constituents such as iron, sulfate, and dissolved carbon dioxide may decrease with time, however, due to chemical interactions within the system. The residence time in the water-table aquifer, such as at Salvo, is relatively short (weeks to months), resulting in a water quality characterized by low dissolved solids (50–150 mg/l) with an acid pH. In a confined aquifer such as at Buxton the residence time may be hundreds of years; the dissolved solids will increase to more than 300 mg/l with the pH changing from acid to neutral or slightly alkaline.

Color in ground water is principally from water-soluble organic chemicals originating in decayed vegetation through which the water has percolated. The organic matter may be recent accumulations as in the low-lying salt marshes adjacent to the sounds and in the higher swamps at Cape Hatteras, or buried peat beds representing older accumulations. Fresh ground water in most of the seashore has some degree of color, but shallow wells completed in, or adjacent to, swamps or marshes, or in wooded areas are more likely to produce highly colored water. The color of water can be reduced through coagulation and filtration processes.

Dissolved iron in the ground water may be as much as 2 mg/l in a few local areas in the seashore. Iron in excess of 0.3 mg/l is objectionable in a water supply because of esthetic and taste considerations. Water must generally be acidic to dissolve an appreciable amount of iron. Iron is usually present in the aquifer or in the metal of the pumping system. Usually the acidity of ground water results from the solution of carbon dioxide from the air and in the soil zones. There is some indication that water high in iron occurs in proximity to deposits of decaying organic material. Water in contact with the beds of shell materials that occur in the aquifers becomes alkaline and, consequently, loses any iron that it might have contained.

The odorous gas, hydrogen sulfide, is a variably occurring nuisance in the shallow ground-water system, and is also associated with decaying organic matter in the marshes and swamps. It may be easily removed from water by aeration or chlorination.

Shell beds are part of the marine deposits on the Outer Banks, and shell fragments also constitute a significant percentage of the sand, silt, and clay beds. Ground water acquires a $CaCO_3$ "hardness" as a result of solution of the shell material as the water percolates through these beds. Water in the confined aquifer is usually much harder (as much as several hundred milligrams per liter as $CaCO_3$) than water in the water-table aquifer, but may be treated to reduce the hardness where necessary. (See chemical analyses table.)

Typical chemical analysis of fresh ground water on the Outer Banks

[Constituents, in milligrams per liter, except color and pH units; hardness expressed as equivalent $CaCO_3$; depth, in feet below land surface.]

	Horizontal well Salvo Campground 7–31–72 Water-table aquifer	Composite sample NPS Buxton Maintenance area 8–1–72 Confined aquifer
Depth of sample	8 feet	75 feet
SiO_2	4.4	18
Fe	.033	.000
Ca	8.6	44
Mg	4.7	27
Na	27	57
K	4.7	19
CO_2	20	6
HCO_3	63	383
SO_4	8.6	2.2
Cl	31	35
F	.3	.6
Dissolved solids	128	402
Color	20	35
Total hardness	41	222
pH	6.7	7.8

AREAS OF POTENTIAL GROUND-WATER SUPPLY

The maps depict three general classifications under which the land areas of the seashore may be grouped with regard to their potential for fresh ground-water supplies: (1) areas favorable for ground-water development; (2) areas of limited ground-water potential; and (3) areas not suitable for ground-water development. The development of water supplies from areas within groups 1 and 2 is also contingent upon variable local hydrologic conditions, as distinguished on the maps.

About 85 percent of the land area of the seashore is not suitable for the development of ground-water supplies. This area mostly includes the low-lying marshes along the sound side of the islands where the water table is at or near land surface and the aquifer contains salty water, or perhaps contains a very thin fresh-water lens under the best of conditions. It also includes the beach and sand ridge areas within 500 to 800 feet of the ocean. These areas are unsuitable not only because the fresh-water lens is thinner, but also because the tidal range of the ocean is larger and produces a broader interface zone in the aquifer. These areas are also subject to wave surge that may top the lower parts of the sand ridges.

Lands in the vicinity of drainage canals are also not suitable for the development of water supplies. The lowering of the water-table resulting from construction of these canals has destroyed the fresh-water lens by raising the interface, as well as allowing ingress of salty water from the sound.

AREAS FAVORABLE FOR GROUND-WATER DEVELOPMENT

The areas that are favorable for ground-water development fall into two categories: areas that are not likely to be inundated by salty water, and areas subject to rare overwash from the ocean during hurricane-like storms. The high and wide island mass at Cape Hatteras and the smaller area on the southern end of Bodie Island, which was ringed by a protective dike, are the only parts of the seashore that are included in the former category. Their height and width have contributed to the build-up of a deep fresh-water lens along with the protection from overwash. Consequently, well yields as much as 100,000 gpd (gallons per day) may be available in these areas.

