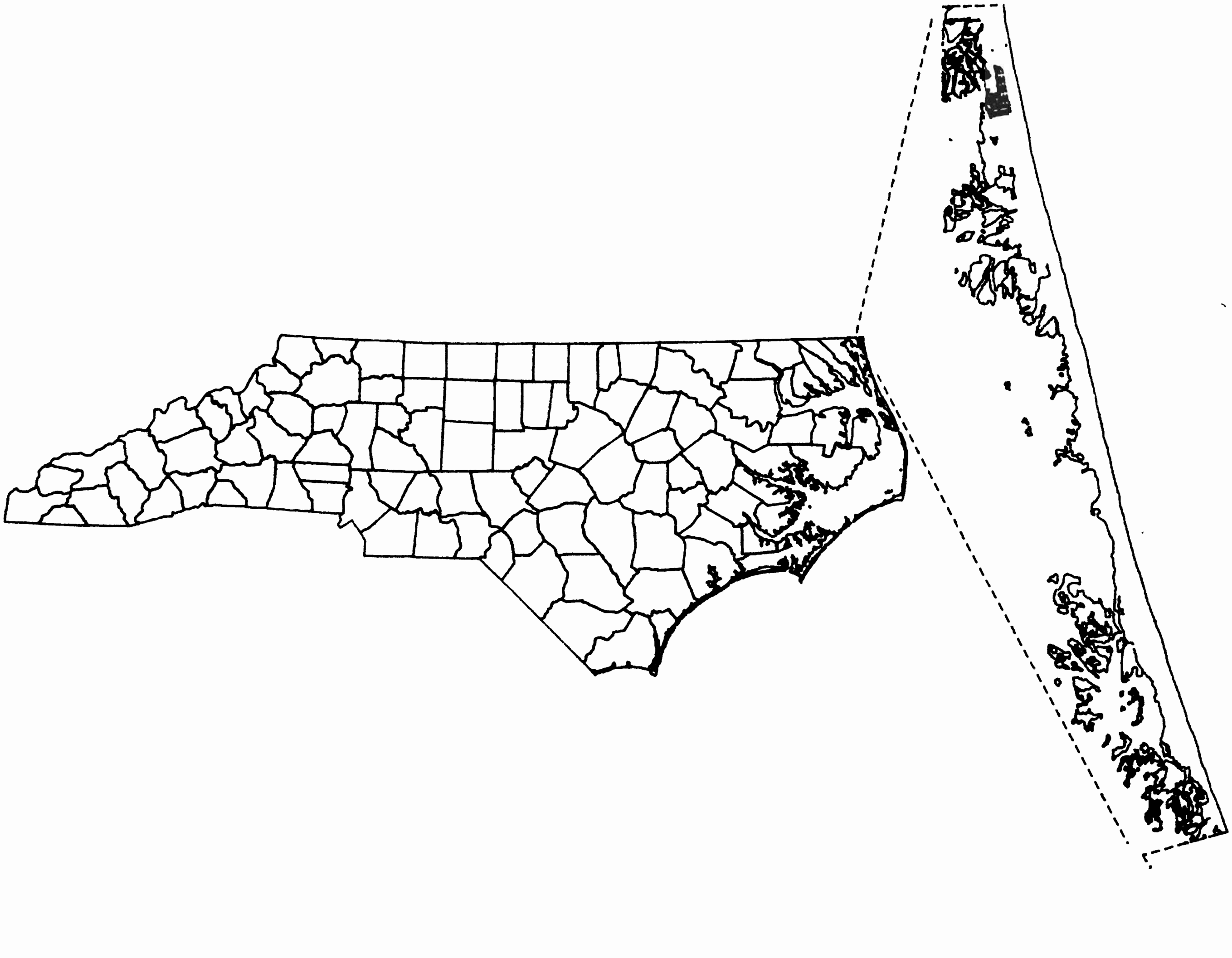
Currituck County Outer Banks
Water Supply Study



Division of Water Resources

November 1991

CURRITUCK COUNTY OUTER BANKS
WATER SUPPLY STUDY

North Carolina
Department of Environment, Health, and Natural Resources
Division of Water Resources

November 1991

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EXECUTIVE SUMMARY

Introduction

Concerned citizens of Currituck County Outer Banks wrote the Department of Natural Resources and Community Development (now the Department of Environment, Health, and Natural Resources [EHNR]) in late 1987 and described a potentially harmful situation. They were anxious that intense property development in the southern half of the Currituck Outer Banks might threaten their drinking water supply (see Figure i). These homeowners asked that the Outer Banks be considered for capacity use area designation under the Water Use Act of 1967. With the cooperation of Currituck County Commissioners and personnel, the Division of Water Resources (DWR) investigated the water supply potential for Currituck Outer Banks. The DWR study began by reviewing previously published reports about the surficial aquifer and by collecting new data on aquifer parameters and water use.

Because of the complexity of the recharge to, the withdrawals from, and the nature of the surficial aquifer, a computer model was chosen to simulate aquifer behavior. After the model was calibrated, it was used to estimate future conditions including projected full build-out of the southern section of the Outer Banks. The model can show the water supply yield of the surficial aquifer under the existing pattern of PUD and individual water system use. The study area is defined as the southern section of the Currituck County Outer Banks, the area facing the heaviest development pressure (Figure i).

The report discusses alternatives to the existing means of water supply, including improving the yield of the aquifer. It also presents conclusions and recommendations for consideration by Currituck County officials and Outer Banks residents in developing a water resource management plan.

Surficial Aquifer Characteristics

The sole source of drinking water for the Currituck Outer Banks is ground water from the surficial aquifer. The sandy surface of the barrier island changes locally into clay- and gravel-rich lenses dispersed in sand. At 10 to 65 feet below mean sea level the sediments change to thicker clay layers. These clay layers define the base of the surficial aquifer. Rainfall percolates through the soil and sandy substrata of the outer banks and is trapped in the surficial aquifer by the clay bottom and the higher density saltwater at the ocean and sound sides. A schematic diagram, labeled Figure ii, illustrates a typical cross-section of the surficial aquifer.

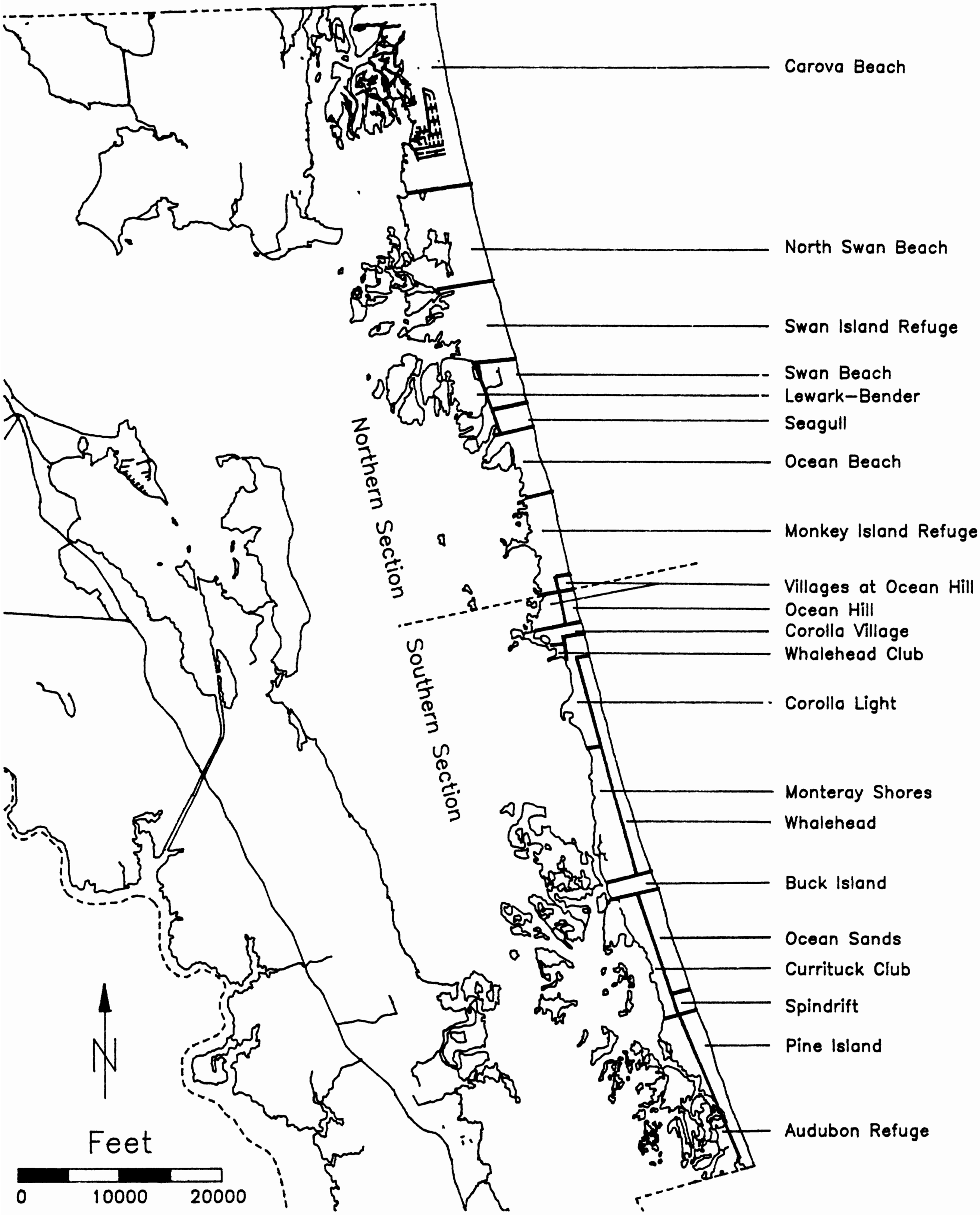


Figure i. Currituck County Outer Banks

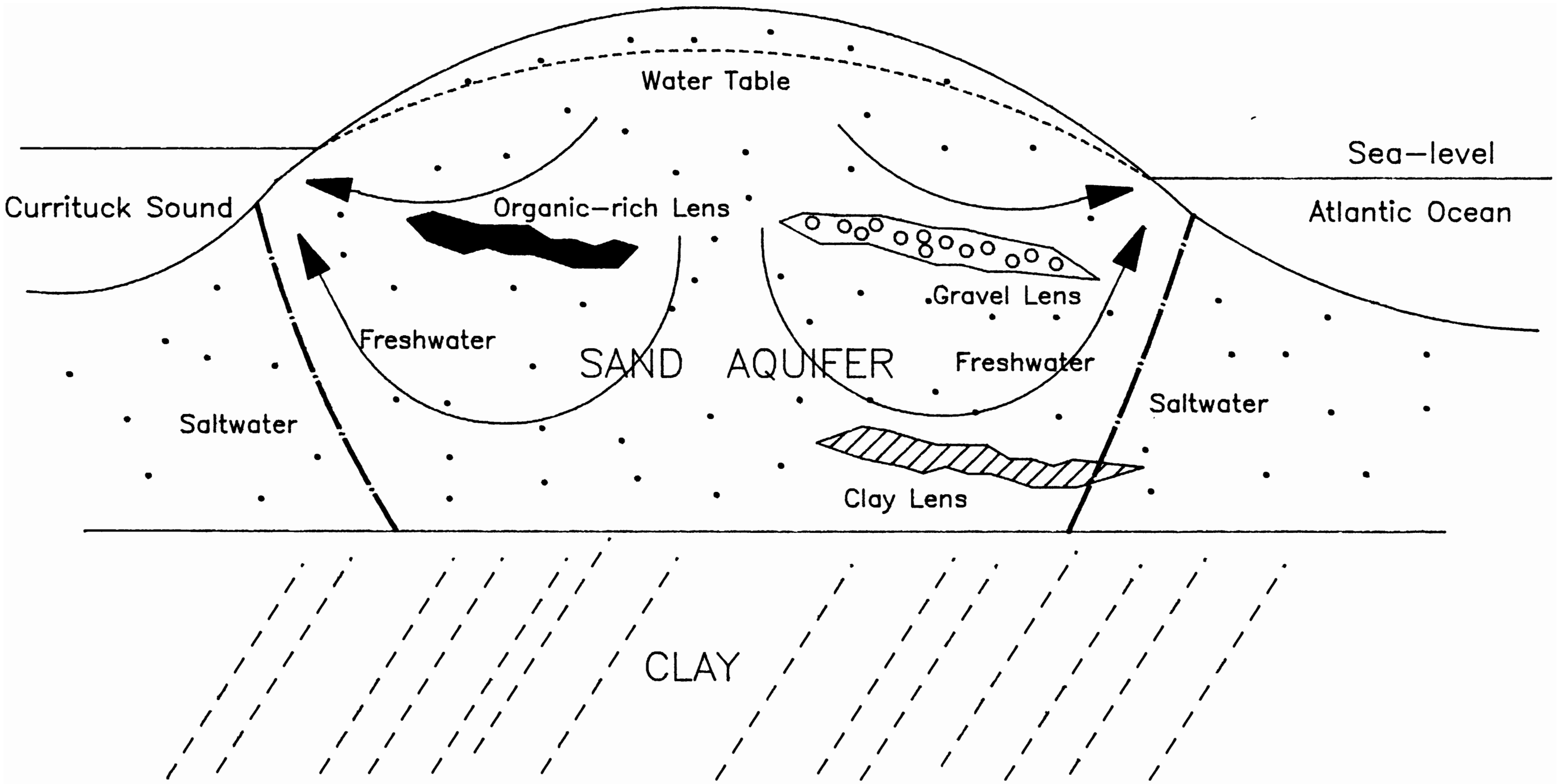


Figure ii. Schematic Cross-section of Currituck Outer Banks Showing Ground Water Flow Patterns

The thickness of the surficial aquifer is estimated from borehole information. The base of the aquifer is shallower at the north end of southern Currituck Outer Banks, which stretches from the Villages of Ocean Hill Subdivision in the north to Pine Island Subdivision in the south. From an elevation of -10 to -15 feet (referenced to mean sea level -- msl) in the north, the base of the aquifer drops to -65 feet msl at the south end of the southern section. The thick clay layer found at these levels acts as the base of the surficial aquifer, because water does not easily move through clay-rich sediments.

Three deeper boreholes drilled on the Outer Banks give some information on the strata beneath the surficial aquifer. The most recent of these boreholes (completed in 1991) cut through only a few sandy zones below the surficial aquifer down to -300 feet elevation and found no sandy zones below -300 feet (Russnow, Kane, and Andrews, Inc., 1991). Water from deeper sandy layers in previous boreholes was highly saline (Andrews, 1990).

Sandy zones are hydraulically conductive and allow production of water from a well screened in those zones. Hydraulic conductivity measures the capacity of the aquifer material to transmit water. Surficial aquifer hydraulic conductivities measured by previous investigators range from 13 to 1,016 feet/day with average values between 40 and 85 feet/day (EPA, 1985; Andrews, 1987a). These values lie in the expected range for medium-grained sand with zones of clay and gravel.

Water table elevations from transects across the short axis of the island show that the greater the width of the island the higher the elevations of the water table; the shallower the base of the aquifer (depth to the clay layers) the higher the water table; and that recharge to the aquifer is larger where the land surface is higher and in areas with high infiltration capacity.

Rainfall measured at the U.S. Army Waterway Experiment Station in Duck, North Carolina was used to calculate recharge to the Outer Banks surficial aquifer. Using estimated evapotranspiration (ET) from Wilmington, North Carolina and a method developed by EPA, monthly recharge was quantified for January 1987 through March 1991 (Hardy and Hardy, 1971; EPA, 1985). Average monthly recharge was calculated for comparative purposes using the same technique from mean monthly rainfall for Elizabeth City, Manteo, and Back Bay, Virginia for the period 1980 through 1988. Recharge also occurs on the island at wastewater disposal facilities where DWR estimated that 38 percent of ground water withdrawn from the aquifer is returned as treated wastewater.

Discharge from the surficial aquifer occurs naturally at the Currituck Sound and Atlantic Ocean boundaries. In addition, ground water is withdrawn from the aquifer by Planned Unit Development (PUD) wellfields and individual home wells.

Water Use

Withdrawal and disposal data from three PUD water systems (Ocean Sands, Corolla Light, and Monteray Shores-Buck Island), along with yearly dwelling unit counts, were available to calculate monthly water use per dwelling. Average yearly water use per dwelling was 332 gallons per day (gpd). Monthly average water use per dwelling ranged from as low as 86 gpd in February to 753 gpd in July. This determination, along with the number of planned units per PUD, allowed estimation of full build-out water use (Table i).

Table i. Southern Currituck Outer Banks
Full Platted Build-out Water Use

Water Use Values in Gallons per Day (GPD)

Month	Ocean Sands	Corolla Light	Mont Sh-Buck Is.	Vil. at Ocean H.	Pine Island	Total
# platted units	2,090	526	714	314	350	3,994
January	215,000	88,000	83,000	21,000	36,000	443,000
February	181,000	74,000	73,000	20,000	30,000	378,000
March	329,000	138,000	139,000	40,000	55,000	701,000
April	518,000	149,000	210,000	96,000	87,000	1,060,000
May	680,000	227,000	284,000	115,000	114,000	1,420,000
June	1,300,000	454,000	540,000	204,000	218,000	2,716,000
July	1,573,000	550,000	611,000	209,000	263,000	3,206,000
August	1,560,000	532,000	597,000	207,000	261,000	3,157,000
September	894,000	337,000	351,000	108,000	150,000	1,840,000
October	506,000	209,000	203,000	54,000	85,000	1,057,000
November	337,000	120,000	129,000	42,000	56,000	684,000
December	229,000	75,000	84,000	30,000	38,000	456,000
Annual Average	694,000	246,000	275,000	96,000	116,000	1,427,000

Aquifer Modeling

Dr. Dinshaw Contractor's saltwater intrusion computer model, SWGUAM, with its ability to simulate two dimensions and two densities of water, allowed analysis of the surficial aquifer (Contractor and Srivastava, 1989). The DWR model was developed for the southern half of Currituck Outer Banks, the area experiencing most rapid growth (Figure iii). This region was divided into triangular shaped elements with nodes at each element apex. Each node can represent wells, wellfields, or disposal fields as appropriate. The model allowed inclusion of monthly tide changes and recharge variations. Recharge to the island was further modified based on drainage characteristics of the soils. Highly drained areas (high land surface elevations)

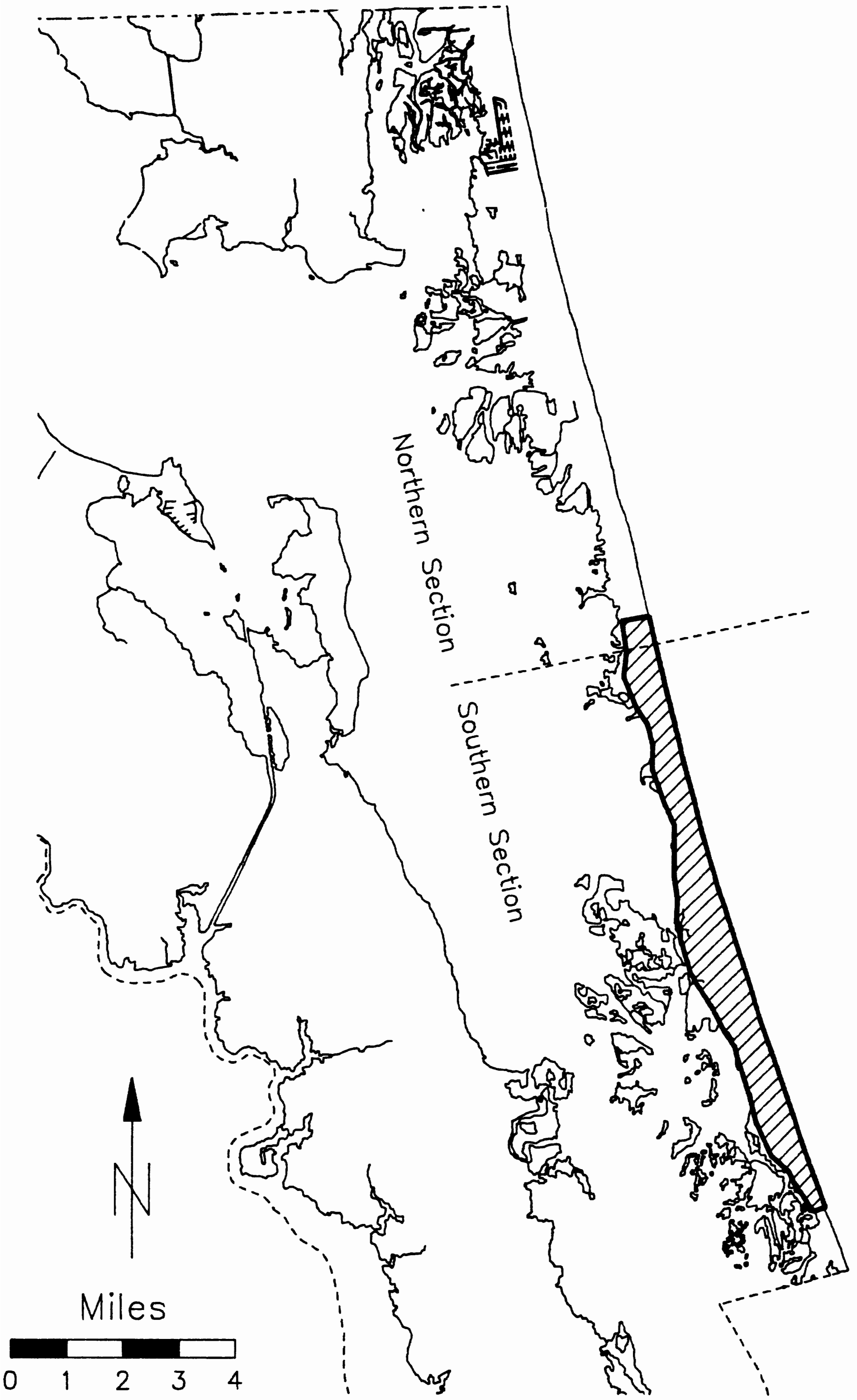


Figure iii. Model Boundary

were recharged with a larger percentage of average monthly recharge. The computer model processes the recharge to and the discharge from the island region and computes monthly water table and saltwater-freshwater interface elevations.

Several limitations exist with the computer model. In general, those limitations make the model a conservative approximation to reality by underestimating the amount of freshwater that can be withdrawn from the aquifer. For example, the model is limited because it calculates the depth to the interface between saltwater and freshwater as if it were sharply defined. In actuality, the interface is a zone of diffusion between seawater, containing chloride concentrations of 18,980 milligrams per liter (mg/l), and freshwater with less than 250 mg/l of chloride. This interface may extend over tens of feet. The model estimates of the interface location are liberal approximations. Depths to the interface may be deeper than in reality. Also, the number of model elements is restricted to 300 because of computer memory size, making the average element size 602,000 square feet. A consequence of this limitation is that some wells are lumped together. Wellfields containing several wells spread out over hundreds of feet may be modeled as one or two wells. Simulated ground water drawdowns in this case would be larger than the real situation.

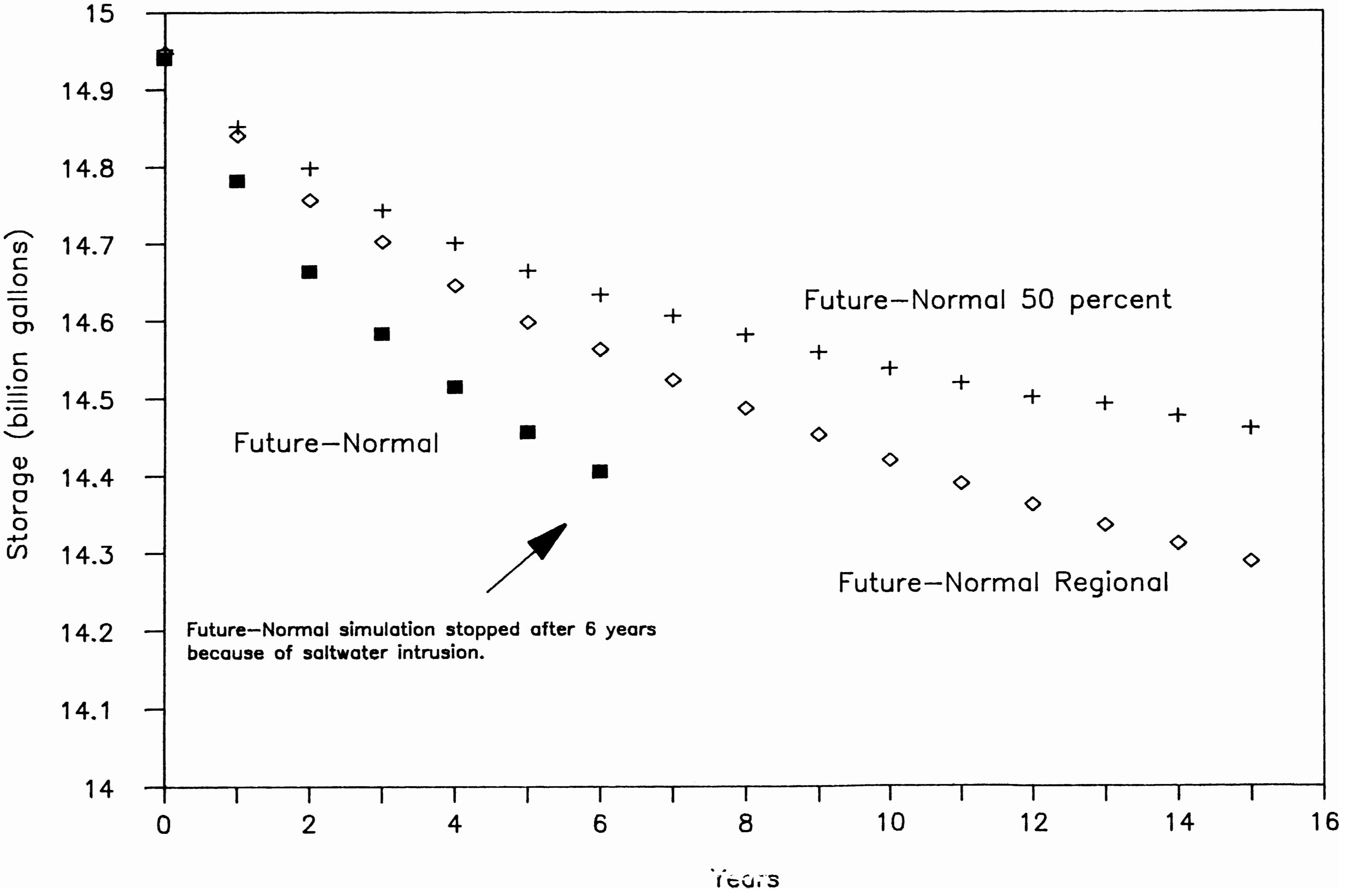
Calibration of the model was accomplished by simulating the aquifer system from January 1989 through March 1991. Computed water table elevations were compared to observed elevations collected in January 1990, August 1990, and March 1991. Model parameters, especially hydraulic conductivity, were adjusted until computed water levels bracketed observed water levels.

Next, two model runs were designed to estimate future aquifer impacts. In the first simulation ground water withdrawals and wastewater discharges were increased to supply the southern section of the island's needs at full build-out of platted lots. This simulation, designated Future-Normal, was halted after six years because of saltwater intrusion induced by overpumping near Corolla Light and Buck Island. Freshwater storage in the aquifer decreased as the saltwater-freshwater interface moved landward. In Figure iv, calculated aquifer storage in the model area for January of each year is plotted.

The second model run simulated the effects on the aquifer of ground water withdrawals and wastewater discharges at 50 percent of full build-out population. In this Future Normal 50 Percent simulation, aquifer storage volume continued to decline through 15 years. Freshwater storage appears to be leveling off; yearly reductions to storage are 0.1 percent of starting storage volume. If storage does not equilibrate at some future simulation year, then saltwater intrusion will occur near Corolla Light and Buck Island as the Future-Normal simulation indicated. See Figure iv for depiction of this model run. Thus, if growth occurs using the present pattern of separate PUD systems and individual home wells and septic tank systems, the aquifer will yield about

Figure iv. Surficial Aquifer Storage

Storage volume in January of each year



Future–Normal simulation stopped after 6 years because of saltwater intrusion.

884,000 gpd and can support a population of about 50 percent of full build-out. This yield is based on average rainfall and recharge patterns.

Alternatives

Several alternatives are available to augment the water supply for Currituck County Outer Banks or to adjust demand to supply. The two types of options are those related to sources of water and those proposing institutional changes. Water source alternatives include a regional surficial aquifer supply, desalinization, and pipelines to either Dare County or mainland Currituck County.

A model simulation including full build-out water use and a proposed regional water and wastewater system was run. It tested the effect of increasing the number of wellfields, positioning them near the center of the long axis of the island to maximize yield, and locating the disposal fields on the Sound side. Wellfields located where the aquifer is thinner were pumped at a lower rate than wellfields in the wider, thicker portions of the aquifer. The new well and disposal sites are only presented as examples. Storage volumes for the 15-year simulation are plotted on Figure iv as the curve labeled Future-Normal Regional. The saltwater-freshwater interface may stabilize at some future simulation year using this regional system, although storage continued to decrease through 15 years. Ground water yield of the modeled area doubled to 1,767,000 gpd with the regional system.

Desalinization can be considered to supply the Outer Banks during the summer season to offset insufficient supplies of freshwater from the surficial aquifer. Sources of saline water (not seawater), including deeper aquifers and Currituck Sound need further evaluation.

Pipelines to either Dare County or mainland Currituck County may provide alternative water sources. Both solutions are viable if the necessary planning and financing arrangements are completed and if water supplies can be allocated or obtained.

Institutional options include possible organizational structures to initiate and manage regional water and wastewater systems, conservation measures, and capacity use area designation. Conservation measures are a necessary part of any water supply plan for the Currituck County Outer Banks. Where water shortages or water use conflicts exist, a capacity use area designation provides a systematic process to allocate water among competing users and to control its use by permits.

Conclusions

Increased property development stresses the surficial aquifer of Currituck County Outer Banks. In late 1987, Whalehead Beach homeowners saw the necessity for evaluation of the limited ground water resources. The Division of Water Resources responded by analyzing the aquifer system. Estimates of the recharge to the surficial aquifer were combined with known and projected water use and surficial aquifer parameters in a computer model. The simulations performed with the model tested the ability of the surficial aquifer to support full build-out of the southern half of the Outer Banks. After about six simulated years at full build-out pumping, saltwater intrusion reached the wellfields near Corolla Light and Buck Island. If build-out was held to 50 percent of proposed construction, storage volumes may reach equilibrium and keep wellfields protected.

In an attempt to improve the capacity of the aquifer, DWR developed model runs simulating regional water and wastewater systems located to maximize ground water yield. These example wellfields and disposal areas appeared to allow development to full platted build-out. Of course, other options exist to increase water supplies for the Outer Banks. Pipelines to Dare County or the Currituck County mainland and desalinization may be feasible.

Regional water and wastewater systems organized by the County or some other entity appear to be necessary to properly manage this finite resource in the future. Conservation measures should be included in any plan of action to make the most efficient use of limited water resources.

Monitoring wells should be installed near pumping centers to track the movement of the saltwater-freshwater interface. Regular sampling of these wells is critical for the preservation of the ground water supply.

At existing growth rates, 50 percent build-out will be achieved by the southern section as a whole by the year 2000. Corolla Light and Whalehead subdivisions are expected to reach 50 percent build-out by 1992 and 1993, respectively. Full build-out is expected at Corolla Light by 2000. Prior to full build-out it will be vital to increase the size of the Corolla Light and Ocean Sands water and wastewater facilities. Thus it is a priority to plan and begin implementation of water supply alternatives before 2000. If a water resources management plan is not developed for Currituck County Outer Banks capable of supplying projected water supply needs, designation of a capacity use area is a regulatory option to allocate water by permit and to protect the aquifer from overpumping.

Recommendations

1. Currituck County should adopt a water conservation strategy for the Currituck Outer Banks to assure the most efficient use of the limited available water supply. The strategy should include requiring efficient plumbing fixtures in

all new construction and possibly a phased retrofitting of fixtures in existing structures. The strategy should also include provisions for zoning, tap-on requirements, building restrictions, and other local government measures as needed to assure the protection and efficient use of water resources.

2. Currituck County should install a system of monitoring wells near ground water pumping centers to track the movement of the saltwater-freshwater interface. Regular sampling of monitoring wells is critical to detect saltwater intrusion and to allow the refinement of the ground water model.

3. The Division of Water Resources should periodically collect data on ground water pumping, wastewater disposal, water use, and water table elevations to allow re-calibration and refinement of the ground water model. The model should be kept current to allow its use by the County to evaluate various development options.

4. Currituck County should consider all issues and constraints relative to the rapid development of the Currituck Outer Banks, including not only water supply but also quality of life, traffic congestion, cost of providing public services, hurricane evacuation, and other relevant growth issues. The County should decide on a development goal for Currituck Outer Banks. The goal could include the full platted build-out or some other ultimate level of development.

5. After adopting a development goal for the Currituck Banks, Currituck County should plan for an adequate water supply to serve the development goal. The County is responsible for conducting whatever additional studies are needed and selecting a water supply alternative from those available.

6. Finally, Currituck County or some other entity should implement a water supply alternative to serve the development goal for the Currituck Banks, phasing in the construction of the system as needed to keep up with population growth. That implementation should begin prior to the year 2000 to avoid potential water supply problems.

ACKNOWLEDGMENTS

Several people outside the Division of Water Resources have reviewed drafts of this report for its content and technical merit. Others have discussed their understanding of the Currituck Outer Banks situation. The report has benefited from comments supplied by Ron Coble, U.S. Geological Survey; Pat McDowell, McDowell & Associates, P.A.; Jack Simoneau, Currituck County Department of Planning and Zoning; Jeanne Robbins, U.S. Geological Survey; Bill Richardson, Currituck County Manager; Roger MacLauchlin, Whalehead Homeowners Association; and Richard Brindley, Outer Banks Ventures, Inc. DWR has been fortunate to receive their helpful advice and criticisms.

CURRITUCK COUNTY OUTER BANKS WATER SUPPLY STUDY

INTRODUCTION

In December 1987 the Department of Natural Resources and Community Development (now the Department of Environment, Health, and Natural Resources [EHNR]) received letters from Whalehead Beach Subdivision property owners in Currituck County who described the potential for water supply shortages in their area. They attributed this threat to intense property development of tracts of land surrounding their subdivisions. Most of the letters requested that the Department consider the possibility of designating that region a capacity use area under the Water Use Act of 1967. This study responds to these concerns about future water availability. The purpose of this study is to give Currituck County officials and residents of the Currituck Outer Banks information for making water resources management and land development decisions.

Currituck County is the most northeastern county in North Carolina (Figure 1). The outer banks form a chain of barrier islands which extend along the entire coast of North Carolina. The Currituck Outer Banks are contiguous with the False Cape State Park in Virginia and extend in a continuous strip of land south to Dare County (Figure 2). The most recently existing inlet, closed in 1828, was about three miles north of present-day Corolla (Pilkey et al., 1979).

Several large tracts of land spanning the width of the Currituck Outer Banks have been set aside for wildlife refuges. Some of this land near Dare County (the Currituck and Pine Island Hunt Clubs) had recently been targeted for development (Figure 2). The Audubon Society protected these lands by a trustee agreement prior to these new development plans. The U.S. Fish and Wildlife Commission owns two large sections of land. The first, the Monkey Island Tract, extends from approximately three miles north of the Ocean Hill Subdivision to the southern part of Ocean Beach. The other, the Swan Island Refuge, extends about two miles north from the Swan Beach Subdivision to North Swan Beach. This land was previously owned by the Nature Conservancy, which maintains a small strip of land in the Monkey Island Tract.

For the purpose of this report the Currituck County Outer Banks have been divided into two parts, a southern and a northern section. This terminology follows the convention of previous studies on the Currituck County Outer Banks, and also the Currituck County Tax Office designation of the northern section as Fruitville Township and the southern section as Poplar Branch Township. The northern section extends from the Virginia border to the southern end of the Nature Conservancy's Monkey Island tract (Figure 2). The southern section begins at the northern end of the Villages of Ocean Hill subdivision and extends southward to the Dare County border.

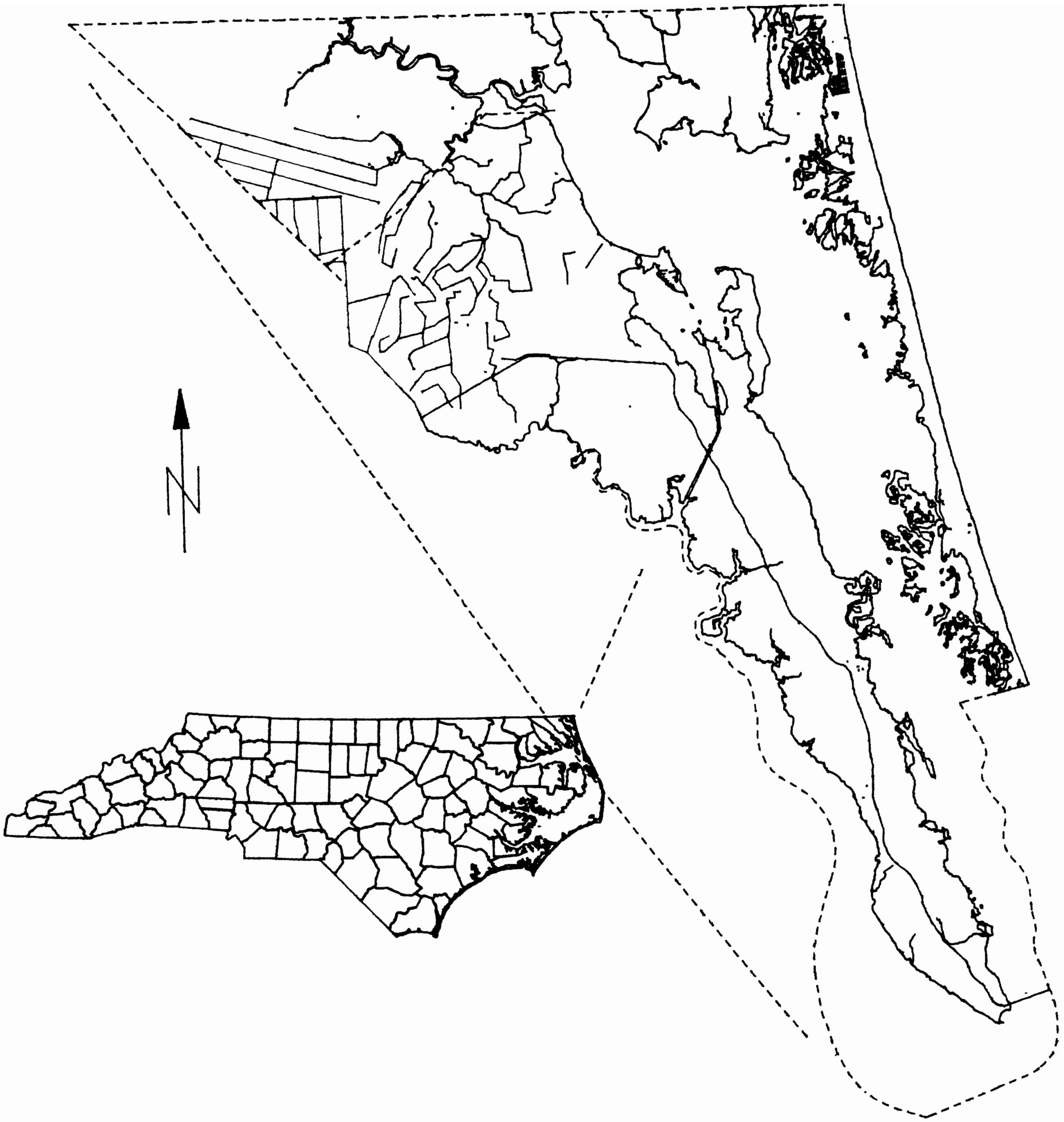


Figure 1. North Carolina with Currituck County Inset

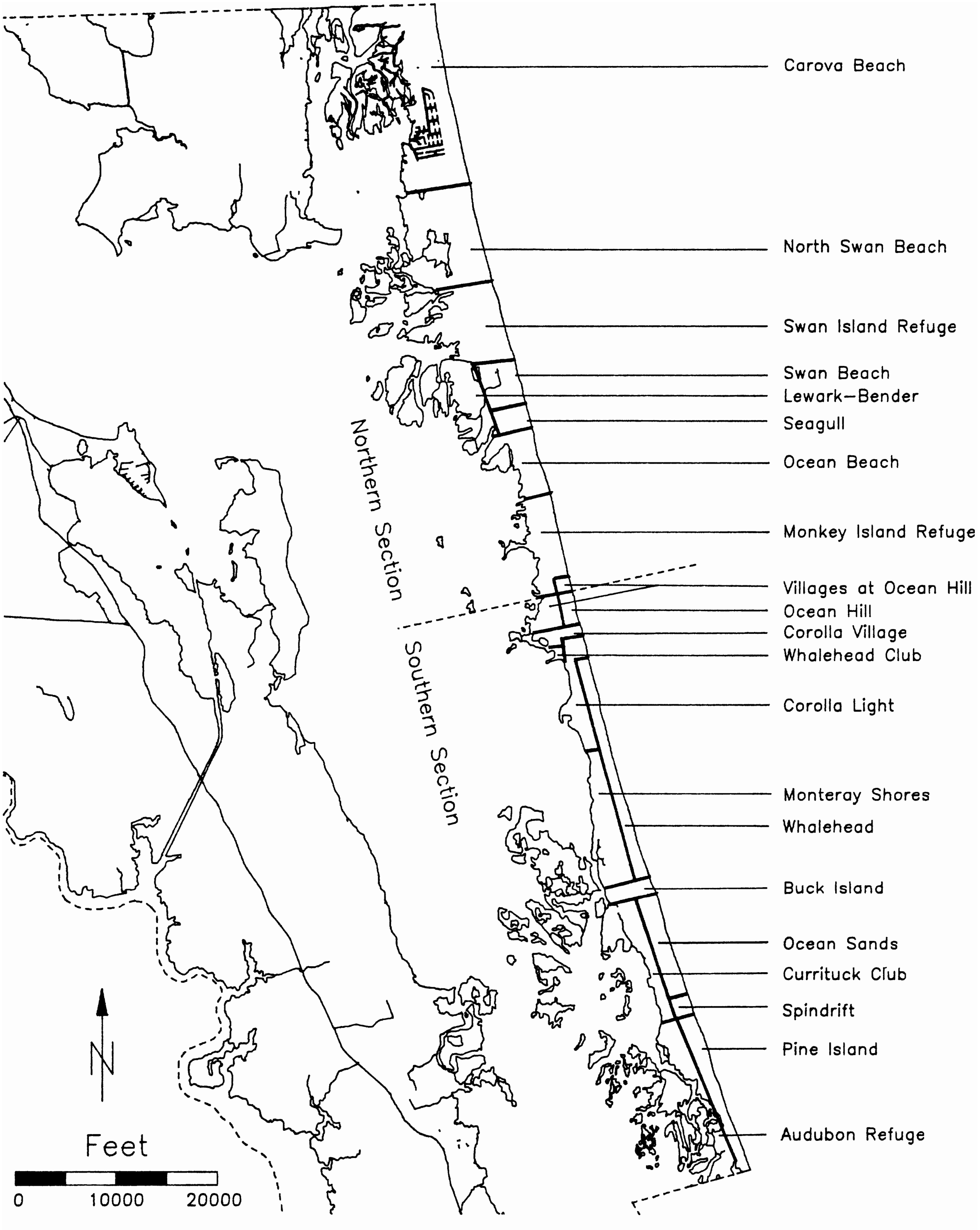


Figure 2. Currituck County Outer Banks

The major differences between the southern and northern sections which lead to this division are the population growth rates and the occupancy rates of dwellings. The northern area has experienced slower growth rates than the southern. It is largely occupied by commuters from the Virginia military bases. The southern section is mostly a second home and retirement community and has seen growth rates more than quadruple since the early 1980s.

One of the factors which has influenced these differences is transportation access. The southern section has an access road which was made public in October 1983. This road is an extension of NC 12 and runs southward from Villages of Ocean Hill, connecting with U.S. 158 in Dare County. A bridge connecting the Currituck mainland and Outer Banks has been approved for construction. This new access to the southern section may increase the growth rate.

The northern area has no paved roads and residents must travel in four-wheel drive vehicles along the beach to their homes. Homeowners in the northern section who work at the military bases in Virginia have special permits to drive through the Back Bay National Wildlife Refuge. Both North Carolina and Virginia have gone on record opposing the construction of a road through the northern area which would connect with Virginia. Growth rates in the northern area would probably increase if this road was built.

Another difference between the two areas is the predominant type of water system. In the northern section, all of the developments rely on individual wells and septic tanks for each residence (Table 1). In the southern section, older developments also have individual systems, but all the newer developments have central treatment systems for water and wastewater. Planned Unit Developments (PUDs) which have central treatment facilities are subject to less restrictive zoning, allowing more homes to be built per acre.

Ocean Sands was the first to install a community water and sewer system. The homes in Phase 1, which are accessed by the three most southern entrances, are on individual wells and septic tanks. The remainder of Ocean Sands is, or will be, served by community water and wastewater treatment systems. Corolla Light installed centralized water and sewer systems after Ocean Sands. The Whalehead Club uses the Corolla Light systems. Monteray Shores and Buck Island (formerly Shipswatch) have opted to share water and wastewater systems. Buck Island has installed a well field which will pump water to the water plant located in Monteray Shores. The shared wastewater treatment plant is housed in Monteray Shores. Ocean Hill is similar to Ocean Sands in that it developed a first phase of the subdivision on individual wells and septic tanks but the second phase, Villages at Ocean Hill,

Table 1. Curritude County Outer Banks Developments and Type of Water Supply and Wastewater Service

Development	Type	PUD Status
South		
Ocean Hill	Individual	
Villages at Ocean Hill	Community	on-line
Corolla Village	Individual	
Whalehead Beach	Individual	
Buck Island (Shipswatch)	Community	on-line
Monteray Shores	Community	on-line
Corolla Light	Community	on-line
Ocean Sands (A,B,&C)	Individual	
Other	Community	on-line
Spindrift	Individual	
Pine Island	Community	planned
North		
Carova Beach	Individual	
North Swan Beach	Individual	
Swan Beach/Seagull	Individual	
Ocean Beach	Individual	

has centralized water and sewer systems on line. Villages at Ocean Hill's water supply system serves a limited number of dwellings and includes a reverse osmosis plant to produce drinking water from water containing high concentrations of iron. Spindrift and Whalehead Beach are completely dependent on individual wells. In the village of Corolla, everyone uses individual wells and septic tanks, with many of the year-round residents having rainwater collection systems. Preliminary plans for the Pine Island subdivision suggest that the development will have community water and wastewater treatment systems.

The following Division of Water Resources report analyzes Currituck County Outer Banks water resources needs and availability. The report is divided into three sections: I. Evaluation of Ground Water Resources and Water Use; II. Water Supply Alternatives; and III. Summary, Conclusions, and Recommendations.

SECTION I: EVALUATION OF GROUND WATER RESOURCES AND WATER USE

Introduction

Because of its location five miles east across Currituck Sound from the mainland of water resource-limited Currituck County, the inhabitants of the Outer Banks have relied on the ground water resources of the island. The barrier island averages about one-half mile wide and extends approximately 25 miles from the Virginia border to Dare County (Figure 2). Fresh water is obtained from a surficial, unconfined aquifer, bounded on the east by saltwater from the Atlantic Ocean and on the west by salty water from the Currituck Sound. Less permeable clay-rich horizon(s) at varying depths delineate the aquifer bottom.

This section of the report first analyzes the hydrogeological system for Currituck County Outer Banks. The regional framework, the boundaries of the freshwater aquifer, the aquifer's hydraulic parameters, and the recharge to and discharge from the aquifer are discussed.

Then, existing and future water use on Currituck Outer Banks are analyzed. Tools used to evaluate the aquifer system for the southern section of the island, including the one-dimensional (1-D) and two-dimensional (2-D) saltwater intrusion computer models written by Dinshaw Contractor, are discussed next.

General ground water flow directions are then analyzed and the ground water quality on the Outer Banks is described along with the results of water quality sampling completed by DWR in November 1988. Next, the development of a monitoring well network to track changes in water table elevation and changes in chloride concentration of the aquifer is recommended.

This section concludes with a discussion of the results from a number of 2-D saltwater intrusion model runs evaluating ground water capacity.

Hydrogeological Framework

Previous Work

A significant portion of research conducted at the Currituck County Outer Banks has been done by engineering firms contracted by subdivision developers and development firms. Examples of this work include that done by Russnow, Kane & Andrews, Inc. for Corolla Light (1984), Monteray Shores (1987a), Villages at Ocean Hill (1989), and Pine Island (1990b); Geraghty & Miller, Inc. for Whalehead Beach (1983); McDowell and Associates, P.A. for Ocean Sands (1984); and Moore, Gardner & Associates, Inc. for Carova Beach (1977). Moore, Gardner & Associates, Inc. also prepared a feasibility study for water facilities for the whole of Currituck County (1982).

Beyond these efforts, there have been hydrogeologic analyses conducted in other areas of the outer banks of North Carolina. These include research conducted in the Cape Hatteras region by Heath (1988), Winner (1975), and Harris and Wilder (1964). Dare County investigations include Peek and others (1972), and Missimer and Associates, Inc. (1987). EPA (1985) conducted investigations of wastewater disposal impacts on barrier islands in Dare, Carteret, and Pender counties.

Regional hydrogeological investigations for the northeastern portion of North Carolina include Peek (1977), Heath (1975), Wilder and others (1978), and Harris and Wilder (1966).

Regional Framework

Northeastern North Carolina's Coastal Plain is underlain by an eastward thickening series of sediments and partially consolidated rock of Cretaceous to Holocene age. These sediments lie on eroded Precambrian or early Paleozoic age igneous and metamorphic basement rocks at depths down to 5,000 feet below mean sea level (Brown and others, 1985; Harris and Wilder, 1966). The sequence is comprised of interbedded sand, clay, silt, and minor limestone and shell units (Harris and Wilder, 1966).

These sediments are subdivided into several formations (mappable units) based on the sequences of strata and fossil evidence. Those formations, from oldest to youngest, are: Lower Cretaceous undifferentiated; Cape Fear Formation; Black Creek Formation; Peedee Formation; Beaufort Formation; Castle Hayne Formation; Pungo River Formation; Yorktown Formation; and Quaternary undifferentiated (Table 2). These formations are divided into units with similar hydrologic properties and given aquifer names as follows: lower Cretaceous aquifer; lower Cape Fear aquifer; upper Cape Fear aquifer; Black Creek aquifer; Peedee aquifer; Beaufort aquifer; Castle Hayne aquifer; Pungo River aquifer; Yorktown aquifer; and surficial aquifer (see Table 2 and Figure 3). Similarly named aquifer and formation boundaries do not correlate to one another exactly (Table 2).

Each of these aquifers, except the surficial aquifer, has an interval of clay rich sediments that create a confining horizon above the aquifer (Figure 3). The clay-rich sediments have a lower hydraulic conductivity and thus restrict ground water movement between the confined aquifers. Because the surficial aquifer lacks this confining layer it is considered an unconfined aquifer.