The high central parts of the narrow island areas are subject to inundations from storms and may be generally described as occurring between the limits of overwash on the sound side to the ocean-side dune ridges. The width of these areas ranges from about 200 to 800 feet. On Ocracoke Island, the most favorable areas for ground-water development occur along the central part of the island in the higher isolated hummocks that are separated by low areas subject to overwash. Should inundation of the higher hummocks occur, the salty water would be flushed fairly rapidly from the aquifer, depending on the amount of subsequent rainfall and the length of the inundation.

The potential yields of these areas, based on pumpage from a horizontal well system for a 100-day period, are estimated to range from 20,000 to 45,000 gpd per well.

AREAS OF LIMITED GROUND-WATER POTENTIAL

Proximity to the sounds and a high frequency of flooding by salty water from the sounds are major factors that limit the ground-water potential in many areas of the seashore. Dolan and Bosserman (1967) have established heights, directions, and recurrence intervals for the maximum probable wave surges at various places along the sound side of the Outer Banks. These were used as a guide in mapping the areas most frequently threatened by storm wave surges; graphs showing the recurrence interval versus the maximum probable wave surge height appear at selected locations on the maps.

The land areas rising from the sound-side marshes to about 5 feet are flooded on the average once every 2 or 3 years. Assuming average ground-water velocities of about 1 foot per day, it would take a year or more to flush the aquifer and to reestablish that part of the fresh-water lens invaded by the salty water. In addition, being on the flank of the barrier island, the lens is thinner and the average position of the salt-water interface is closer to land surface. Under the best conditions in these areas, potential yields up to 25,000 gpd may be expected from a horizontal well system.

Former beach ridges and other dune masses are found on the sound side of the islands. These usually are not inundated by wave surge from the sound, but they are surrounded by salty-water during these surges. A small fresh-water lens is maintained under these higher areas after a major inundation, however, the effects of pumping may induce lateral as well as vertical salt-water encroachment owing to the salty water in the aquifer surrounding the higher ground. The potential yield from such areas is up to 25,000 gpd, but may be considerably less after an inundation, depending on the depth and duration of the flooding and the size of the fresh-water lens under the dune mass.

The potential for ground-water development in some areas may be somewhat reduced by the shallow confining bed underlying the water-table aquifer. The water table in these areas is higher because downward movement of water is restricted by the confining bed, so that the water table rises until evapotranspiration losses and lateral outflow balance recharge to the system.

Since the downward circulation of fresh water is retarded, the salt-water interface may be within the confining bed itself, or just below it (geohydrologic section *E-E'*). Normally, a confining bed is a good barrier to vertical water movement, however, the hydraulic conductivity and extent of the silt and clay layers must be known in order to predict their effectiveness as a barrier, especially near pumping wells. Potential yields in areas underlain by shallow beds of clay or silt may be as much as 45,000 gpd from a horizontal well system.

PROTECTION OF THE GROUND-WATER SUPPLY

All ground-water supplies in the seashore should be protected from the seepage of sewage drainfields, shower outfalls, and general camping areas. Because waste effluents will enter the soil and move into the ground-water system as easily as rainfall, the best protection for a water supply is to locate it at a sufficient distance up the hydraulic gradient from contaminating facilities so that the effects of pumping are negligible.

Sizable parts of areas mapped as having a limited ground-water potential may be improved to protect and enhance the existing ground-water supply. Dikes or levees could be built to prevent salt-water inundation as has been done at Bodie Island and Wright Memorial; drainage canals could be equipped with one-way gates to prevent back-flooding of salty water; or the height of the land surface could be built up in the vicinity of wells to reduce evapotranspiration losses, raise the water table, and lower the salt-water interface. Depending on the situation, any combination of these methods might be considered where there is a need for ground-water supplies in the less favorable areas. However, the use of these enhancement methods should be as consistent as possible with good environmental practices.

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Conversion from English units of measurement used in this report to metric system equivalents

English units	Multiply by	To obtain metric equivalents
Inches	2.540	centimetres
Feet	.305	metres
Feet per day	.305	metres per day
Feet squared per day	.093	metres squared per day
Miles	1.609	kilometres
Square miles	2.590	square kilometres
Gallons	3.785	litres
Gallons per minute	3.785	litres per minute
Gallons per day	3.785	litres per day
Gallons per square mile	1.461	litres per square kilometre

Base modified from U.S. Geological Survey topographic quadrangles

INTERIOR—GEOLOGICAL SURVEY, RESTON, VIRGINIA—1975

GROUND-WATER RESOURCES OF THE CAPE HATTERAS NATIONAL SEASHORE, NORTH CAROLINA

By
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1975