Water quality studies in this region show a restricted potable ground water supply. Only the Yorktown and surficial aquifers in the areas east of Sunbury in Gates County contain fresh ground water. Chloride concentrations of 250 milligrams per liter (mg/l) or higher mark the limit of freshwater in an aquifer in accordance with EPA's secondary standards (40 CFR 143.3). Most aquifers to the west of Sunbury have potable ground water (Winner and Coble, 1989) (Figure 3). East of Elizabeth

Table 2. Northeastern North Carolina Hydrogeologic Units

Geologic Age	Geologic Units	Aquifer
Quaternary Pleistocene	Quaternary Deposits	Surficial Aquifer
Pliocene	Yorktown Formation	Yorktown Aquifer
Miocene	Pungo River Formation	Pungo River Aquifer
Eocene	Castle Hayne Formation	Castle Hayne Aquifer
Paleocene	Beaufort Formation	Beaufort Aquifer
Cretaceous	Black Creek Formation	Black Creek Aquifer
	Upper Cape Fear Formation Lower Cape Fear Formation	Upper Cape Fear Aquifer Lower Cape Fear Aquifer
	Lower Cretaceous Undifferentiated	Lower Cretaceous Aquifer

Source: Winner and Coble, 1989

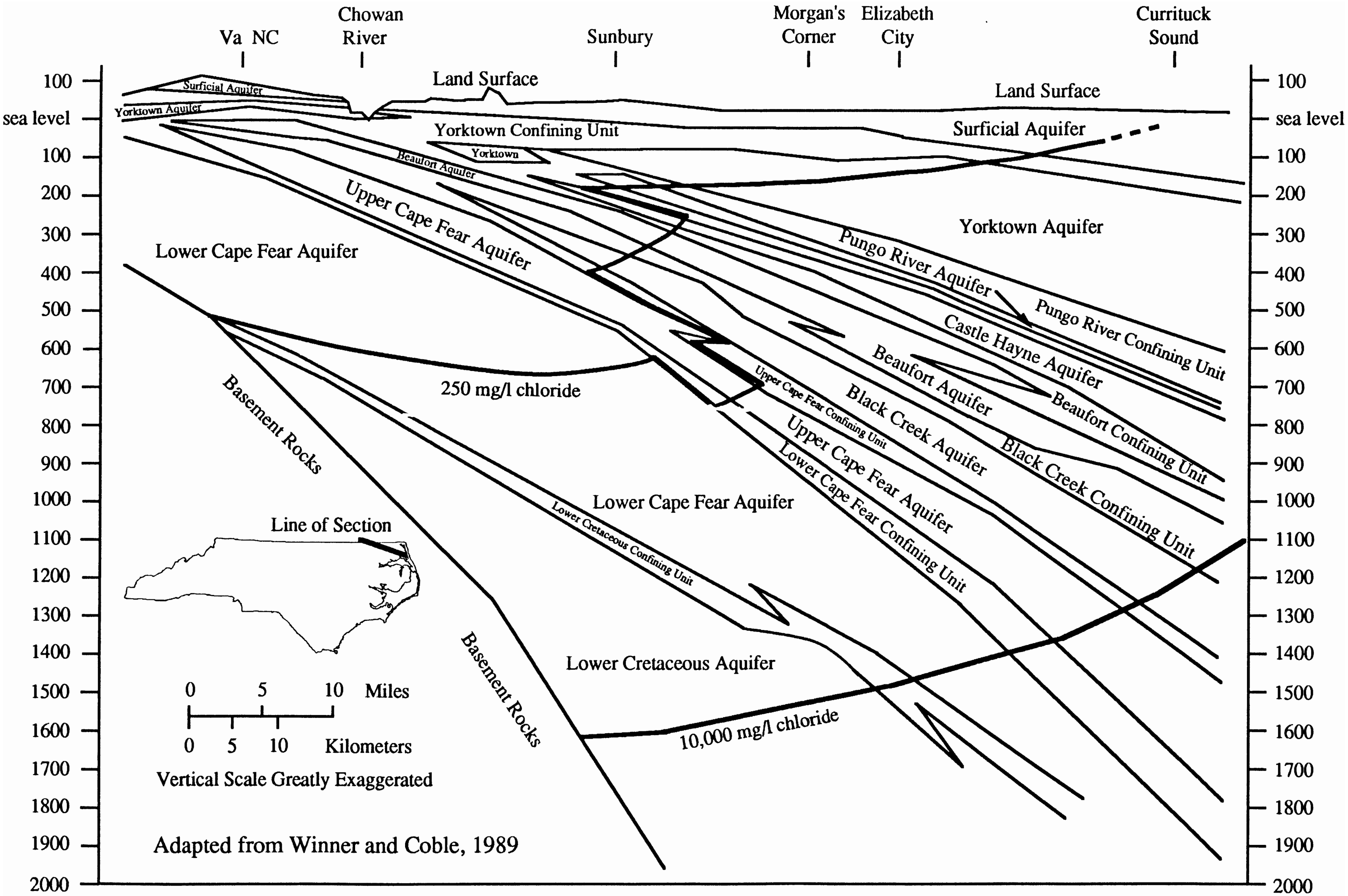


Figure 3. Hydrogeologic Section from Southhampton County, Virginia to Currituck County, North Carolina

City, including the Outer Banks, the Yorktown aquifer has chloride concentrations higher than 250 mg/l, and so parts of Currituck, Camden, and Pasquotank counties are limited to the surficial aquifer for ground water supply (DWR, 1987).

The surficial sands of the outer banks trap and store fresh rainwater because the higher density saltwater of the ocean and sound give buoyancy to the lens-shaped layer of freshwater.

The hydrogeological characteristics of this surficial aquifer must be analyzed in detail in order to gauge its water supply potential.

Outer Banks Surficial Aquifer Characteristics

The hydraulic properties of the Outer Banks surficial aquifer including aquifer boundaries, hydraulic conductivity, porosity, and specific yield, are defined and discussed below (Table 3).

The elevation of the bottom of the aquifer is the hardest of these parameters to estimate because of its variability and the lack of data. The base consists of clay strata (the number of units is unknown), each usually averaging about 10 feet thick, that dip toward the east and south (Andrews, 1990). Clay appears to outcrop north of Ocean Hills subdivision and is about -65 feet elevation beneath Ocean Sands (Andrews, 1990). Directly below these clay units the ground water in lower sandy units is saline. Thus the tops of the clay-rich horizons are the base of the aquifer containing fresh water. Based upon data from three deeper boreholes (up to 1,500 feet below mean sea-level), there are only a few sandy strata about 20 feet thick or less between the clay base of the surficial aquifer and about 300 feet below mean sea-level (Russnow, Kane, & Andrews, Inc., 1991). Below 300 feet no limestone or sandy strata with a high capacity to transmit water exist according to these deep boreholes.

Hydraulic conductivity, or the capacity of aquifer material to transmit water, is obtained from aquifer tests by dividing the transmissivity, determined from the tests, by the aquifer thickness. Transmissivity is the rate at which water will move through aquifer material. Hydraulic conductivity varies about 12 orders of magnitude in naturally occurring rocks and sediments (Heath, 1983). A hydraulic conductivity range of 10 to 1,000 feet/day is consistent with the fine to medium textured sand with coarse sand to gravel lenses (Heath, 1983). The cited range from Currituck aquifer tests correlates with this range (see Table 3).

Cross-sections were constructed across the island with elevations of land surface and the water table in order to evaluate certain aquifer parameters (for example, island width and aquifer thickness). Some of this information was collected by the Division of Water Resources in January 1990 on two traverses (A and B), in August 1990 on three traverses (A, B, and C), and in March 1991 on five traverses (A, B, C, D, and E) (Figure 4). Elevation data is based on the North Carolina

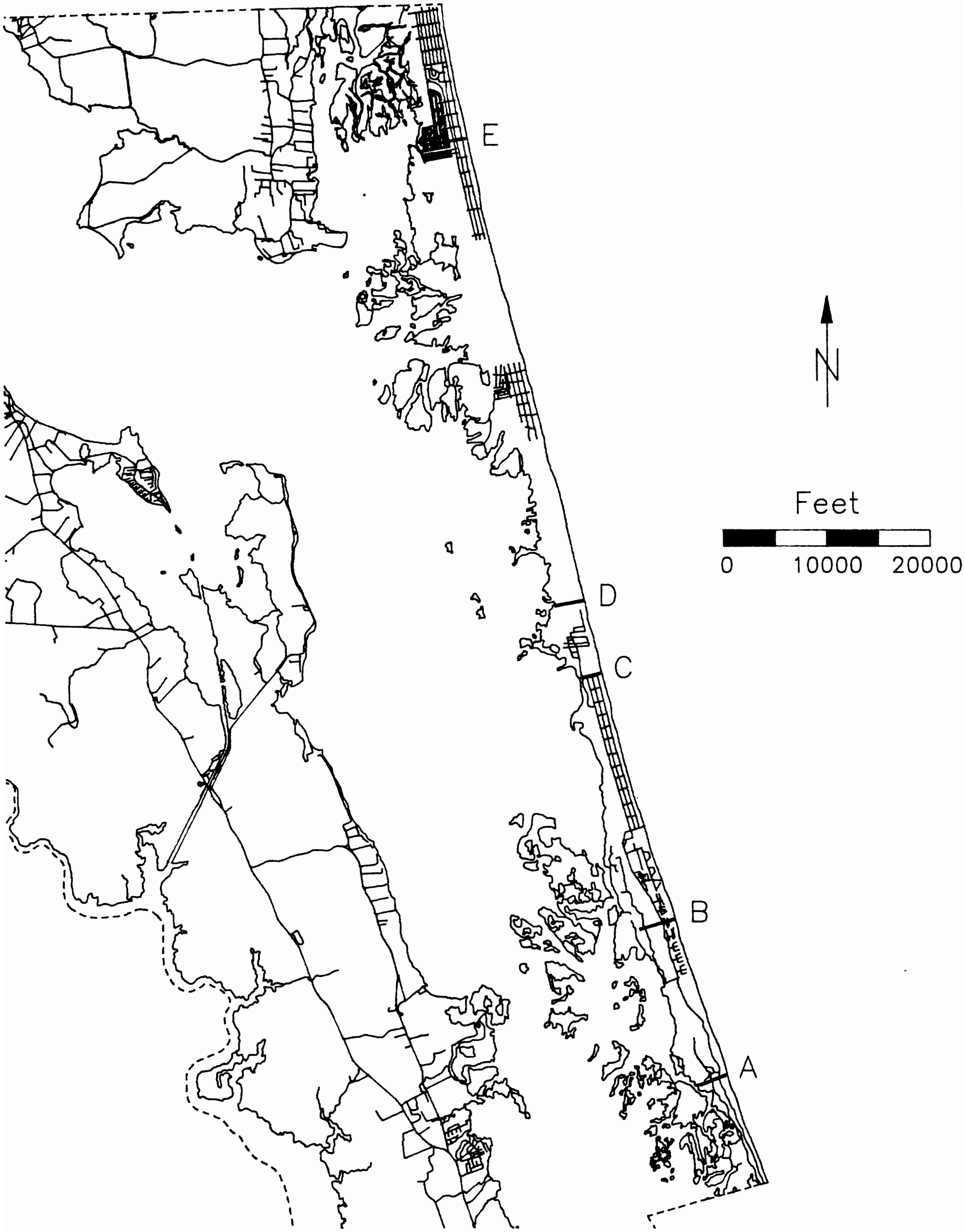


Figure 4. Traverse Location Map

Geodetic Survey (NCGS) benchmark network referenced to the National Geodetic Vertical Datum (NGVD) of 1929.

The following observations were made concerning the cross-sections, shown in Figure 5, obtained from this surveying work: 1. The water table elevation is dependent upon the width of the island. Water table elevations are lower on the Pine Island Club traverse (A) than the Ocean Sands traverse (B); 2. A secondary determinant, but also critical, is the thickness of the aquifer. The water table rises to a higher elevation over thinner aquifer sections; thinner aquifer sections have a lower transmissivity. Traverses C and D transect a portion of the island where the aquifer is less thick. Along the Whalehead (C) and Ocean Hill (D) transects, the aquifer is about 15-feet thick, compared to 70-feet in the two other cross-sections; 3. The theoretical lens-shape of the water table is modified by topography. Mounding beneath the dunes defines an area of higher volume of recharge. Spatially variable recharge causes the deviations from the theoretical lens-shape. The mounds are probably not due to differences in hydraulic conductivity because the sediments are fairly well-sorted.

Several traverses with monitoring wells should be constructed in order to observe more accurately the fluctuation of the water table over an extended period of time and gauge the effects of variable recharge on the the water table profile. Nineteen monitoring wells have been installed by Currituck County in early 1991 at traverses A through E. Monthly water table elevations are presently being measured.

Another important surficial aquifer parameter to consider is porosity. Porosity is defined as the ratio of the volume of openings in a material to the total volume of the material. Thus, porosity of 0.25 indicates that 25 percent of the total volume of clayey to gravelly sand on the Outer Banks is openings or voids. In the saturated portion of the aquifer material those voids are filled with water. Specific yield is the volume of water that will drain by gravity from that volume of saturated aquifer material. Specific yield of 0.15 for the Currituck Outer Banks means that 15 percent of that volume of aquifer material is water that can be withdrawn by pumping. The remaining 10 percent of the water is retained by the sediments as a film on particle surfaces.

Ranges of aquifer parameter values found in the literature search from previously referenced articles are listed below.

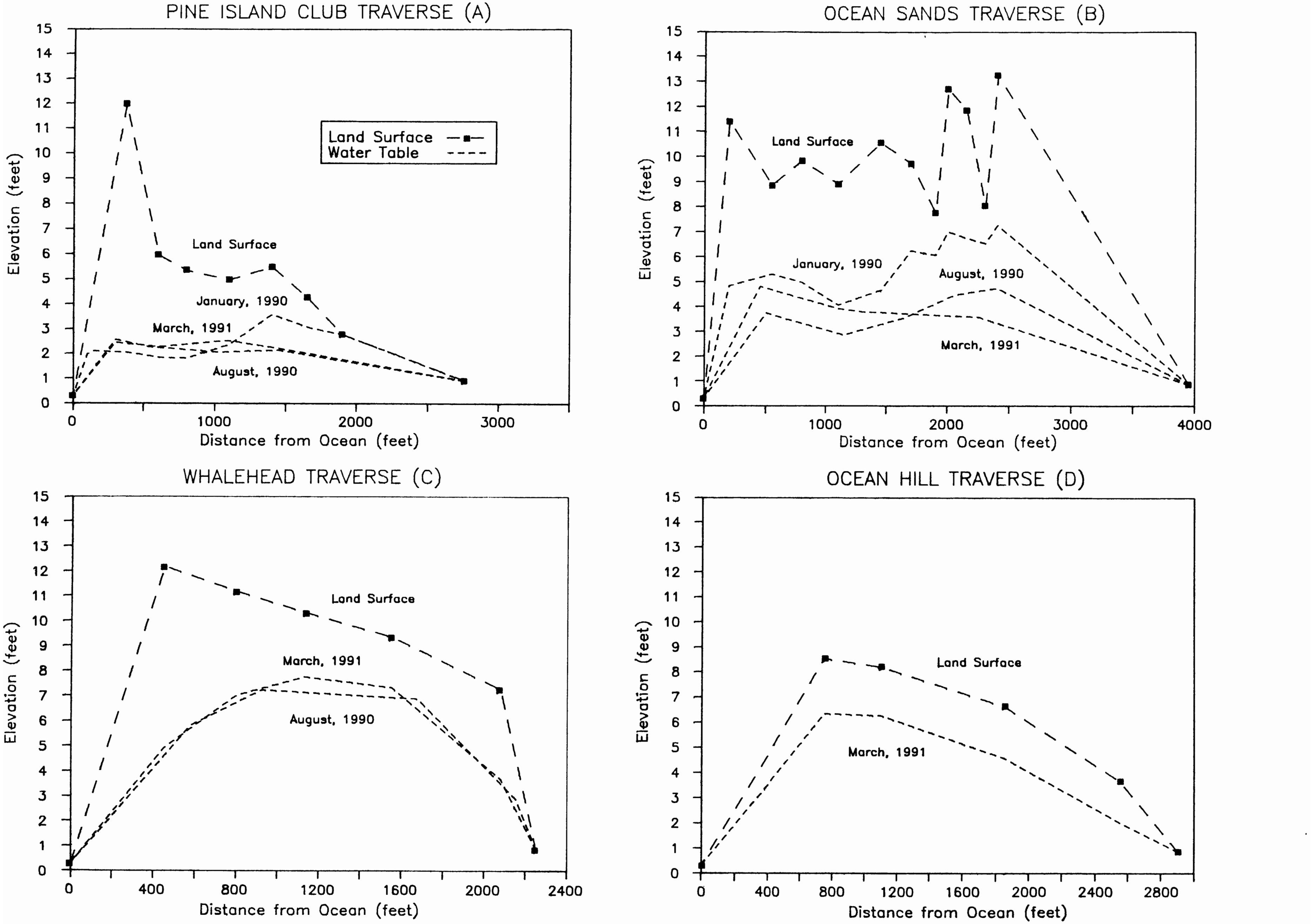


Figure 5. Land Surface and Water Table Cross-sections

Table 3. Surficial Aquifer Parameters

Parameter	Range
Elevation of Base of Aquifer (feet, referenced to mean sea-level)	-10 to -65
Hydraulic Conductivity (feet/day)	13.4 to 1016
Transmissivity (feet squared/day)	174 to 21,390
Water Table Elevation (feet)	0.7 to 11.3
Porosity	.25
Specific Yield	.15

Recharge

Recharge is equal to precipitation less evapotranspiration (ET) less overland run-off. In many of the analyses provided by consultants, average yearly recharge is estimated by yearly precipitation less yearly ET. Overland run-off is assumed to be negligible on the Outer Banks. Precipitation values used in other studies range from 44 to 51 inches/year and ET values range from 33 to 36 inches/year, which leaves 11 to 15 inches/year for ground water recharge (Bell and others, 1983; Moore, Gardner & Associates, Inc., 1982; Winner, 1975; and Wilder and others, 1978). These estimates are yearly estimates and thus do not quantify the seasonal variation of recharge.

Recharge can also be estimated by comparing monthly values of average rainfall versus monthly average ET for a monthly recharge approximation (Hardy and Hardy, 1971). Recharge calculated in this report used average daily rainfall data from Manteo, Elizabeth City and Back Bay, Virginia for 1980-1988 and daily data from Duck for 1987 to March 1991 (see Figure 6). Average rainfall from Elizabeth City and Manteo (1951-1980) is also plotted in figure 6. Yearly average rainfall at Manteo, Elizabeth City, and Back Bay from 1980-1988 was about 0.0106 feet/day or 46 inches/year. Yearly average rainfall from 1951 to 1980 was 0.0116 feet/day or 51 inches/year. Yearly average rainfall at Duck, in figure 6, ranged from 0.0072 to 0.0126 feet/day or from 32 to 55 inches/year during the four year period (1987-1990). Estimated Wilmington ET was used because of its similar coastal location, although Hardy and Hardy (1971) explain that average monthly ET does not vary much across North Carolina. Some months exhibit negative recharge (ET is higher than average rainfall, see Figure 7).

ET from Wilmington was modified based on estimated soil moisture content fluctuation during dry and wet periods of the year (EPA, 1985). The modified ET was subtracted from average rainfall (Manteo, Elizabeth City, and Back Bay) and from Duck rainfall giving modified recharge in Figures 8 and 9,

Figure 6. Rainfall

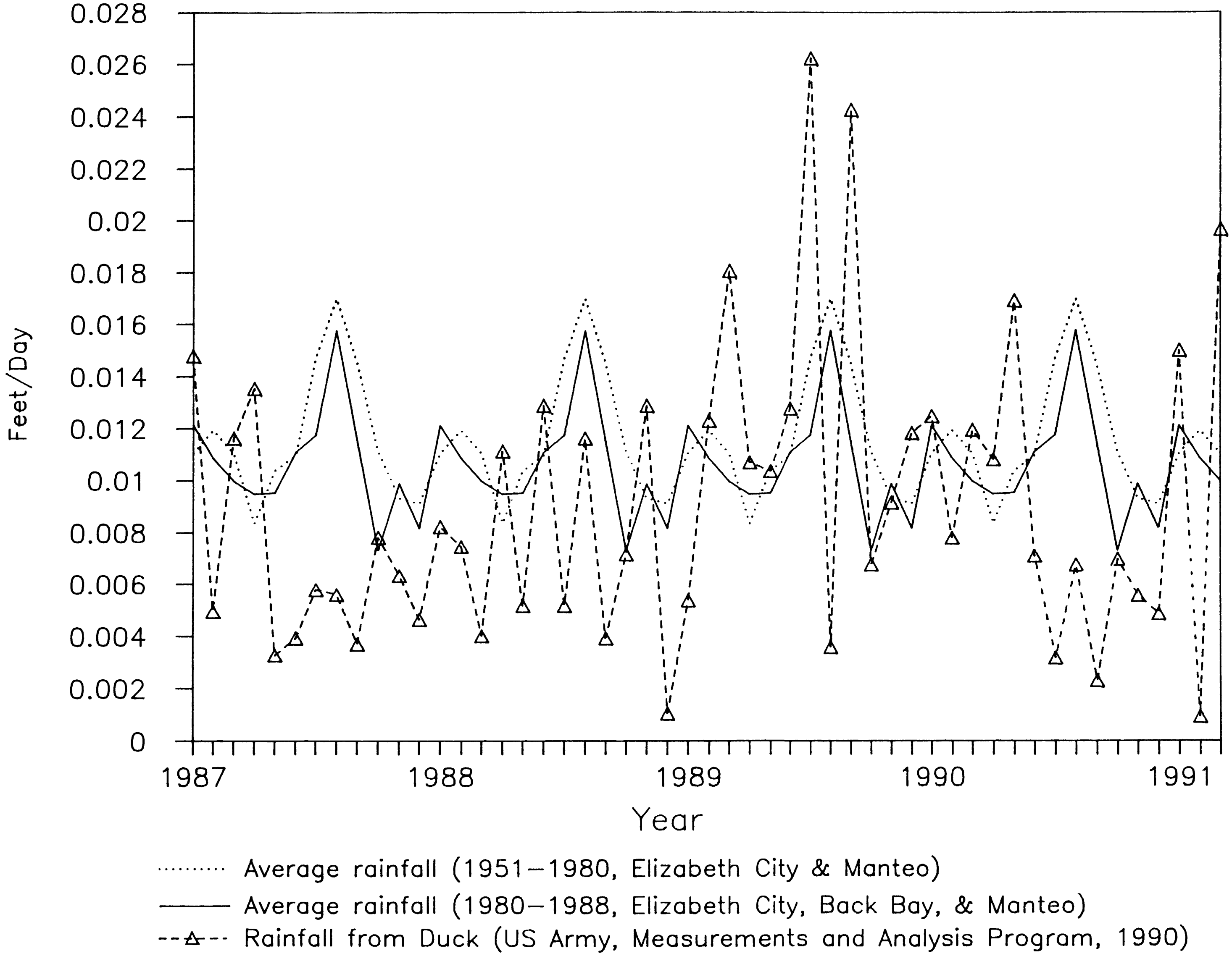


Figure 7. Average Recharge from Average Rainfall and ET

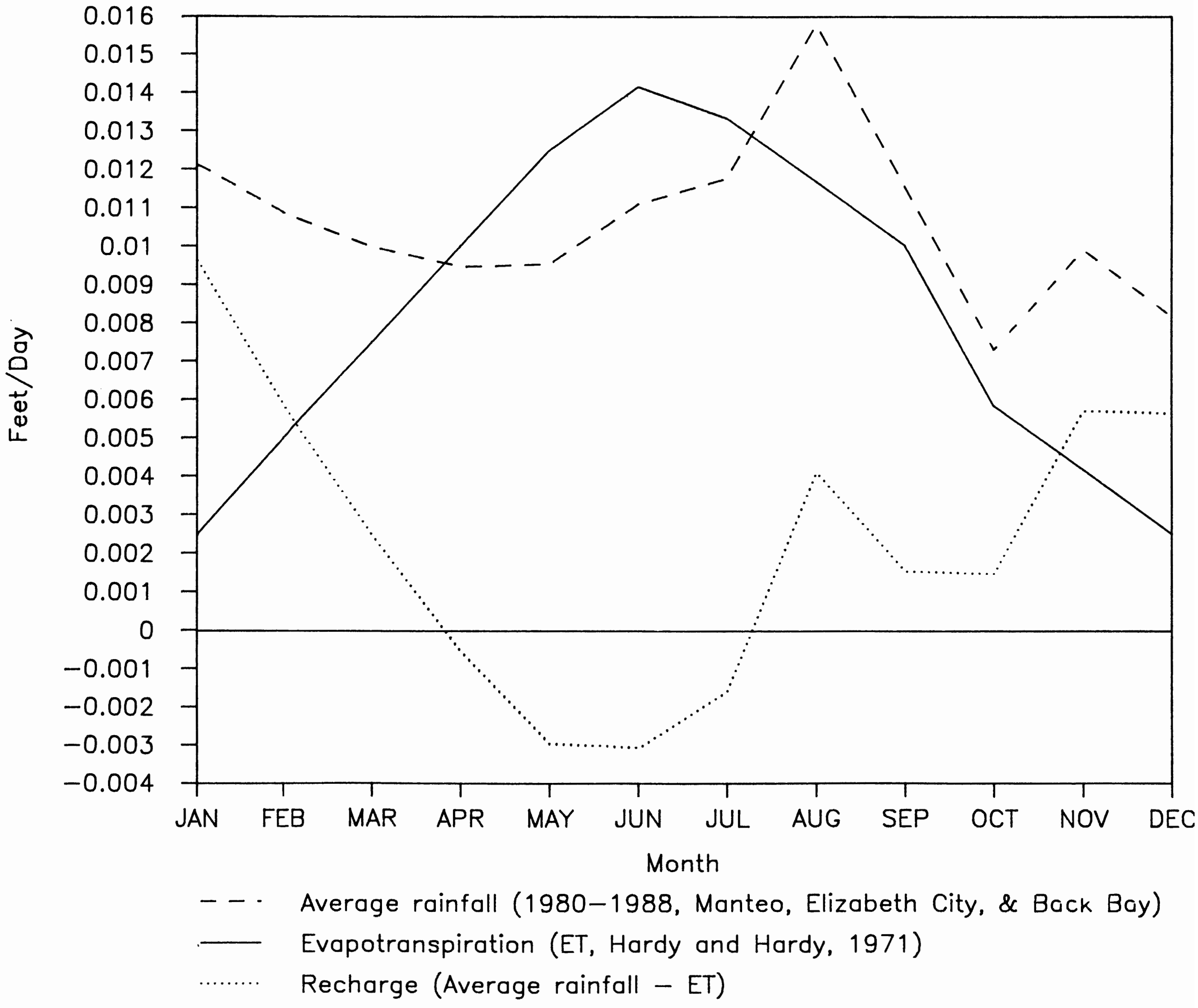


Figure 8. Modified Recharge from Average Rainfall and ET

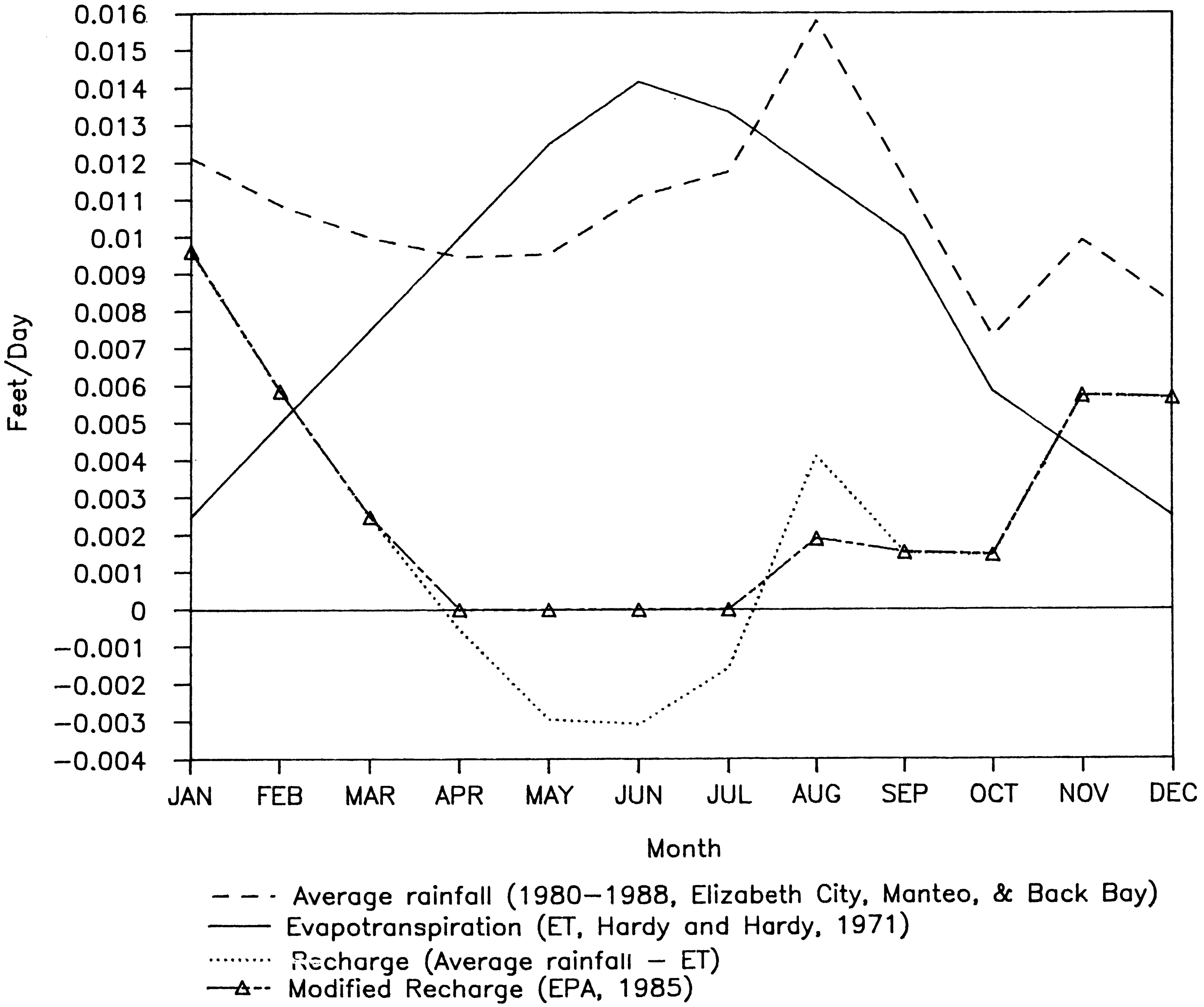
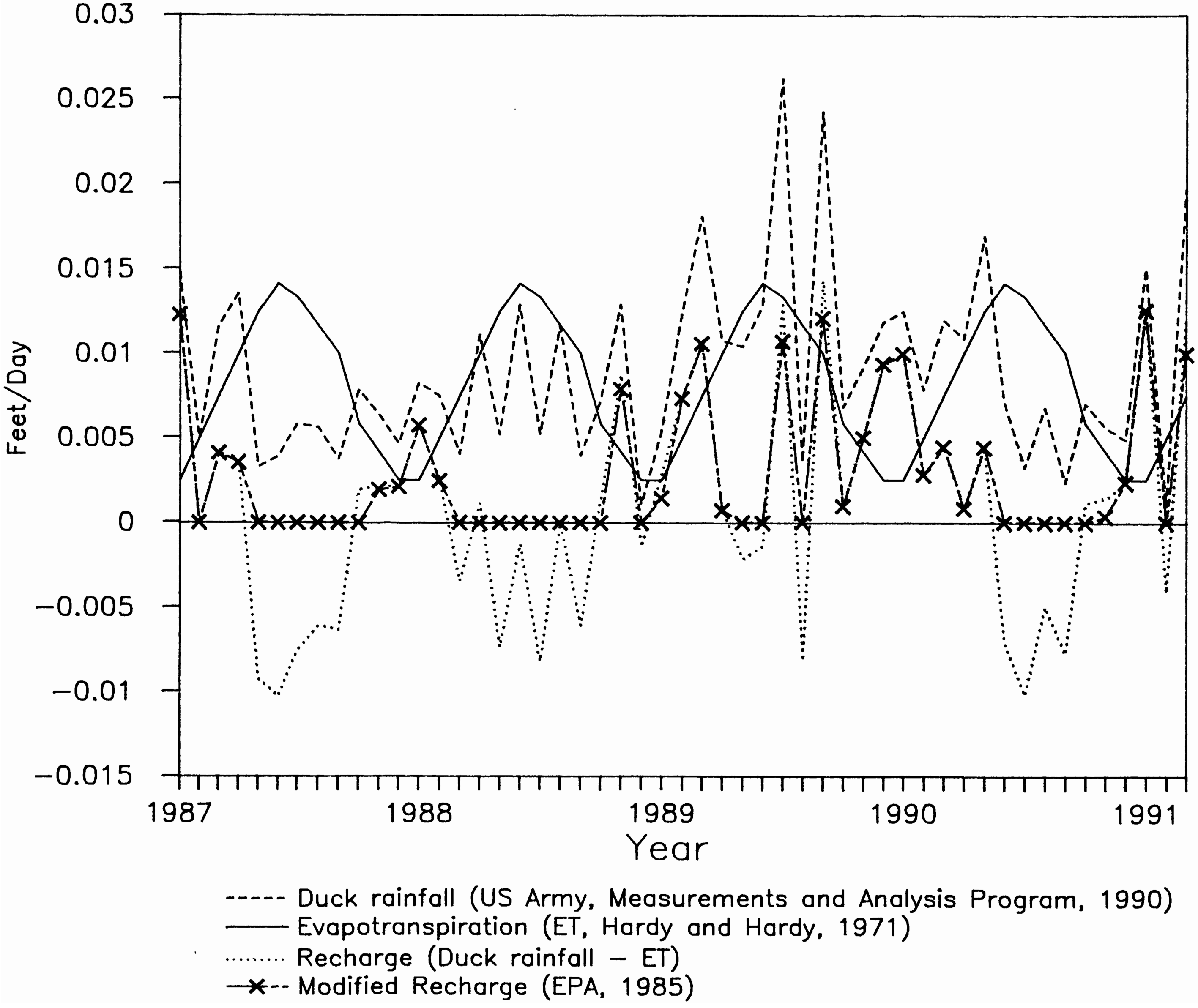


Figure 9. Modified Recharge from Duck Rainfall and ET



respectively. Modified average recharge equaled 0.0029 feet/day or 13 inches/year based on Manteo, Elizabeth City, and Back Bay rainfall and modified Duck recharge ranged from 0.0013 to 0.0049 feet/day or 6 to 21 inches/year based on Duck rainfall (yearly averages).

Another method of estimating recharge is to use a ground water level recession curve (Winner 1975). A well near Cape Hatteras was monitored for water levels during a dry 23-day period of the winter. The levels were plotted versus days and the resulting curve had a -.03 feet/day slope. The discharge from the aquifer to the sound and ocean could be calculated from this by multiplying -.03 by .15 (specific yield) to get -.0045 feet/day or about -20 inches/year. Because this discharge rate occurred while the water table level dropped through the mean yearly water table level it is assumed to be equivalent to the average yearly recharge (20 inches/year). In other words, at the mean water table level there is equilibrium; discharge equals recharge.

This is an average value; actual recharge may vary significantly during the year, and even be negative in some months, as well as vary from year to year. This variability in recharge occurs geographically as well; the dunes and higher elevations have a higher volume of recharge compared to the low areas where the water table is close to the surface and ET is more likely.

Besides natural recharge from rainfall, recharge on the Outer Banks occurs at the individual septic tank systems and the community waste disposal facilities, which return a fraction of the water that wells remove from the aquifer. That percentage is estimated to be 38 percent when effluent volumes are compared to the amount of ground water pumped (DWR, 1991).

Discharge

Discharge from the aquifer occurs at the ocean and sound boundaries and by withdrawals at individual home wells and subdivision wellfields. DWR (1991) estimated water use for the Currituck Outer Banks by dwelling unit. A summer (June-August) average use of 707 gallons per day (gpd) per dwelling unit was determined. Yearly water use averaged about 332 gpd/dwelling for community systems at Corolla Light, Ocean Sands, and Monteray Shores-Buck Island, the systems with the longest periods of record. The Ocean Sands system of wells has a potential to pump about 850,000 gpd, whereas Corolla Light and Monteray Shores have smaller systems of approximately 600,000 and 320,000 gpd, respectively.

Of course, as the population of the Outer Banks grows then the volume of withdrawal increases. 2-D modeling scenarios will be discussed below that explore impacts of growth on the ground water resource. In the Water Use part below withdrawals from the surficial aquifer are discussed more thoroughly.

Water Use

The Currituck County Planning and Zoning Department reported that development for the years 1986 to 1989 on the Currituck Outer Banks far exceeded previous estimates projected for these years. This knowledge prompted interest in learning more about the existing and future water needs.

Existing Water Use

Future water use forecasts require several types of existing water use information. These data include historical monthly water volumes pumped, historical numbers of homes and metered users, planned numbers of dwelling units, and consumptive water use. The following discussion elaborates on the collection and manipulation of these data.

Three developments, Ocean Sands, Corolla Light, and Monteray Shores-Buck Island had public water system information available. Each system's water use per month as reported to the N.C. Division of Environmental Health (DEH) was reviewed to determine the monthly raw water use in gpd through 1990 (Table 4). The Currituck County Water Department also gathered this type of water use information. The Water Department began collecting volumes of raw water pumped and numbers of meters for Ocean Sands in 1986. Records for Corolla Light and Monteray Shores-Buck Island begin in the years 1987 and 1989, respectively.

The estimated number of dwelling units on-site at the end of each year for 1985 through 1990 and full build-out, in Table 5, were provided by the Currituck County Planning and Zoning Department in 1991.

Monthly treated wastewater discharge that was reported to the N.C. Division of Environmental Management (DEM) for these systems was reviewed. These data, shown in Table 6, were helpful in determining the amount of consumptive water use, ground water withdrawal minus return water to the surficial aquifer. The ratio of treated wastewater discharge to metered water use in 1989 and 1990 for the Corolla Light and Ocean Sands systems indicate that disposal averaged 38 percent. Consumptive use, the water lost from the island system, averaged 62 percent. These ratios of disposal to water use in Table 6 show a wide range of variability from 0.12 to 1.06. Several possible situations might account for variable discharge including lag time of water movement in system due to storage tanks, inaccurate meters, and leaking water and sewer systems. It is possible that some of the water considered part of consumptive use is actually recharging the aquifer (such as outside showers), however, those water volumes are difficult to quantify.

Average water use per day per dwelling unit for each month of the year was based on water use data available for the Ocean

Table 4. Existing Water Use 1986-1990
(in GPD)

Year/Month		Ocean Sands	Corolla Light	Monteray Shores	Total
1986	January	12,000			12,000
	February	8,000			8,000
	March	14,000			14,000
	April	29,000			29,000
	May	24,000			24,000
	June	37,000			37,000
	July	98,000			98,000
	August	107,000			107,000
	September	45,000			45,000
	October	29,000			29,000
	November	24,000			24,000
	December	19,000			19,000
1987	January	13,000			13,000
	February	13,000			13,000
	March	16,000			16,000
	April	22,000			22,000
	May	31,000			31,000
	June	77,000			77,000
	July	110,000			110,000
	August	128,000			128,000
	September	89,000			89,000
	October	32,000			32,000
	November	29,000			29,000
	December	17,000			17,000
1988	January	22,000	20,000		42,000
	February	17,000	13,000		30,000
	March	21,000	33,000		54,000
	April	43,000	28,000		71,000
	May	49,000	38,000		87,000
	June	100,000	76,000		176,000
	July	145,000	96,000		241,000
	August	155,000	101,000		256,000
	September	78,000	67,000		145,000
	October	53,000	44,000		97,000
	November	29,000	32,000		61,000
	December	27,000	18,000		45,000
1989	January	24,000	14,000		38,000
	February	16,000	13,000		29,000
	March	27,000	30,000		57,000
	April	41,000	24,000	3,000	68,000
	May	70,000	57,000	7,000	134,000
	June	151,000	110,000	14,000	275,000
	July	219,000	142,000	15,000	376,000
	August	222,000	128,000	19,000	369,000
	September	132,000	75,000	11,000	218,000
	October	68,000	40,000	3,000	111,000
	November	52,000	25,000	2,000	79,000
	December	42,000	22,000	4,000	68,000
1990	January	28,000	19,000	2,000	49,000
	February	16,000	24,000	2,000	42,000
	March	33,000	25,000	4,000	62,000
	April	80,000	55,000	13,000	148,000
	May	90,000	72,000	10,000	172,000
	June	165,000	158,000	18,000	341,000
	July	226,000	186,000	20,000	432,000
	August	223,000	188,000	16,000	427,000
	September	108,000	128,000	8,000	244,000
	October	59,000	87,000	8,000	154,000
	November	56,000	40,000	7,000	103,000
	December	42,000	22,000	2,000	66,000

Table 5. Number of Dwelling Units by Subdivision
Currituck County Outer Banks

Number Through the End of Each Listed Year

North Section	1985	1986	1987	1988	1989	1990	Platted Lots
Carova Beach	157	162	173	184	196	202	2,017
North Swan Beach	5	7	7	7	7	7	414
Swan Beach/Seagull	30	41	45	49	52	56	577
Ocean Beach	0	0	0	0	0	0	14
Total	192	210	225	240	255	265	3,022

South Section	1985	1986	1987	1988	1989	1990	Platted Lots
Corolla Village	43	44	45	46	51	51	119
Corolla Light	0	29	73	117	154	170	526
Whalehead	174	217	246	277	315	333	864
Monteray Shores	0	0	0	7	30	36	608
Ocean Sands	198	281	343	415	472	508	2,290*
Spindrift	1	6	11	14	14	14	31
Buck Island (Shipswatch)	0	0	0	0	0	1	106
Ocean Hill	23	26	29	39	41	48	113
Villages at Ocean Hill	2	2	2	2	2	3	314
Pine Island	0	0	0	0	0	0	350*
Total	441	605	749	917	1,079	1,164	5,321

* Total platted lots do not include 1,250 hotel rooms for Ocean Sands, and 150 hotel rooms for Pine Island. Hotel water usage is considered commercial.

Source: Currituck County Planning and Zoning Department, 1991

Table 6. Consumptive Water Use in Corolla Light and Ocean Sands Subdivisions

	Corolla Light			Ocean Sands		
	Water Use (MGD)	Wastewater Pumped (MGD)	Ratio	Water Use (MGD)	Wastewater Pumped (MGD)	Ratio
DEC 88	0.018	0.006	0.33	0.027	0.019	0.70
JAN 89	0.014	0.006	0.43	0.024	0.017	0.71
FEB 89	0.013	0.007	0.54	0.016	0.017	1.06
MAR 89	0.030	0.019	0.63	0.027		
APR 89	0.024	0.013	0.54	0.041		
MAY 89	0.057	0.019	0.33	0.070		
JUN 89	0.110	0.035	0.32	0.151		
JUL 89	0.142	0.054	0.38	0.219		
AUG 89	0.128	0.054	0.42	0.222		
SEP 89	0.075	0.022	0.29	0.132	0.067	0.51
OCT 89	0.040	0.011	0.27	0.068	0.033	0.49
NOV 89	0.025	0.008	0.32	0.052	0.022	0.42
DEC 89	0.022	0.007	0.32	0.042	0.005	0.12
JAN 90	0.019	0.007	0.37	0.028	0.006	0.21
FEB 90	0.024	0.005	0.21	0.016	0.007	0.44
MAR 90	0.025	0.005	0.20	0.033	0.007	0.21
APR 90	0.055	0.011	0.20	0.080	0.017	0.21
MAY 90	0.072	0.017	0.24	0.090	0.030	0.33
JUN 90	0.158	0.040	0.25	0.165	0.051	0.31
JUL 90	0.186	0.060	0.32	0.226	0.104	0.46
AUG 90	0.188	0.062	0.33	0.223	0.144	0.65
SEP 90	0.128	0.027	0.21	0.108	0.056	0.52
OCT 90	0.087	0.011	0.13	0.059	0.029	0.49
NOV 90	0.040	0.009	0.22	0.056	0.019	0.34
DEC 90	0.022	0.006	0.27	0.042	0.012	0.29

Subdivision	Average Ratio (%)	Consumptive Use (%)
Corolla Light	32	68
Ocean Sands	45	55
Average	38	62

Sands, Corolla Light, and Monteray Shores-Buck Island water systems. The average use per dwelling is shown in Table 7. This monthly use per dwelling will be multiplied by the number of platted units (planned lots) to project the water supply needs for other developments.

The water use data shown in Table 7 and Figure 10, indicates that the summer months of June, July, and August exhibit maximum water demand. The average combined monthly water use per dwelling unit for the three subdivisions during the summer months was 707 gpd, or about 2.1 times the yearly average of 332 gpd. In Figure 10, Corolla Light dwelling units show the highest water use of the three subdivisions. Each dwelling unit in Corolla Light appears to consume more water than the other PUDs because these rates include a larger percentage of commercial use. Water use rates for Ocean Sands are lowest indicating the least amount of commercial usage.

It is not possible with existing data to identify accurately the volumes of commercial water pumped for each subdivision's restaurants, stores, pools, golf courses, hotels, etc. If possible, that analysis would allow better resolution of residential water use rates. The best estimate at this time is a gpd/dwelling unit value that includes other water uses. By using these rates DWR assumes that commercial growth will keep pace with residential growth; the volume of water pumped for commercial use will remain at a certain percentage of total water pumped as the subdivision grows to full build-out.

Future Water Use

A forecast of the water needs of the planned unit developments for full build-out is shown in Table 8. Each PUD's water use forecast is calculated using the monthly averages in Table 7 and Figure 10. The water use forecasts for Ocean Sands and Pine Island are based on the combined average of Corolla Light, Ocean Sands, and Monteray Shores-Buck Island monthly water use per dwelling unit (Table 7) multiplied by the number of planned units for each development (Table 5). It is assumed that the rate of water use for these subdivisions will rise with the addition of commercial water use. Water needs for the build-out of Corolla Light subdivision is based on its monthly average water use per dwelling unit rate. Monteray Shores-Buck Island future build-out water use is calculated using an average of Monteray Shores and Corolla Light monthly water use. This assumed increase is also due to increased commercial water use. Lastly, the Villages of Ocean Hill's water use is based on Monteray Shores-Buck Island present-day water use because of the similarity between these PUDs.

The estimated number of dwelling units existing at the end of each year from 1985 to 1990 for the northern and southern sections are shown on Table 5. A linear regression of the number of homes in the southern section over the five year period 1985 to 1990 revealed an increase of approximately 149 units per year.

Table 7. Average Monthly and Yearly Water Use Per Dwelling Unit by Subdivision

per dwelling unit water use in gpd*

	Ocean Sands	Corolla Light	Monteray Shores	Average
January	77	167	66	103
February	55	140	65	86
March	83	263	127	158
April	155	283	305	248
May	180	432	365	325
June	352	862	651	622
July	546	1045	666	753
August	568	1011	661	747
September	300	640	343	428
October	157	397	172	242
November	122	228	134	161
December	92	142	94	109
Yearly Average	224	468	304	332
Summer Average (June-August)	489	973	659	707

* Averages are calculated from data in Table 4. Ocean Sands average per dwelling unit water use is calculated from 1986-1990 data, Corolla Light from 1988-1990 data, and Monteray Shores from 1989-1990 data.

Figure 10. Average Monthly Water Use per PUD Dwelling Unit

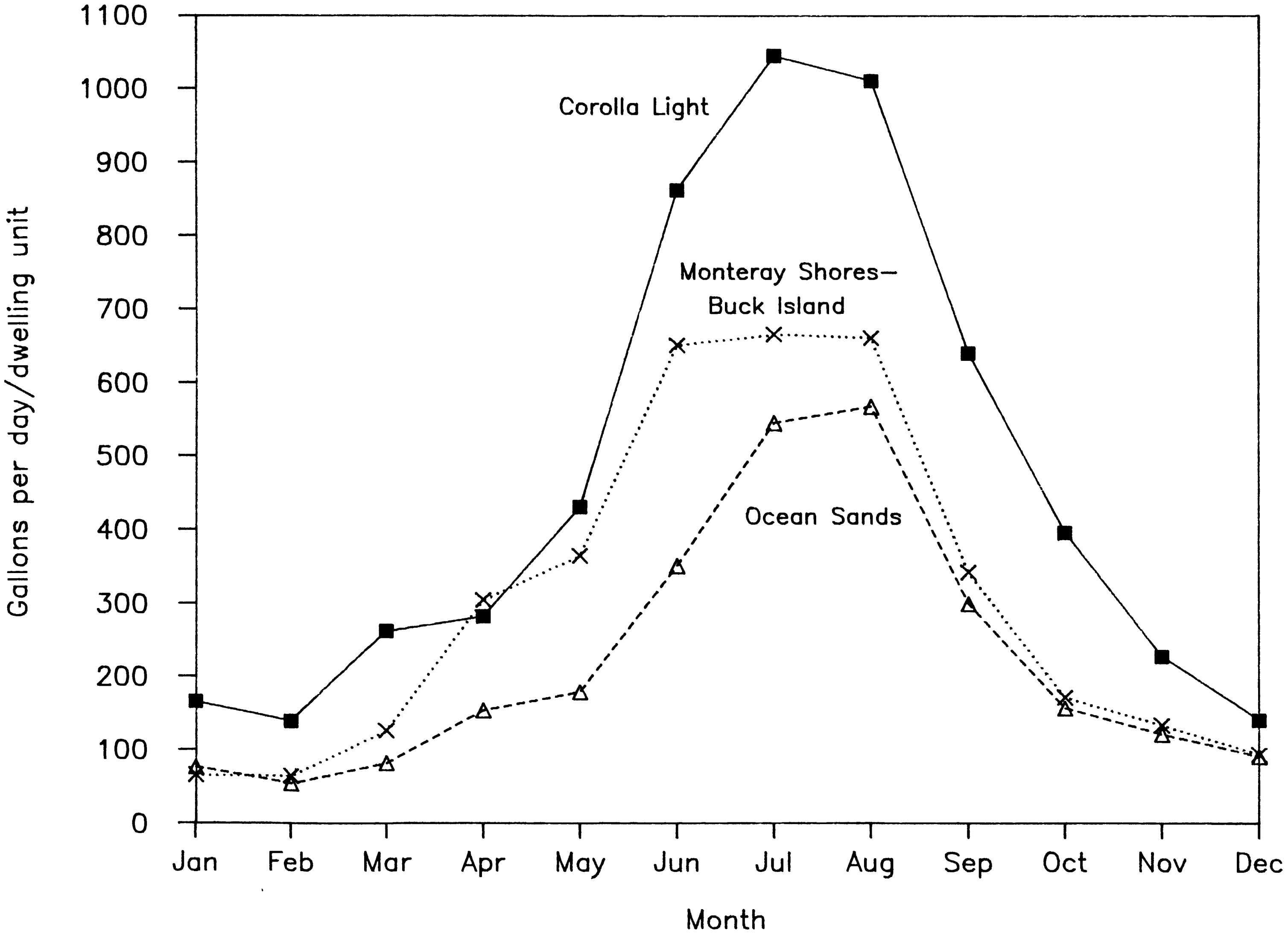


Table 8. Southern Currituck Outer Banks
Full Platted Build-out PUD Water Use

(in gpd)

Month (projected)	Ocean Sands	Corolla Light	Mont Sh/ Buck Is.	Vil. at Ocean H.	Pine Island	Total
# platted units	2,090*	526	714	314	350	3,994
January	215,000	88,000	83,000	21,000	36,000	443,000
February	181,000	74,000	73,000	20,000	30,000	378,000
March	329,000	138,000	139,000	40,000	55,000	701,000
April	518,000	149,000	210,000	96,000	87,000	1,060,000
May	680,000	227,000	284,000	115,000	114,000	1,420,000
June	1,300,000	454,000	540,000	204,000	218,000	2,716,000
July	1,573,000	550,000	611,000	209,000	263,000	3,206,000
August	1,560,000	532,000	597,000	207,000	261,000	3,157,000
September	894,000	337,000	351,000	108,000	150,000	1,840,000
October	506,000	209,000	203,000	54,000	85,000	1,057,000
November	337,000	120,000	129,000	42,000	56,000	684,000
December	229,000	75,000	84,000	30,000	38,000	456,000
Annual Average	694,000	246,000	275,000	96,000	116,000	1,427,000

* Ocean Sands full build-out value does not include 200 homes on individual wells and septic tank systems.

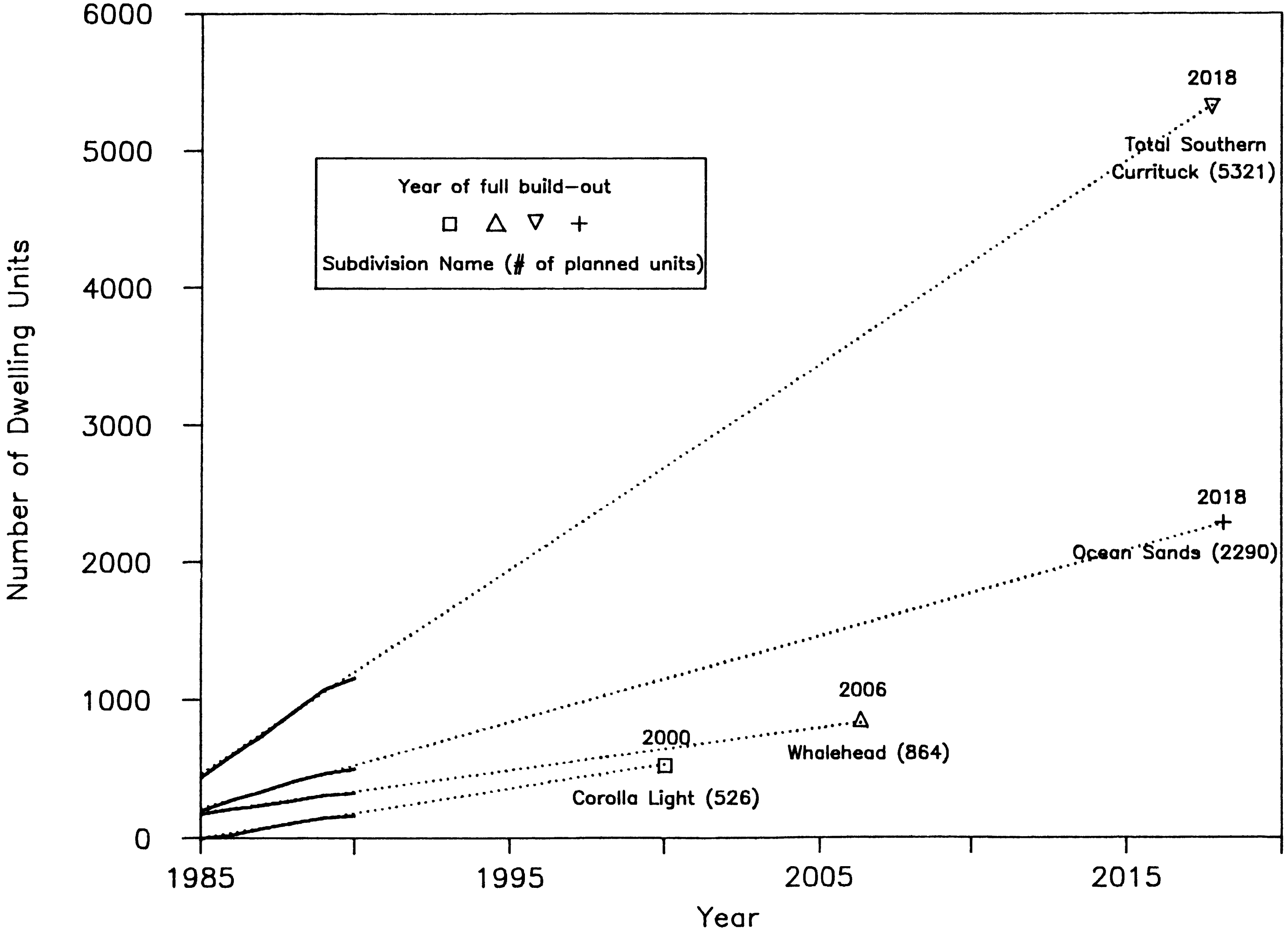
During the same period the northern section added about 15 units per year. A trend line projection of 149 units and 15 units added per year to the southern and northern sections, respectively, was applied to estimate the year of full build-out (Figure 11). Full build-out for the Northern Section was not illustrated due to the unlikelihood of that trend (15 units per year) continuing until the year 2177.

Other projections are indicated on Figure 11 for the Southern Section subdivisions. Full platted build-out is projected to be reached by the Southern Section as a whole in the year 2018 and by individual subdivisions between the years 2000 and 2018. These linear projections are used to show the fast rate of growth and provide a rough timetable of development.

A forecast of water supply needs has also been estimated for a worst-case-scenario that assumes a build-out of all units as platted in 1990 plus all other potential development. In 1991, the Currituck County Planning and Zoning Department estimated that potential development of lands not platted in 1990 would add about 554 units in the southern section (Currituck Hunt Club only) and 279 units in the northern section. The housing units for the platted and potential development were added together and multiplied by the yearly water use average (332 gpd/dwelling unit) to project the estimated water demand, shown in Table 9.

Figure 11. Southern Currituck Outer Banks Growth by Subdivision

Linear Forecast from 1985–1990 Data



Source: Division of Water Resources and
Currituck County, 1991

Table 9. Water Use for Potential Build-Out
Currituck County Outer Banks

	Southern Section	Northern Section	
Township	Poplar Branch	Fruitville	Total
Platted Units	5,321	3,022	8,343
Yearly Water Use (MGD)	1.767	1.003	2.770
Potential Units *	554	279	833
Yearly Water Use (MGD)	0.184	0.093	0.277
Total Units	5,875	3,301	9,176
Yearly Water Use (MGD)	1.951	1.096	3.047

MGD: million gallons per day

Assumes a yearly water need of 332 gallons per day per unit.

* Based on Currituck County Planning and Zoning Department projections, 1991.

Model Development

Setup

Because of the complexity and dynamics of the surficial aquifer system underlying the Currituck Outer Banks, analysis of this region merits computer simulation. Previous attempts to examine smaller portions of the island did not use computer modeling suitable for the complexity of the aquifer and thus can not be expanded to include the hydrology of the island as a whole. Therefore, a search for computer programs able to deal with a saltwater-freshwater interface was conducted. The discovery of Dr. Dinshaw Contractor's program led to the use of this analytical tool.

Early one-dimensional (1-D) computer modeling using the saltwater intrusion program written by Dr. Contractor allowed parameter ranges to be tested and water table elevations on a transect across the island to be reproduced (Contractor, 1988). Use of this model enabled more efficient and knowledgeable use of Contractor's 2-D model (entitled SWGUAM). A two-dimensional (2-D) computer program allowed analysis, on a monthly basis, of the interplay of pumping and recharge over the entire model area. The mathematics of the model, model setup, and description of 2-D modeling results follows.

Two-dimensional modeling of ground water conditions on the Currituck Outer Banks utilized Contractor's SWGUAM computer program (Contractor and Srivastava, 1989). The model uses the finite element numerical method to solve for freshwater and saltwater heads at nodes over a domain divided into triangular elements. These heads are measures of the pressure exerted by a column of freshwater or saltwater with a specific height above datum. The computed freshwater head equals the elevation of the water table at a particular node. Sample input and output data sets can be found in Appendix A.

The model is based on the following assumptions: 1. Darcy's law is valid; 2. A sharp interface exists between freshwater and saltwater; 3. Horizontal permeability varies negligibly in the vertical direction; 4. Both freshwater and saltwater are homogeneous and isotropic fluids with constant densities and viscosities; 5. Saturated flow (water completely fills all voids in aquifer material) occurs in the freshwater and saltwater zones; 6. Soil and water compressibilities are small; and 7. There is no saltwater source or sink (Contractor and Srivastava, 1989). The model also allowed steady state and transient model runs. Transient simulations for Currituck County Outer Banks use a month long time-step. The guiding differential equations for the freshwater and saltwater heads and the elevation of the interface are reported in Appendix A. The reader is referred to Contractor and Srivastava, 1989, for the description of the numerical method to solve these equations. The size and shape of the Currituck model area and additional output for illustrative purposes required slight modifications to Contractor's code.

The first step in developing the model was the establishment of nodes and triangular elements (a node is defined as each apex of the triangular element) to fill in the area of interest. The model covers the southern section of the island, or the portion beginning just north of the Dare County line and ending to the north of Villages of Ocean Hill subdivision near Corolla (Figure 12). This area (6.48 square miles or 181 million square feet) is experiencing the most rapid development. Triangular elements were laid out over the island to provide the best cross-sectional information from model runs. Figure 13 shows a portion of the modeled area to illustrate the method of identifying element boundaries. Nodes define the apexes of each element and correspond to wells or wellfields where appropriate. Figure 14 shows the entire model area, element boundaries, and node positions (apexes of each element).

It was necessary during program input data set preparation to use a numbering system for the elements and nodes. Computation time for model runs and size of array (computer memory needed) depend on the numbering system selected. Contractor included a program in his documentation that optimizes this numbering scheme. Therefore, once the numbers have been assigned to nodes, the program SWGUAM optimizes that numbering system and assigns new numbers to the nodes. After setting the grid and fixing the nodal numbers, the assigning of hydraulic conductivity, elevation of clay layer, recharge rates, and boundary conditions followed.

Because hydraulic conductivity (K) obtained from pump tests ranged widely and K has only been measured in a few areas, an average value was used for all model elements. K was set at 20 feet/day initially throughout the model area. This K value represents the low end of the plausible range determined from 1-D modeling using January water table elevations and average yearly recharge. January represents higher than average recharge with higher than average water table elevations, so K is expected to be somewhat higher than 20 feet/day. Other reports indicate K may average about 40 -- 85 feet/day (EPA, 1985; Russnow, Kane & Andrews, Inc., 1987a). Two-dimensional model runs have indicated a very high degree of water table elevation sensitivity to the value of hydraulic conductivity. Model runs showing the most accurate estimate of the water table elevations have K set to 68 feet/day.

The clay layer elevation was probably the least well known of the model parameters due to lack of borehole information. Nine elevations extracted from the literature and personal communications allowed contouring. The resulting estimate of the top of the clay layer surface (Figure 15) is depicted in a cross-section of the model area from north-northwest to south-southeast. There may be more than one clay layer creating the indicated surface. Elevation values for each node were interpolated from this cross-section assuming the clay layer is horizontal across the short axis of the island. For modeling purposes it is assumed the clay layer is impervious and

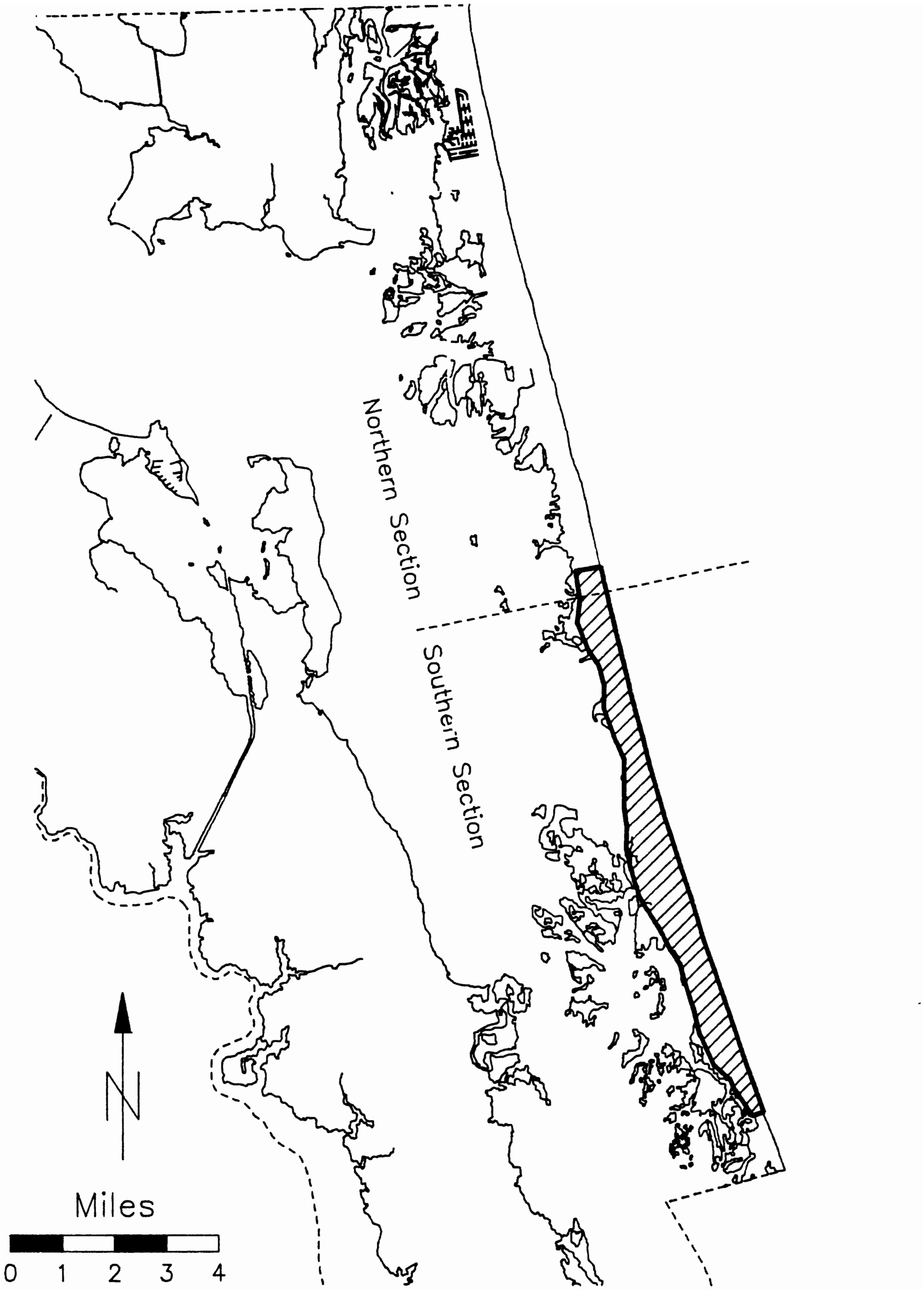


Figure 12. Model Boundary

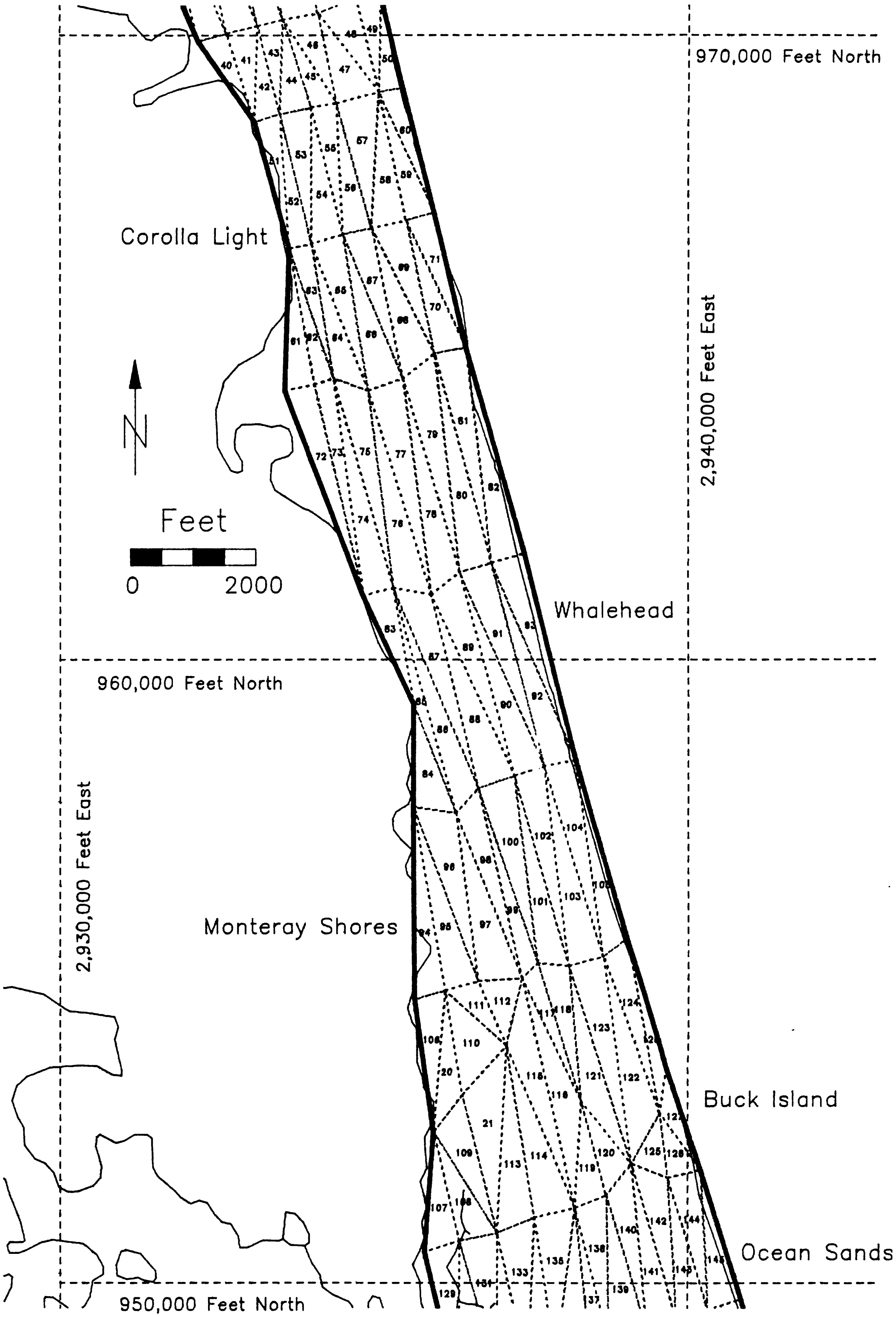


Figure 13. Elements and Nodes in Portion of Model Area

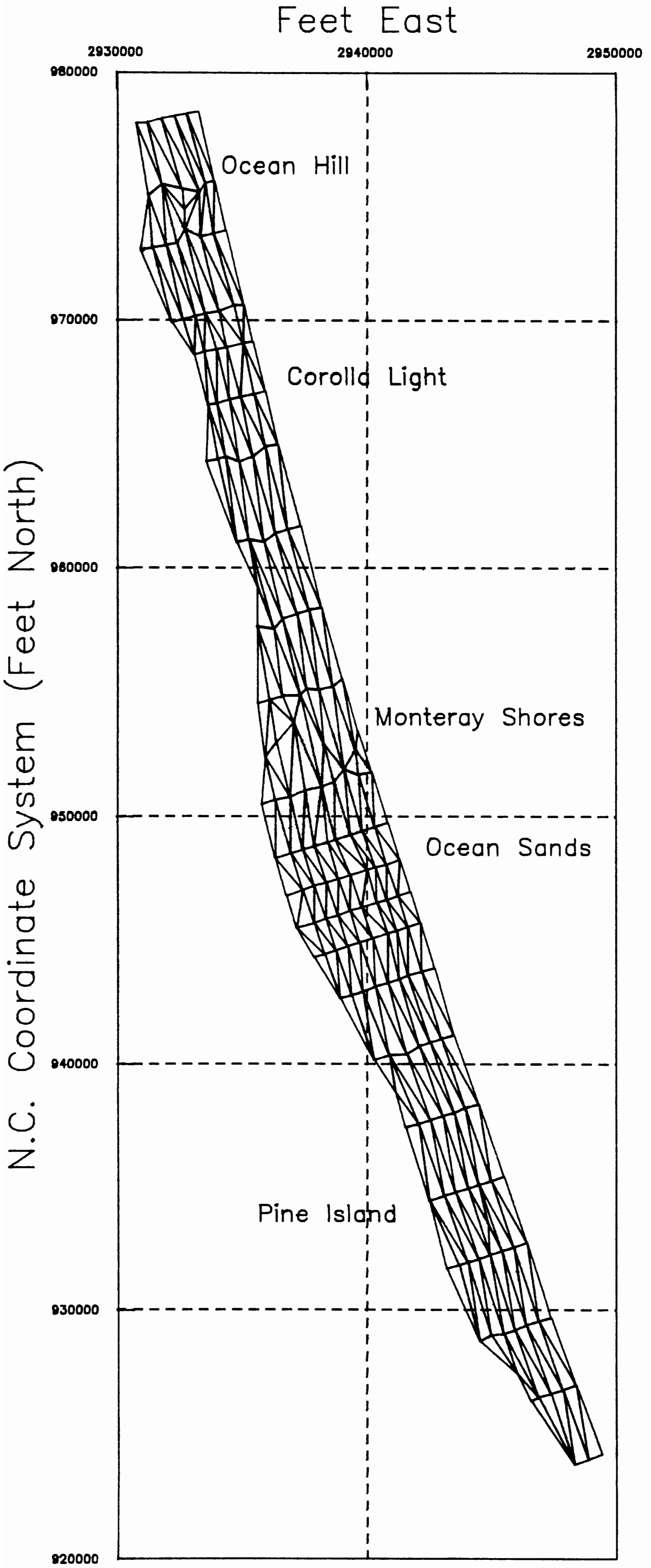
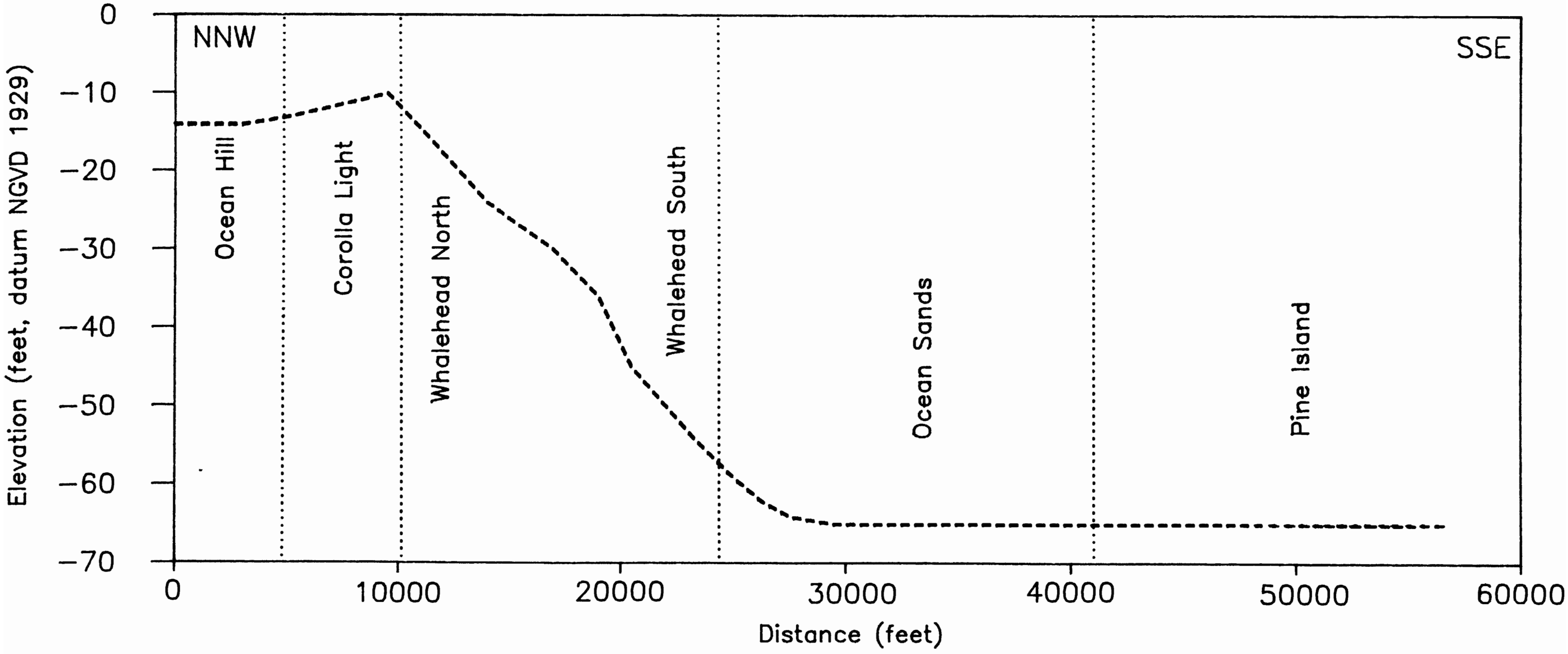


Figure 14. Model Element Boundaries

SCALE 1 inch = 6667 feet

Figure 15. Elevation of Top of Clay Layer

Estimated from borehole data.



represents the base of the aquifer. The limited data obtained from the Outer Banks suggests that the relative difference between the permeabilities of the upper sands and the clay layer is quite large. Whereas chloride levels are less than 250 mg/l above the clay layer, chloride concentrations below the clay layer are very high (about 8,500 mg/l at Ocean Sands and 1,700 mg/l at Villages at Ocean Hill) suggesting a low vertical hydraulic conductivity in the clay layer (Andrews, 1990).

Two-dimensional modeling shows that the elevation of the clay layer or the thickness of the aquifer causes minor changes in the water table elevation. Only major changes (tens of feet) in the depth of the clay layer result in largely different water table levels. Water table elevation is, however, extremely sensitive to recharge. Thus estimation of this parameter is very important and requires accurate rainfall records.

Recharge was estimated using two data sets -- 1) daily rainfall records from Manteo, Elizabeth City, and Back Bay for 1980-1988 and monthly estimated evapotranspiration (ET) data from Wilmington (NOAA, 1988; Hardy and Hardy, 1971), and 2) daily rainfall data from Duck for September 1986 to March 1991 and the same ET data from Wilmington. A modified ET subtracted from average monthly rainfall produced monthly recharge values in the form of a rate in feet/day in Figure 16 (EPA, 1985). Run-off was assumed to be negligible because only a few limited streams and canals exist in the model area.

ET data from Wilmington and rainfall data were manipulated in the following manner after EPA, 1985 (see examples in Tables 10 and 11). Monthly ET (ET potential -- ETp) was subtracted from monthly rainfall (I) to get column 3 (I-ETp). Negative I-ETp values were summed in column 4 (SumNeg (I-ETp)) to calculate accumulated potential water loss. Soil moisture storage (S) is estimated to be a maximum of 0.0022 feet/day based on available water capacity numbers for sand (0.133) and 0.5 foot thick soil coverage ((0.133 * 0.5 feet)/days in month). S fluctuates between 0 and 0.0022 because of I-ETp values. In column 6 (DelS) is calculated based on the change in S value from the preceding month. When I-Etp is positive then ET actual (ETa) in column 7 is equal to ETp. When I-ETp is negative then ETa = ETp + ((I - ETp) - DelS). Modified recharge is finally calculated in column 8 on Tables 10 and 11 using the formula, recharge = I - ETa - DelS.

Recharge has also been adjusted in the model to allow for spatial distribution due to highs and lows in topography, and areas where drainage is poor (the water table is at or near land surface). High recharge occurs in highly drained soils, low recharge in poorly drained soils, and areas with a mixture of soils received medium recharge. Soil maps from Soil Conservation Service mapping of Currituck County identified areas with low or high drainage (U.S. Soil Conservation Service, 1982).

The ratio of monthly rainfall to monthly recharge (MRATIO,

Figure 16. Modified Recharge

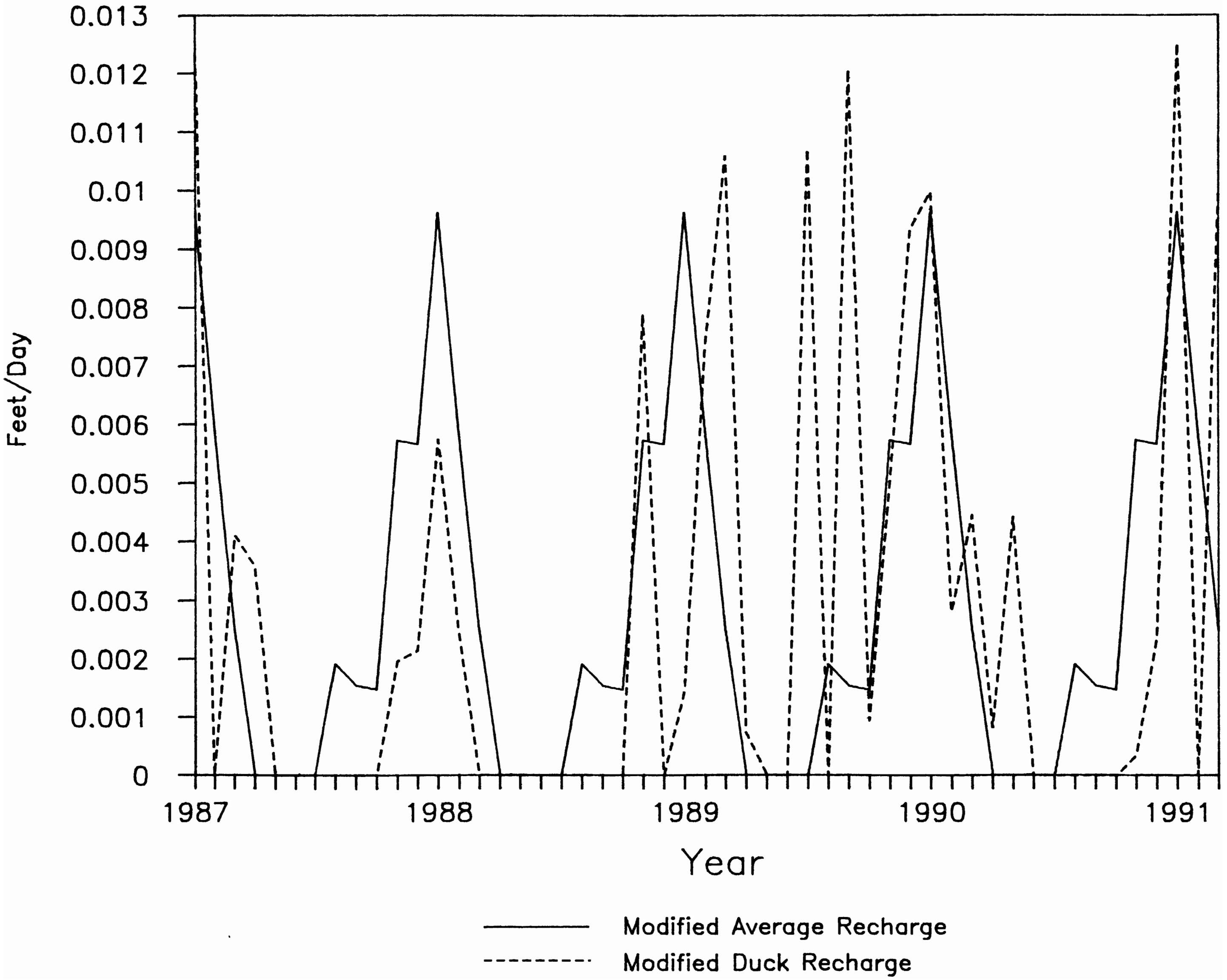


Table 10. Modified Average Recharge Based on Wilmington ET and Average Rainfall from Elizabeth City, Manteo, and Back Bay

(in feet/day)

	Rainfall I	ETp	I-ETp	SumNeg (I-ETp)	S	DelS	ETa	I-ETa-DelS Recharge
JAN	0.012138	0.002500	0.009638		0.002200	0.000000	0.002500	0.009638
FEB	0.010869	0.005000	0.005869		0.002200	0.000000	0.005000	0.005869
MAR	0.009980	0.007500	0.002480		0.002200	0.000000	0.007500	0.002480
APR	0.009470	0.010000	-0.000530	-0.000530	0.001669	-0.000530	0.010000	0.000000
MAY	0.009547	0.012500	-0.002953	-0.003483	0.000000	-0.001670	0.011217	0.000000
JUN	0.011103	0.014167	-0.003064	-0.006546	0.000000	0.000000	0.011103	0.000000
JUL	0.011768	0.013333	-0.001565	-0.008111	0.000000	0.000000	0.011768	0.000000
AUG	0.015783	0.011667	0.004117		0.002200	0.002200	0.011667	0.001917
SEP	0.011535	0.010000	0.001535		0.002200	0.000000	0.010000	0.001535
OCT	0.007302	0.005833	0.001469		0.002200	0.000000	0.005833	0.001469
NOV	0.009905	0.004167	0.005738		0.002200	0.000000	0.004167	0.005738
DEC	0.008165	0.002500	0.005665		0.002200	0.000000	0.002500	0.005665
AVG	0.010630							0.002859

ETp = Potential Evapotranspiration
ETa = Actual Evapotranspiration
S = Soil Moisture Storage

Table 11. Modified Duck Recharge Based on Wilmington ET and Rainfall from Duck

(in feet/day)

	Month	Rainfall I	ETp	I-ETp	SumNeg (I-ETp)	S	DelS	ETa	I-ETa-DelS Recharge
	SEP	0.004593	0.010000	-0.005407	-0.005407	0.000000	0.000000	0.004593	0.000000
	OCT	0.001799	0.005833	-0.004034	-0.009441	0.000000	0.000000	0.001799	0.000000
	NOV	0.005030	0.004167	0.000863		0.000863	0.000863	0.004167	0.000000
	DEC	0.007196	0.002500	0.004696		0.002200	0.001337	0.002500	0.003359
1987	JAN	0.014816	0.002500	0.012316		0.002200	0.000000	0.002500	0.012316
	FEB	0.004977	0.005000	-0.000023	-0.000023	0.002177	-0.000023	0.005000	0.000000
	MAR	0.011641	0.007500	0.004141		0.002200	0.000023	0.007500	0.004118
	APR	0.013560	0.010000	0.003560		0.002200	0.000000	0.010000	0.003560
	MAY	0.003280	0.012500	-0.009220	-0.009220	0.000000	-0.002200	0.005480	0.000000
	JUN	0.003937	0.014167	-0.010230	-0.019450	0.000000	0.000000	0.003937	0.000000
	JUL	0.005820	0.013333	-0.007513	-0.026963	0.000000	0.000000	0.005820	0.000000
	AUG	0.005609	0.011667	-0.006058	-0.033021	0.000000	0.000000	0.005609	0.000000
	SEP	0.003718	0.010000	-0.006282	-0.039303	0.000000	0.000000	0.003718	0.000000
	OCT	0.007831	0.005833	0.001998		0.001998	0.001998	0.005833	0.000000
	NOV	0.006342	0.004167	0.002175		0.002200	0.000202	0.004167	0.001973
	DEC	0.004656	0.002500	0.002156		0.002200	0.000000	0.002500	0.002156
1988	JAN	0.008255	0.002500	0.005755		0.002200	0.000000	0.002500	0.005755
	FEB	0.007466	0.005000	0.002466		0.002200	0.000000	0.005000	0.002466
	MAR	0.004021	0.007500	-0.003479	-0.003479	0.000000	-0.002200	0.006221	0.000000
	APR	0.011154	0.010000	0.001154		0.001154	0.001154	0.010000	0.000000
	MAY	0.005185	0.012500	-0.007315	-0.007315	0.000000	-0.001154	0.006339	0.000000
	JUN	0.012904	0.014167	-0.001263	-0.008578	0.000000	0.000000	0.012904	0.000000
	JUL	0.005185	0.013333	-0.008148	-0.016726	0.000000	0.000000	0.005185	0.000000
	AUG	0.011641	0.011667	-0.000026	-0.016752	0.000000	0.000000	0.011641	0.000000
	SEP	0.003937	0.010000	-0.006063	-0.022815	0.000000	0.000000	0.003937	0.000000
	OCT	0.007196	0.005833	0.001363		0.001363	0.001363	0.005833	0.000000
	NOV	0.012904	0.004167	0.008737		0.002200	0.000837	0.004167	0.007900
	DEC	0.001058	0.002500	-0.001442	-0.001442	0.000758	-0.001442	0.002500	0.000000
1989	JAN	0.005398	0.002500	0.002898		0.002200	0.001442	0.002500	0.001456
	FEB	0.012331	0.005000	0.007331		0.002200	0.000000	0.005000	0.007331
	MAR	0.018098	0.007500	0.010598		0.002200	0.000000	0.007500	0.010598
	APR	0.010717	0.010000	0.000717		0.002200	0.000000	0.010000	0.000717
	MAY	0.010372	0.012500	-0.002128	-0.002128	0.000072	-0.002128	0.012500	0.000000
	JUN	0.012795	0.014167	-0.001371	-0.003500	0.000000	-0.000072	0.012867	0.000000
	JUL	0.026247	0.013333	0.012913		0.002200	0.002200	0.013333	0.010713
	AUG	0.003598	0.011667	-0.008068	-0.008068	0.000000	-0.002200	0.005798	0.000000
	SEP	0.024278	0.010000	0.014278		0.002200	0.002200	0.010000	0.012078
	OCT	0.006773	0.005833	0.000940		0.002200	0.000000	0.005833	0.000940
	NOV	0.009186	0.004167	0.005020		0.002200	0.000000	0.004167	0.005020
	DEC	0.011853	0.002500	0.009353		0.002200	0.000000	0.002500	0.009353
1990	JAN	0.012488	0.002500	0.009988		0.002200	0.000000	0.002500	0.009988
	FEB	0.007806	0.005000	0.002806		0.002200	0.000000	0.005000	0.002806
	MAR	0.011959	0.007500	0.004459		0.002200	0.000000	0.007500	0.004459
	APR	0.010827	0.010000	0.000827		0.002200	0.000000	0.010000	0.000827
	MAY	0.016933	0.012500	0.004433		0.002200	0.000000	0.012500	0.004433
	JUN	0.007108	0.014167	-0.007058	-0.007058	0.000000	-0.002200	0.009308	0.000000
	JUL	0.003175	0.013333	-0.010158	-0.017217	0.000000	0.000000	0.003175	0.000000
	AUG	0.006773	0.011667	-0.004893	-0.022110	0.000000	0.000000	0.006773	0.000000
	SEP	0.002297	0.010000	-0.007703	-0.029813	0.000000	0.000000	0.002297	0.000000
	OCT	0.006985	0.005833	0.001152		0.001152	0.001152	0.005833	0.000000
	NOV	0.005577	0.004167	0.001411		0.002200	0.001048	0.004167	0.000362
	DEC	0.004868	0.002500	0.002368		0.002200	0.000000	0.002500	0.002368
1991	JAN	0.015028	0.002500	0.012528		0.002200	0.000000	0.002500	0.012528
	FEB	0.000937	0.005000	-0.004063	-0.004063	0.000000	-0.002200	0.003137	0.000000
	MAR	0.019685	0.007500	0.012185		0.002200	0.002200	0.007500	0.009985

with a maximum value of 2.0) multiplied by monthly recharge determined infiltration in high recharge (high drainage) areas. Medium recharge areas were valued with the monthly recharge amount. Low recharge areas were assigned to [(1 - (MRATIO - 1)) * monthly recharge]. This recharge distribution, illustrated in Figure 17, compared to constant monthly recharge (when totaled over the model area) differed by less then 0.8 percent. Thus, distribution of the recharge did not introduce any error of significance and may help account for water table elevation variations.

Consumption of water, the volume pumped from the aquifer minus the volume disposed of through septic tank systems, led to adjustment of the recharge rates for affected model elements. Homes using septic tank systems and individual wells were tallied from aerial photographs (Harris Aerial Surveys, Inc., 1989). The number of homes within each element multiplied by the average monthly amount pumped per day (see Table 7 for monthly averages), in cubic feet per day, times the average consumption rate in Table 6 (0.62), divided by the area of the element in square feet, gives the rate of water lost from that element (feet/day). This value was subtracted from the recharge rate applied to the element for each time-step. Water loss rates were also calculated for full build-out estimates. A similar calculation using the estimated future number of homes within elements containing non-PUD housing produced water loss figures for build-out conditions.

PUD water system operators recorded pumping volumes beginning in 1986. Those records from 1986 and 1990 are presented in Table 4. A disposal rate of 38 percent was calculated in the Water Use portion of this report, and is used to estimate return rates at disposal fields. Full build-out pumping is set out in Table 8. In simulations of future conditions, it is assumed that existing well and disposal fields accommodate these pumping and disposal rates. Although current facilities certainly are not large enough to deal with build-out conditions, it is plausible to assume that additional well or disposal fields will be constructed nearby.

The influence of sea level tidal fluctuation, especially on the ocean boundary, has been included in the model. Monthly average sea-level elevations calculated from tide tables are part of the input data set (NOAA, 1988 and NOAA, 1989). The Atlantic Ocean average monthly tides ranged about 0.45 feet above and below an average sea-level of 0.3 feet above NGVD of 1929. The Currituck Sound elevation, obtained from EPA (1985), averaged about 0.89 feet above NGVD of 1929. This Sound elevation was held constant during model runs.

Two other boundary conditions of importance were the northern and southern model boundaries, and consideration of whether or not to use the Ghyben-Herzberg relationship. The northern and southern borders have been set as no-flow boundaries. The appropriateness of this depends largely on the geographic

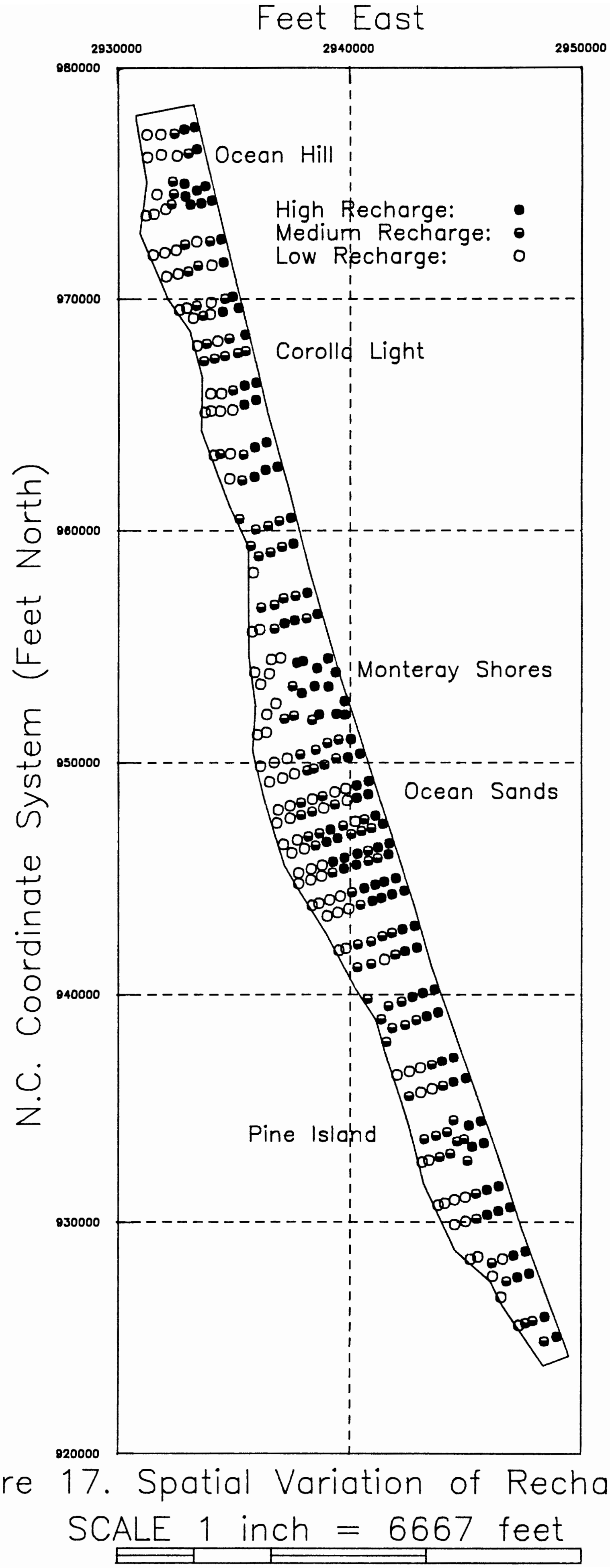


Figure 17. Spatial Variation of Recharge

SCALE 1 inch = 6667 feet

variation of island width, because this parameter affects flow patterns most significantly. If the island becomes wider or narrower at the boundary then this assumption may need modification. In both cases (north and south boundaries) the island is a consistent width inside and outside the model boundary. Also, both northern and southern boundaries are far removed from development making them less likely to impact wellfield pumping areas.

According to Contractor (1988) the Ghyben-Herzberg relationship (shown below) need not be used for transient runs.

$$\text{Depth to seawater} = \frac{\text{water table elevation} * \text{freshwater specific gravity}}{\text{seawater specific gravity} - \text{freshwater specific gravity}}$$

If seawater and freshwater specific gravities are 1.025 and 1.000, respectively, then the depth to the seawater interface is 40 times the height of the water table. Previous studies in the outer banks of North Carolina derived an empirical ratio of the water table elevation to the depth of the 250 mg/l isochlor averaging about 1 to 20 (Winner, 1975). This lower ratio is due to tidal fluctuations, differences in vertical hydraulic conductivities (intervening clay layers that slow the equilibration of the interface to the static 1 to 40 ratio), and the realization that the interface is not sharp and may extend over tens or hundreds of feet (Winner, 1975).

Model runs were made with and without the approximation imposed to test its pertinence. In general, the Ghyben-Herzberg relation dampened the calculated fluctuation in the water table to tenths of a foot over the course of a year. This is unreasonable when compared to the fluctuation observed on the barrier island of up to several feet (EPA, 1985; DWR field measurements, 1990-1991).

The 2-D model simulations estimate the depth to the sharp saltwater-freshwater interface and the location of the saltwater toe (the intersection of the interface and the clay layer). However, the model interface location should be taken as a liberal approximation; 250 mg/l or higher chloride concentrations may in reality be found at a shallower depth than indicated by the model. The actual thickness and location of the boundary, especially the 250 mg/l isochlor, requires additional field analysis to quantify.

Preliminary Model Runs

Preliminary analysis using the 2-D model allowed parameter ranges to be tested (especially hydraulic conductivity) as described in the previous section. This analysis was conducted by attempting to reproduce known water table elevations.

Prior to initiating transient model runs, a steady-state model was executed to determine initial freshwater and saltwater heads to be used in later transient simulations.

A simulation was set up with known or estimated pumping rates, recharge rates based on Duck rainfall, hydraulic conductivity, porosity, and aquifer thickness and run over the time period from January 1989 to March 1991 using one month time-steps. As represented in Figure 18, a wellfield that may actually contain several wells spread out over a few hundred feet is signified by one well in the model. This will make the resulting freshwater heads a conservative approximation to actual water table elevations. The pumping is more concentrated in the model simulations, thus drawdown is more substantial.

The computed freshwater heads were tabulated for the months of January 1990, August 1990, and March 1991 to compare with field data taken during those months. Figure 19 illustrates the known and computed values for freshwater heads at transects A, B, C, and D. Although there are obvious discrepancies between some of the values, most of these differences can be explained.

The measured values of the water table elevation are an instantaneous value and thus may not compare well to the computed head calculated as the average for the month. Therefore, short-lived changes to the water table elevation such as transient cones of depression due to daily cycles of pumping can not be estimated by the model with a monthly time-step. In addition, the model does not take into account aquifer vertical hydraulic conductivity, so clay or organic strata (with low vertical hydraulic conductivity) interbedded in the sandy sediments will not be represented. This attribute makes the model more conservative; that is, the water table will have larger fluctuations as represented by the model than it would in reality.

Aquifer parameters (especially K and elevation of clay layer or aquifer thickness) were adjusted so computed water table elevations bracketed the measured water table elevations. Although not shown in Figure 19, the greatest recharge month, September 1989, was used to check the highest possible water table position. August 1990, with no recharge, illustrated the lowest computed elevations attained by the water table.

The model appears to be adequately calibrated for Currituck Outer Banks. However, new parameter data such as depths to the clay horizon, records of rainfall, water table elevations, and depths to the saltwater-freshwater interface within the model area would allow better calibration of the model and improve the accuracy of simulations. As a reminder, this model is a tool that produces simulations of the surficial aquifer. It is only as accurate as the assumptions in the programming and the field data allow. The model needs to be updated as new field data are available to improve simulation quality.

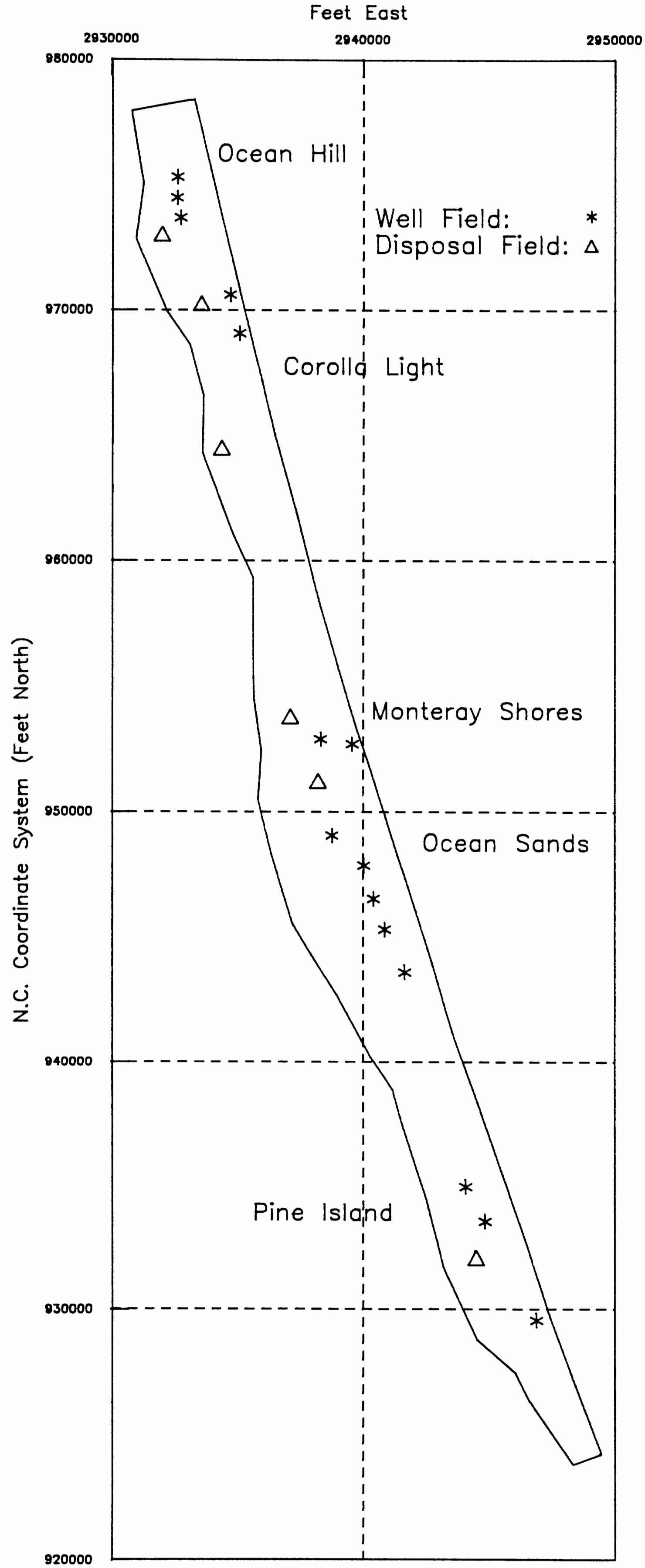
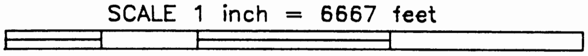


Figure 18. Model Boundary and Present Pumping and Disposal Sites



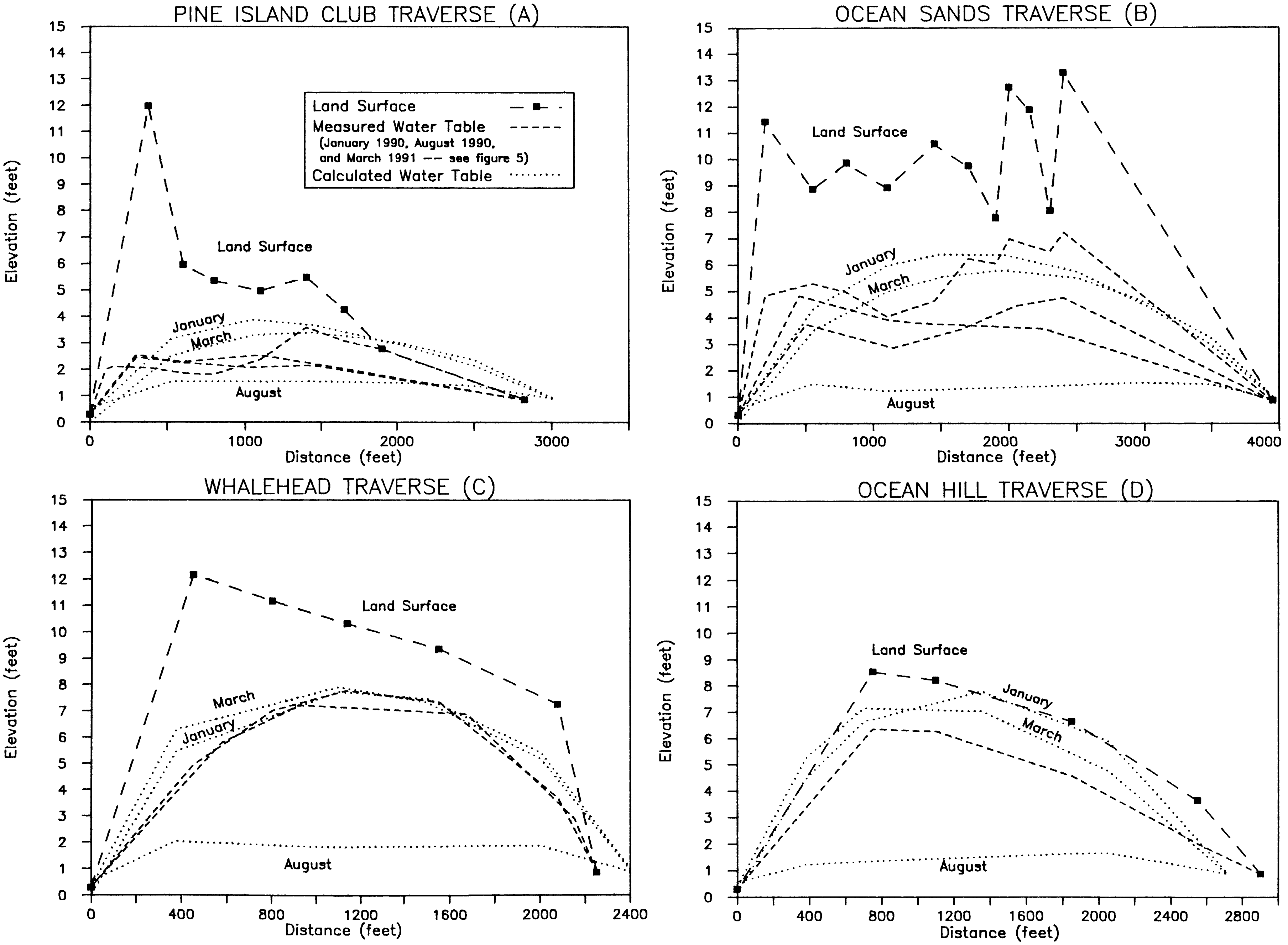


Figure 19. Observed versus Calculated Water Table Elevations

Ground Water Flow Directions

Ground water flow on Currituck County Outer Banks, under natural non-pumping conditions, can be described very simply as outward from the center of the island toward the Atlantic Ocean and Currituck Sound (see Figure 20). Local flow patterns, contrary to the regional flow just described, exist near mounds or cones of depression.

Natural conditions which create a mounded water table occur on a large scale in the wider portions of the island and on a smaller scale beneath dunes. Also, disposal systems such as low pressure piping (LPP) fields, septic tank drain-fields, or rotary distributors, create mound conditions on the water table. In all these cases, both naturally and through waste disposal practices, ground water flow is radially away from the mound.

As can be seen in Figure 21, a contour map of an estimated water table for a present-day winter month, flow directions and magnitudes can be compared. Flow is perpendicular to contour lines and down gradient. On traverses across the short axis of the island, regions with closely spaced contour lines indicate relatively higher flow velocities. For example, at Ocean Sands, ground water flow near the middle of the island is slower than near the Ocean and Sound boundaries. Similar flow directions apply at Corolla Light and Ocean Hill, but contour lines here are more closely spaced indicating faster flow. The aquifer is thinner at Corolla Light so transmissivity is lower. This causes a higher water table mound and increases the gradients toward the Ocean and Sound boundaries. Ground water flow is, in general, outward from the center of the island toward the ocean and sound. However, in several places where the width of the island reduces, flow is from the wider segment toward an adjacent narrower segment and then outward toward the Ocean or Sound.

Because of the size of the triangular elements in the model, local mounding effects from dunes or individual septic tank systems are obscured. However, PUD pumping and disposal effects can be illustrated. Figure 22 is the flow pattern during a present-day summer month when pumping of ground water is at its highest and natural recharge is lowest. Notice that the cones of depression and mounds produced by pumping and disposal systems, respectively, have influenced the flow pattern. The flow is radially toward and away from these features, respectively. Also, the water table is, in general, much lower over the entire model area compared to water table levels in Figure 21 (compare contour intervals on Figures 21 and 22).

Water Quality

There are very few references to the quality of ground water on Currituck Outer Banks. Robison (1977) discusses high iron and hardness content in ground water in the upper sandy aquifer of Currituck County. Wilder and others (1978) and Moore, Gardner &

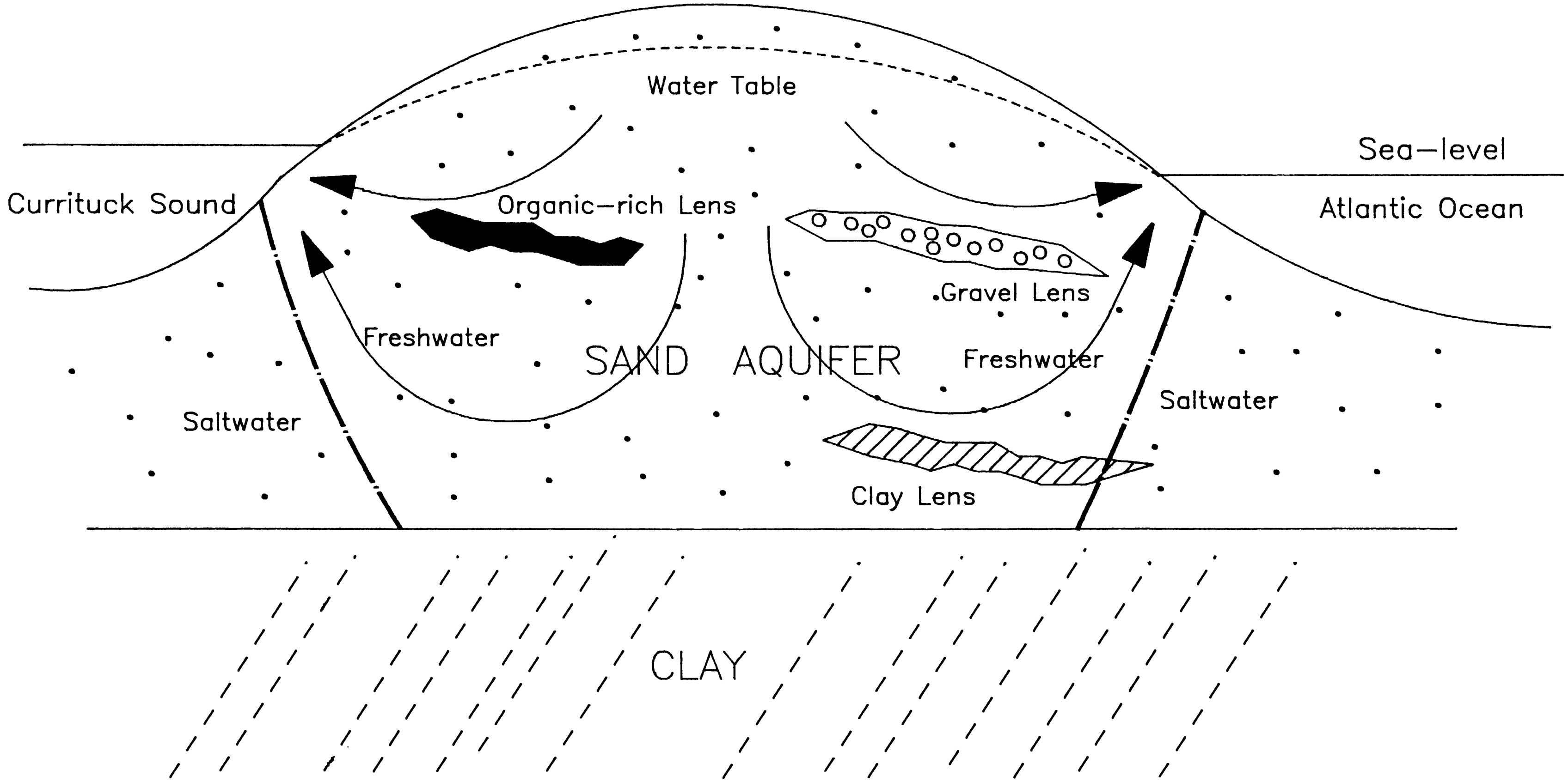


Figure 20. Schematic Cross—section of Currituck Outer Banks Showing Ground Water Flow Patterns

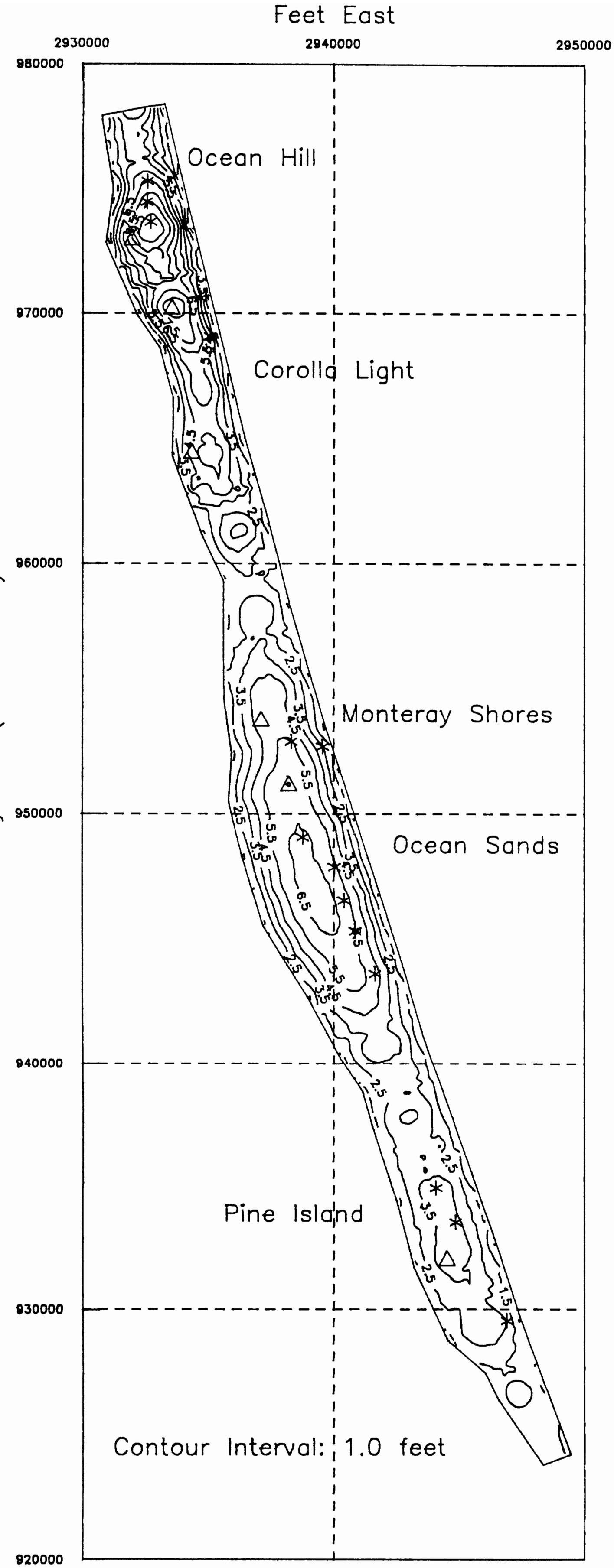


Figure 21. Calculated Jan 1990 Water Table

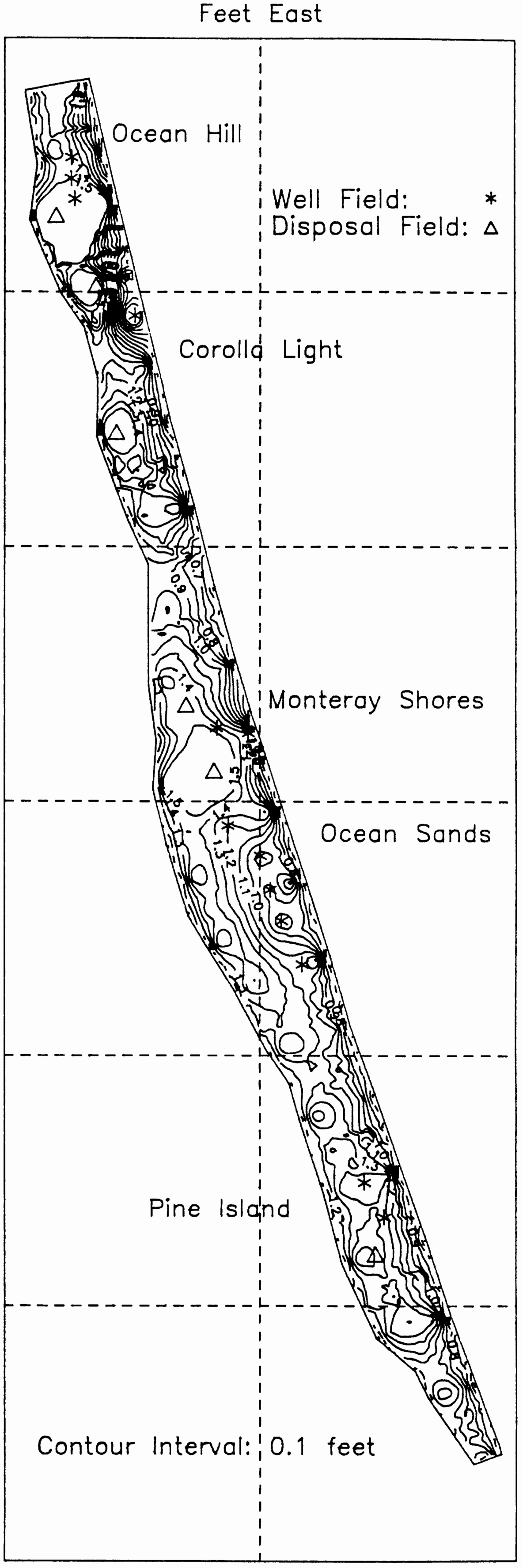


Figure 22. Calculated July 1990 Water Table

SCALE 1 inch = 6667 feet

Associates, Inc. (1982) discuss potentially high concentrations of iron and hardness. Also, hydrogen sulfide may be generated as organic material decays anaerobically (Moore, Gardner & Associates, Inc., 1982; ESEI, 1981). Winner (1975) lists chloride, color, dissolved iron, hydrogen sulfide, dissolved solids, and hardness as the major contaminants of generally good quality ground water near Cape Hatteras. He explains that these problems are attributed to local geologic conditions. Saltwater intrusion is of great concern and is primarily caused by over-pumping or storm over-washes near the ocean.

Ground water is polluted by the disposal of wastewaters from individual septic tank systems, and from PUD rotary distributors and LPP fields. The extent of pollution in the ground water is proportional to the degree of effluent treatment, the volume of effluent, and the rate of movement of the ground water. While PUD effluent is treated to the tertiary level, that volume of wastewater is far greater than the volume of wastewater from septic tank systems which have almost no treatment capability.

Common pollutants from septic tank systems include nitrate, nitrite, fecal coliform bacteria, MBAs (laundry detergent additives), ammonia, and orthophosphate. EPA researchers found these substances in varying concentrations in all three study sites in Dare, Carteret, and Pender counties (EPA, 1985). Other studies of septic tank systems indicate that contamination of ground water is more likely at sites with a small vertical distance between drainage lines and water table, and at sites in sand-rich soils (Division of Environmental Management, 1989). Contamination of ground water from septic tank systems may include other pollutants besides those listed above, such as trace organic compounds. Some trace organic compounds are carcinogenic and may pose a health hazard.

In November 1988, DWR staff collected nine water samples from homes in Whalehead Subdivision which use individual wells and septic tank systems. An independent laboratory in Greenville, North Carolina analyzed each sample for fecal coliform and found no colonies present.

From 1968 to 1975, Atlantic Research Company, a subsidiary of Susquehanna Corporation, developed and tested solid rocket fuels. Drums of waste materials and experimental rocket fuel associated with that testing were transported to what is now Whalehead Subdivision, at the corner of Corolla Drive and Herring Street in lots 55-56. These materials were emptied into 1-2 foot deep trenches and burned. The empty drums were stored on site.

Between 1983 and 1984 the Susquehanna Corporation hired a remediation firm to remove 413 drums and 21 cubic yards of soil from the site and install monitoring wells to check for possible pollutant levels in the ground water. A water sample from one monitor well in 1983 contained 0.036 mg/l selenium (the North Carolina ground water quality standard for selenium is 0.01 mg/l). However, ground water samples taken in May 1990 did not contain any contamination (Durway, 1990). It is recommended that new drinking water wells in the vicinity of the site be tested for selenium and other metals (Durway, 1990). The Division of Solid Waste Management evaluated the Whalehead site as having a low priority for further Superfund evaluation or remediation.

Water Quality Network to Monitor Changes

If the residents of Currituck County Outer Banks continue to use the unconfined aquifer for their water supply, adequate protection against saltwater intrusion should be provided. The modeling results below and field data indicate that the area of highest concern for intrusion is the ocean side just above the clay confining layer at the base of the aquifer.

The clay layer appears to be thick enough, or at least has a low enough vertical hydraulic conductivity, to prevent upconing, as evidenced by the large difference between the chloride concentration in the surficial aquifer and the sands beneath the clay confining unit. Upconing is the process of saltwater moving upward beneath a pumping well and displacing freshwater. Detection of upconing is possible by monitoring the chloride concentration at pumping centers.

Thus, saltwater intrusion monitoring wells should be constructed with a screen just above the clay layer (Figure 23). Traverses of these monitoring wells, with wells positioned less than 500 feet apart and near pumping centers (areas of high stress), would be most effective in monitoring saltwater intrusion. They would also help define the limits of the aquifer or depths to the clay layer. Additional traverses of shallow wells could be used to monitor water table elevations (19 of these shallow monitoring wells were installed by Currituck County from November 1990 to February 1991).

Estimating Ground Water Capacity

In earlier studies of the Outer Banks of North Carolina, authors use a percentage of annual recharge as the safe yield of the surficial aquifer. These safe yields range up to 71 percent of estimated recharge or up to 5.95 million gallons per day (MGD) for the entire Currituck Outer Banks (Moore, Gardner & Associates, Inc., 1977; Wilder and others, 1978). However, these are percentages of annual recharge and do not account for the seasonal nature of recharge, pumping rates, or for the spatial distribution of pumping and disposal. On Currituck Outer Banks, as elsewhere on the barrier island system of North Carolina, pumping rates are highest during summer months when recharge is lowest. Development of the 2-D model was initiated in order to simulate the aquifer as accurately as possible on a monthly basis and allow for variable recharge and pumping over long time periods.

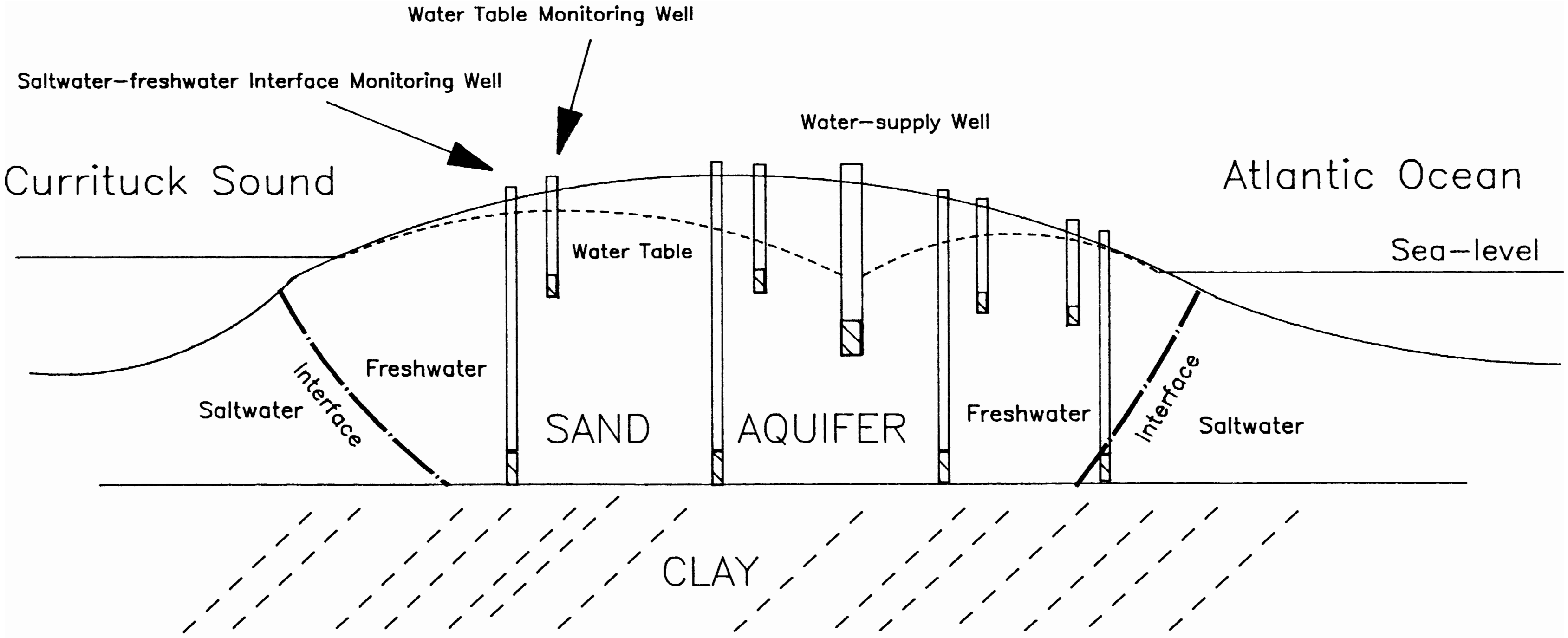


Figure 23. Schematic Cross–section of Currituck Outer Banks Showing Proposed Monitoring Well Network

The model described above can be used to estimate future aquifer conditions under a variety of assumptions about future water use and recharge. Three input data sets were prepared for future simulations. Each simulation included full platted build-out water supply pumping from PUD and individual home wells and wastewater disposal to the ground water system through rotary distributors, LPP fields, and septic tank systems. The three data sets differed in the recharge rates used and were named Future-Wet, Future-Dry, and Future-Normal.

Future-Wet simulation used 1989-1990 Duck data where recharge was 127 percent of normal. Average consumptive use (pumped water minus wastewater disposal) in this simulation equals 23 percent of recharge. The two previous drier years at Duck, 1987-1988, averaged 59 percent of average recharge. This low yearly rainfall rate (about 32 inches/year) occurred only two other times since 1890 in the Manteo record. The simulation of these dry conditions on Currituck Outer Banks was labeled Future-Dry. Average consumptive use in this scenario equals 47 percent of recharge to the aquifer. A third or Future-Normal simulation used average rainfall and average modified recharge. Average consumptive use equals 28 percent of recharge for this model run. Recharge rates for each simulation were adjusted for the number of future individual homes withdrawing water as discussed in Model Setup.

Figure 24 illustrates the stress to the aquifer system by these recharge and pumping rates along a typical traverse (Ocean Sands -- B). Each figure shows the water table and saltwater-freshwater interface position at January of the first year and July of the following year to indicate the change over 1.5 years. The change in storage calculation associated with each plot shows the difference in storage volume in gallons between January and July for the entire model area.

Future-Normal cross-section (Figure 24) shows the interface shifting position and a loss in storage. The water table is lowered and a cone of depression exists due to pumping. Although there are displacements in the water table in Future-Wet, the interface holds fairly constant. January of 1989 was a low recharge month compared to the average January. This causes the water table to be lower than the Future-Normal January. Storage decreased slightly during this time period. Future-Dry simulation causes large displacements in both the water table and interface positions. Although the water table rebounds after periods of increased recharge, the interface continues to move landward. Storage decreases substantially as the interface retreats from both the Sound and ocean sides. Presumably, with enough recharge the interface would expand to its previous position.

The water table equilibrates in each one month time-step and attains equivalent elevations as the same month in previous years with the same recharge and discharge. In a heavily pumped summer month the water table is drawn down and large cones of depression

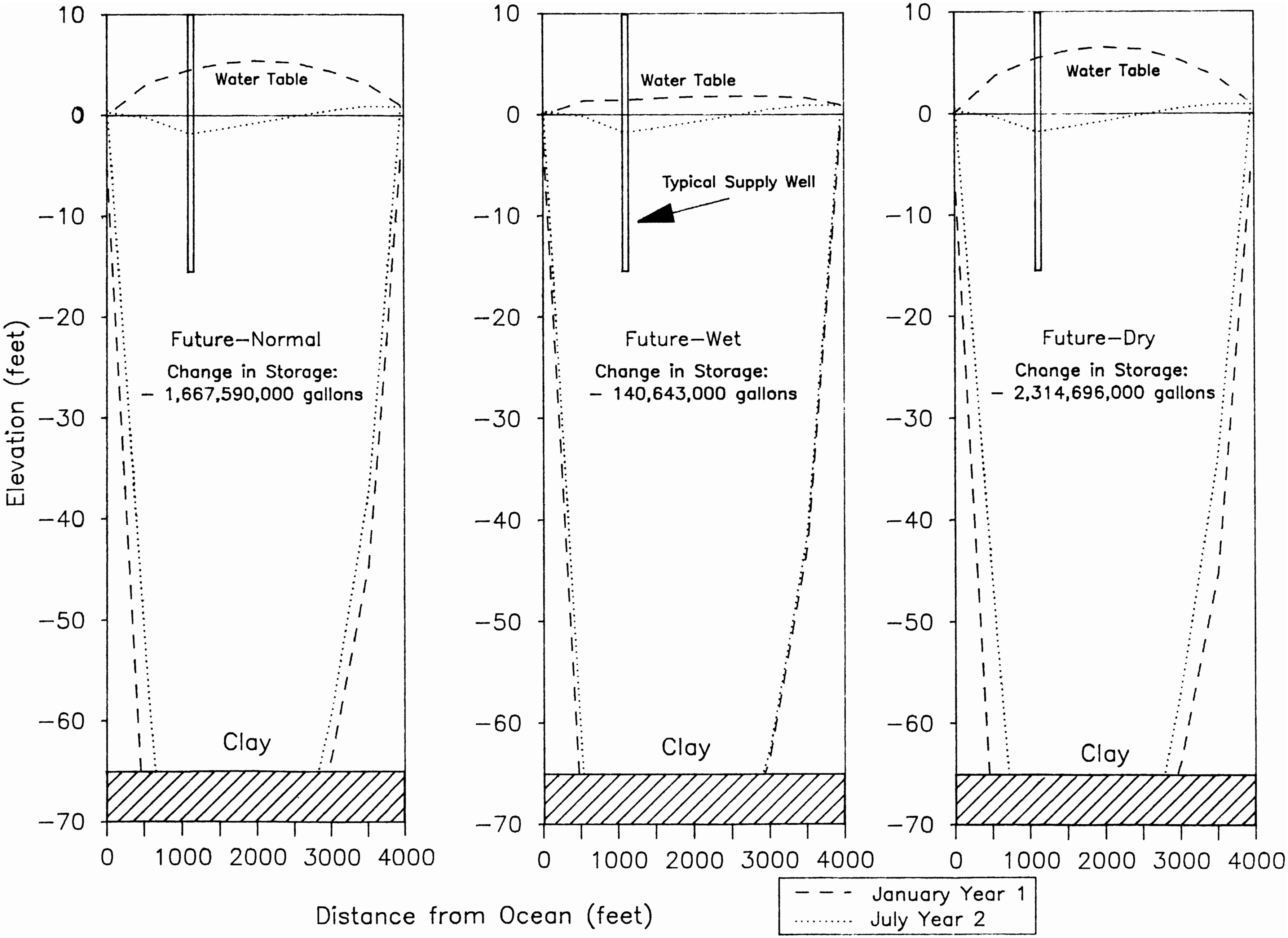


Figure 24. Future Stress to the Currituck Outer Banks Aquifer System along a Typical Traverse under Normal, Wet, and Dry Recharge Conditions

and mounds are formed near pumping and disposal centers, respectively. With increased recharge, the water table rises back to the heights of the year before. Thus the water table yearly fluctuations appear to be independent of the interface equilibration process. These dissimilar behaviors illustrate the different rates of equilibration for the water table and the saltwater-freshwater interface.

After these initial simulations, the effects of longer periods of future build-out pumping on the surficial aquifer were evaluated. The first of two data sets included recharge from the low rainfall years of 1987-1988 and represents dry conditions. The odd years of the simulation used 1987 monthly modified recharge and even years used 1988 monthly modified recharge. The second input data set employed average modified recharge for all years to model normal recharge conditions.

The results of these model runs document the slow pace of saltwater-freshwater interface equilibration in response to discharge and recharge changes. In the average modified recharge simulation (second data set), storage decreased by 356 million gallons in three years (January of the first year to January of the fourth year). After six years the aquifer storage decreased approximately 534 million gallons and the model was stopped because of saltwater intrusion near Corolla Light and Monteray Shores-Buck Island. The dry recharge simulation was not done. It is clear that the aquifer can not support the entire island community (southern section) with full build-out conditions, existing water facilities, and average modified recharge. In Figure 25, simulation cross-sections are depicted comparing January year one with July year six. In both cases (Corolla Light and Monteray Shores/Buck Island) the saltwater-freshwater interface has moved landward and has endangered the wellfields. If initial plans for Pine Island are followed then saltwater intrusion may be a problem here also. Several proposed wellfields in these plans are set too close to the Ocean. In this modeling, Pine Island wellfields are centered on the island.

In order to gauge the ability of the existing PUD systems to support the island community, various percentages of build-out were simulated. The simulation employing average recharge and 50 percent full build-out pumping seems to be supported by the aquifer. This model run did not reach equilibrium after 15 years. However, at this time the storage had dropped by approximately 487 million gallons (3% of initial storage) and yearly reductions to storage were 0.1 percent of the starting volume. Saltwater intrusion will occur at the same locations (Corolla Light and Buck Island) at a future simulated year if storage does not equilibrate. Confidence could be improved to allow simulations past 15 years by gathering data about the saltwater-freshwater interface location and thickness, and depths to the clay layer.

Although the interface has moved landward (creating the reduced volume of freshwater storage) the impacts outside of the

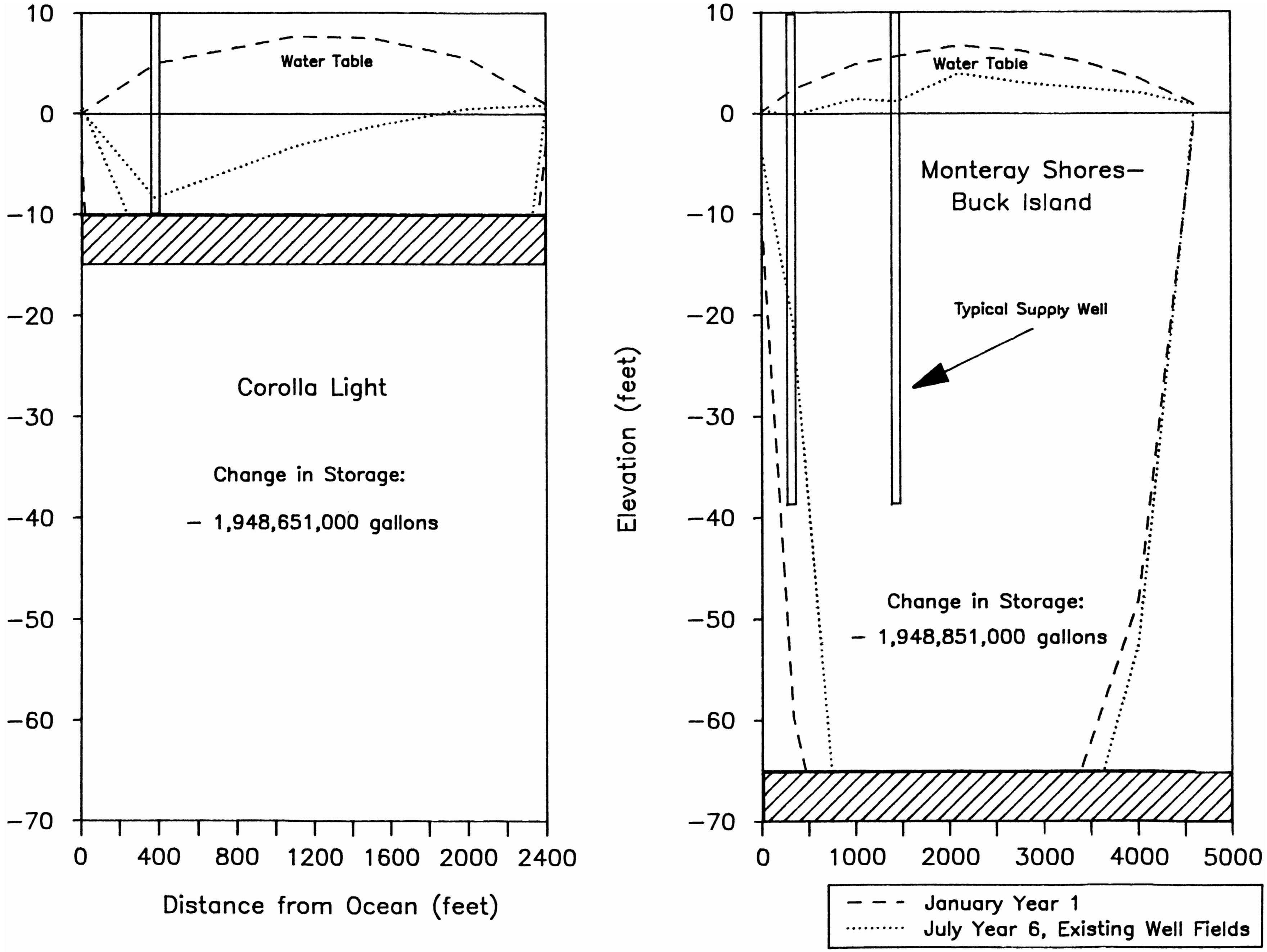


Figure 25. Future–Normal Corolla Light and Monteray Shores Traverses

major pumping zones do not appear to be as large as those impacts located at the pumping centers. Thus, Whalehead Beach is not affected, with the possible exception of houses closest to the beach near the large pumping centers. Those homes are already susceptible to saltwater intrusion and ocean over-wash.

The surficial aquifer and the existing water system design appears to be able to support up to 50 percent of the planned development for the southern Currituck County Outer Banks. Therefore, capacity of the aquifer with the present, separate systems is about 884,000 gpd (half of water needs in Table 10). Average consumption equals 62 percent of that (548,000 gpd) or 14 percent of average recharge to the island. However, positioning of the water-supply wells in the middle of the island, distributing the impact of pumping over a larger area, and monitoring the position of the interface will allow development to occur beyond the 50 percent limit imposed by the existing systems. This scenario of island build-out is described below in Section II: Water Supply Alternatives.

SECTION II: WATER SUPPLY ALTERNATIVES

Introduction

Water supply alternatives for Currituck Outer Banks water needs have been under consideration by Currituck County for more than twenty years. The purpose of this section is to identify options that may be considered as a result of recent water supply development within the region. In addition, some of the alternatives related in earlier studies have been included. The options for consideration are:

Water Source Options

1) Regional surficial aquifer supply
2) Desalinization
3) Pipeline to a ground water supply on the mainland
4) Interconnecting with the Dare County water system

Institutional Options

5) Regional water and sewer system organization
6) Water conservation
7) Capacity use investigation

Water Source Options

Regional Surficial Aquifer Supply

A regional surficial aquifer system entails drilling new wells, building additional treatment plants, and installing water mains and service lines to serve all existing and future water users from the Dare County line through Ocean Hill. In the DWR example regional system all septic tank systems were removed and wastewater service was extended to all homes. However, a regional wastewater system may not be technically feasible or required.

The existing wellfields will not accommodate the required pumping necessary for full platted build-out. DWR's regional system eliminates some of the wellfields positioned close to the Ocean and adds others more centrally located. The example regional system consists of 22 wellfields spread out from northwest to southeast in the middle portion of the island (see Figure 26). Each field is constructed with eight wells, each with an average yield of 31 gpm (equal to yields commonly achieved on the Outer Banks). The wells should be constructed in a line parallel to the beach. Nine disposal fields are located toward the sound side of the island (see Figure 26). This location on the west side of the water table divide would promote movement of possible contamination away from the wellfields. Each disposal field would accommodate up to 213,000 gpd. Regional wellfield discharges and disposal area recharges are

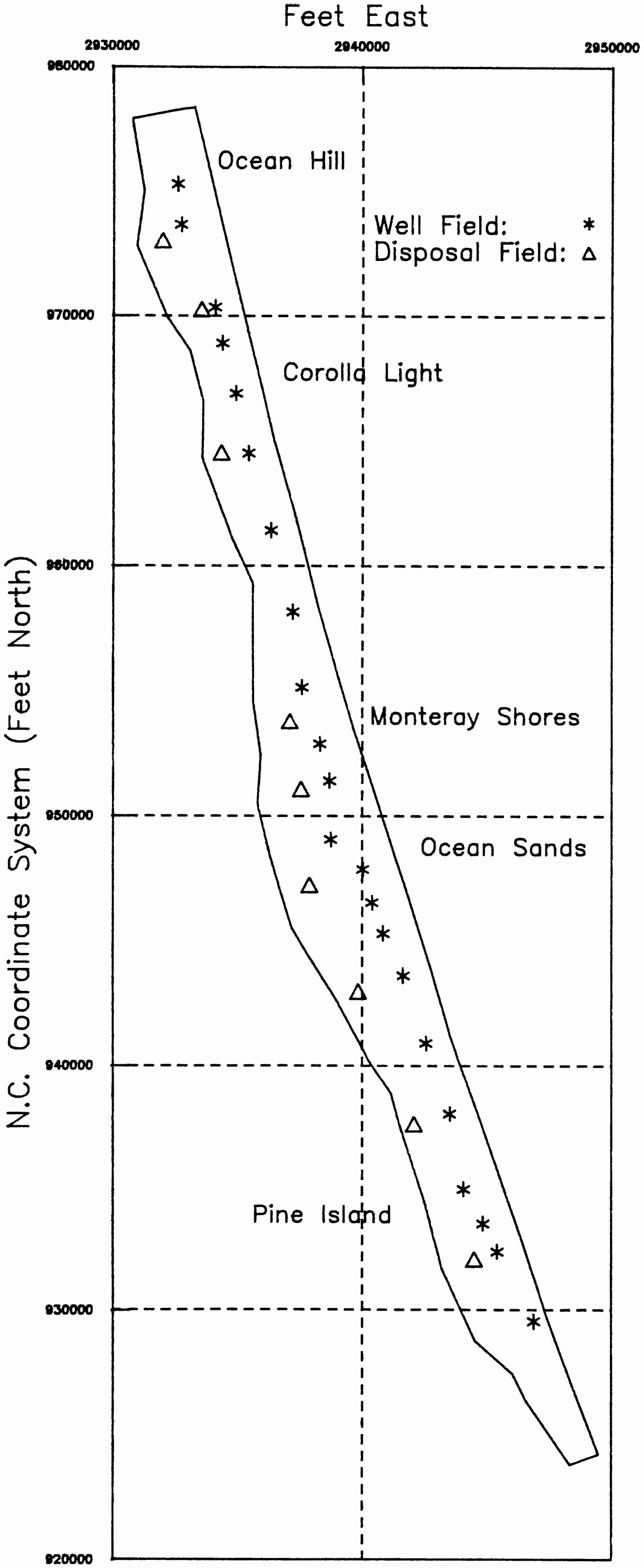


Figure 26. Regional Well and Disposal Field Locations

SCALE 1 inch = 6667 feet

shown in Appendix A.

Model simulations were run with full platted build-out water needs and the new water and wastewater configuration. Using these new well locations instead of existing wells, surficial aquifer storage and water table elevation show less impact in both normal and dry recharge conditions. Storage did not reach equilibrium after 15 years of simulation. After 15 years, storage had decreased by 660 million gallons (about 4% of initial storage) and yearly loss to storage was less than 0.2 percent of starting storage. It seems likely that freshwater storage will reach an equilibrium at some later simulation year. Yield of the aquifer with a regional system, in the modeled area, is about 1,767,000 gpd. Sixty-two percent of that total is 1,096,000 gpd consumption and equals 28 percent of average recharge. Cross-sections in Figure 27 illustrate the difference in the resultant movement of the interface after 15.5 years between this regional system and a 50 percent full build-out simulation using existing wells. Although a slightly higher percentage of storage was lost in the regional system, twice the volume of ground water was pumped and movement of the interface was acceptable. Furthermore, the water table fluctuated less dramatically with the regional well field run, as seen in Figures 28 and 29. Cones of depression are less deep and are centered on the island.

There is a low probability that more than two years of poor rainfall similar to that experienced in 1987-1988 will occur. However, even with two years of dry conditions, there is enough ground water storage for full build-out conditions with a regional well system. Constructing wellfields near the center of the island in a regional water system with monitoring wells to observe the movement of the saltwater-freshwater interface and water table fluctuation should allow full build-out of the island.

It is critical that monitoring wells be installed at high stress areas whether or not a regional system is constructed. Data collected from these wells is necessary to gauge saltwater intrusion.

Development beyond full build-out of platted units to include potential units as indicated in Table 9 would require a 10 percent increase in pumped water. Consumptive use would jump to 31 percent of average recharge. A model incorporating these new pumping volumes was not run.

Although this example of regional water and wastewater systems used disposal fields located on the Sound side of the water table divide, it may be possible to set up disposal facilities on the Ocean side. It is also assumed in this simulation that both water and wastewater systems are regional. However a regional water supply system may be technically more feasible than a regional wastewater system. If the wastewater system is not made regional, more care must be taken to avoid contamination of wellfields.

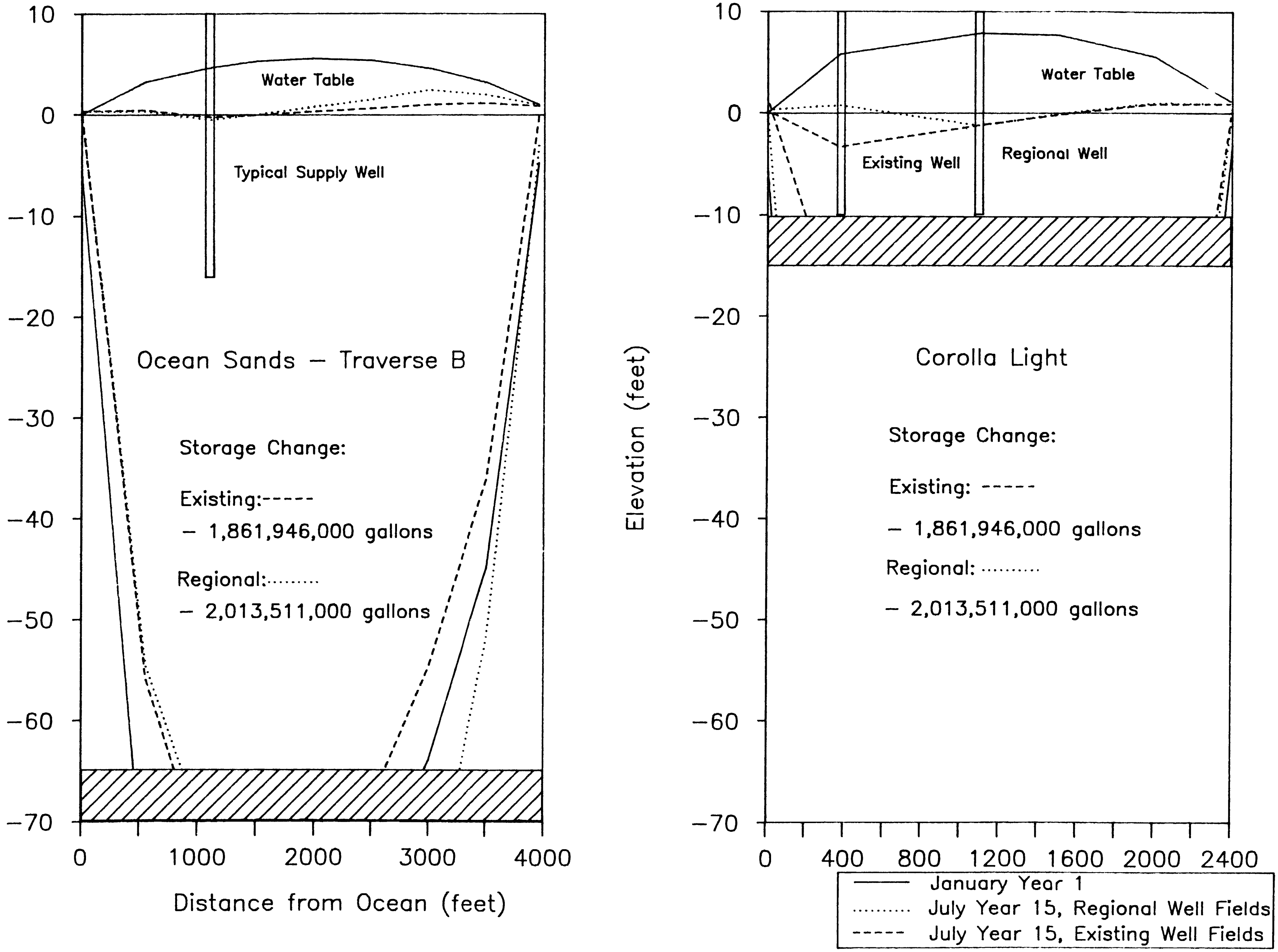


Figure 27. Regional versus Existing (50% pumping) Well and Disposal Fields

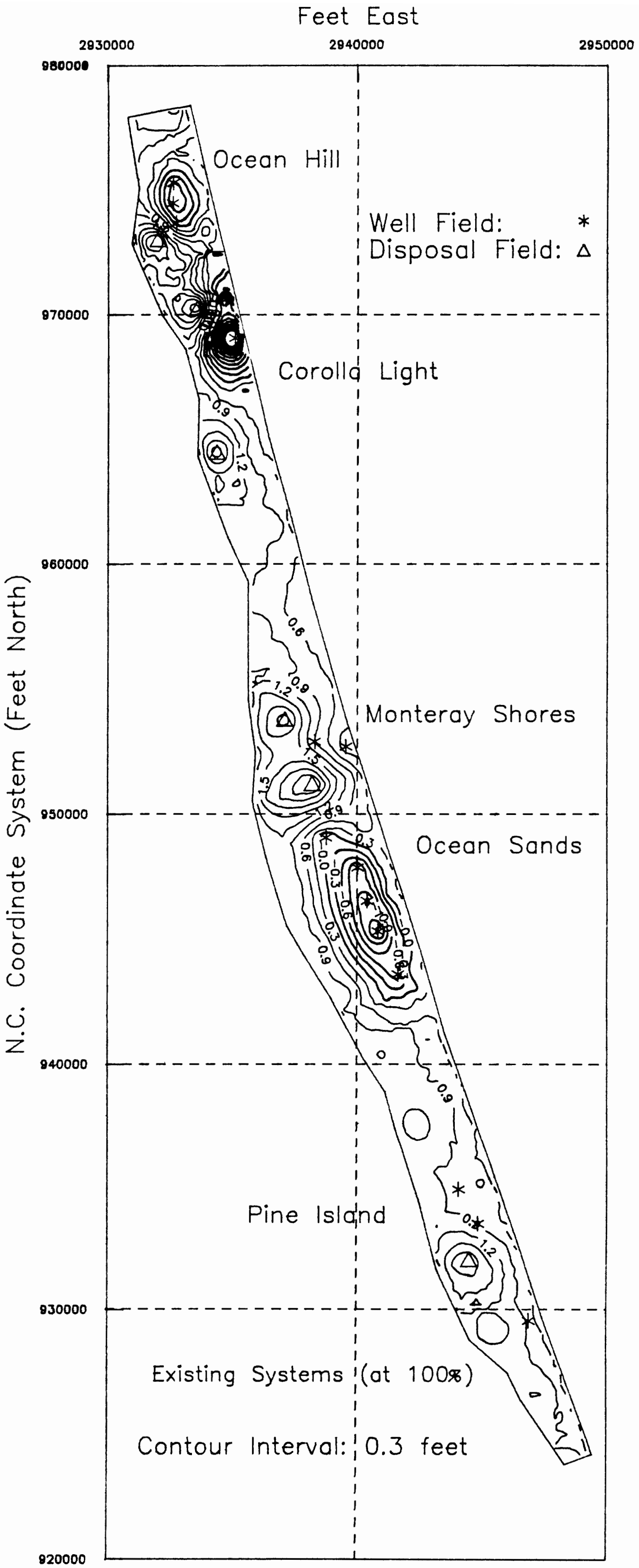


Figure 29. Future July Water Table with Existing Systems (at 100%)

SCALE 1 inch = 6667 feet

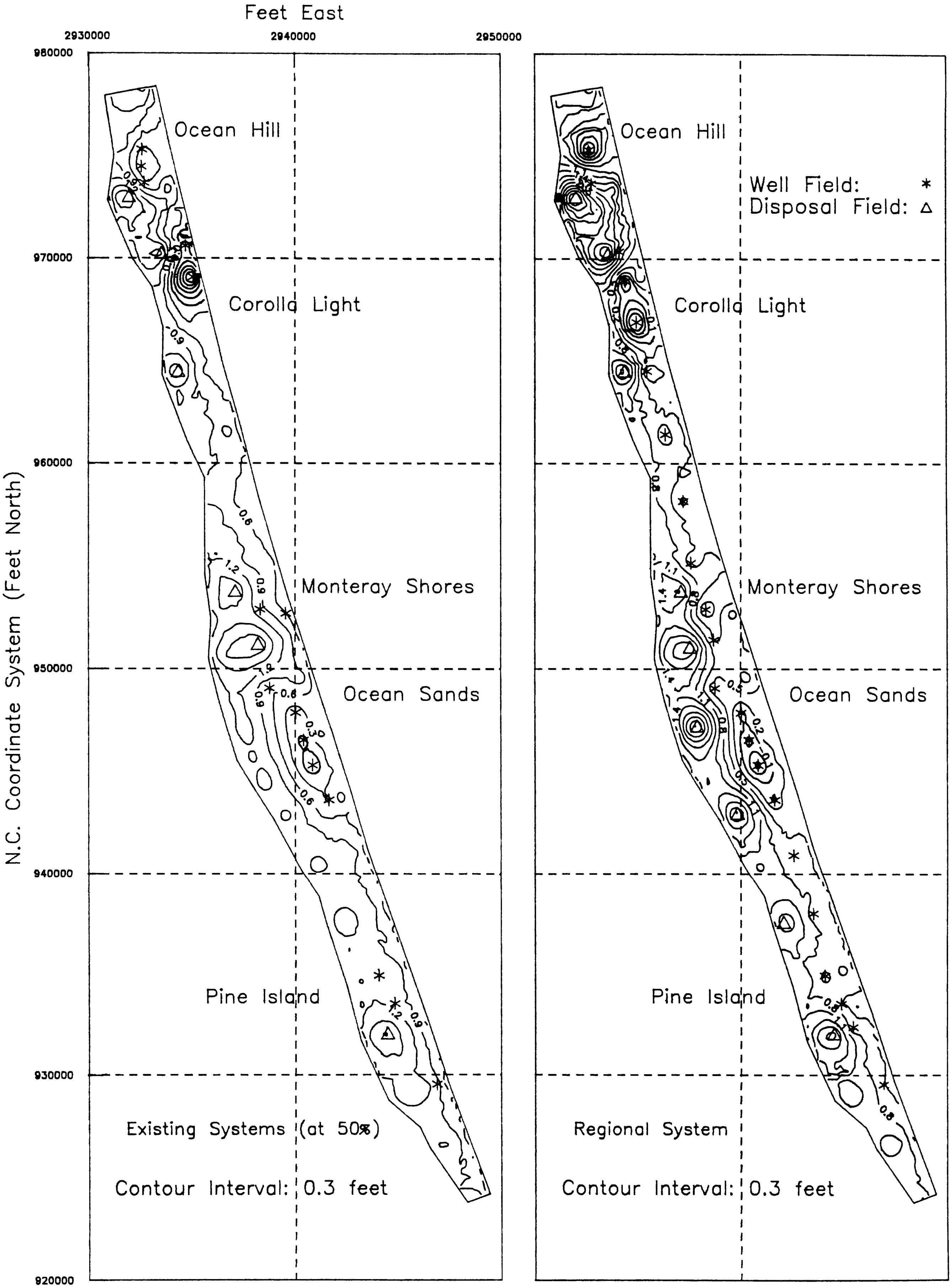


Figure 28. Future July Water Table, Existing (at 50%) and Regional Systems

SCALE 1 inch = 6667 feet

Desalinization

Desalinization converts saline water into fresh water and could be an attractive water supply alternative for the Currituck Outer Banks. Reverse osmosis (RO) is becoming a primary method for desalinating brackish water and seawater for water supply purposes. This process pumps salty or brackish water under pressure through a membrane. The membrane captures the unwanted brine and produces freshwater.

In just 18 years RO has gone from an insignificant percentage to more than 70 percent of the desalting capacity of the United States and has become a cost effective alternative to importing freshwater over long distances (AWWA, 1989). According to the Water Quality Association of Illinois, more than 120,000 RO units were shipped in 1989, 2.5 times the number shipped in 1985 (AWWA, 1990). There are several water systems in eastern North Carolina that use a reverse osmosis process. Three existing RO plants are located in the immediate area. One plant began operation in July 1990 on the Currituck Outer Banks, in the Villages at Ocean Hill. This plant was designed to produce about 80,000 gpd of fresh water from an iron-rich ground water source. Chloride is not presently a contamination problem here. In August 1989, a three million gallon-per-day (MGD) RO plant began operation near Kill Devil Hills in Dare County operated by a partnership between Dare County, Nags Head, and Kill Devil Hills. That plant has already been expanded to handle a peak usage of six mgd. Total cost of the facility including eight wells was $11 million. An RO plant located in Hyde County on Ocracoke Island has been providing residents with drinking water since 1977, with a capacity of approximately 250,000 gpd.

Feedwater sources for a Currituck Outer Banks RO facility include shallow wells tapping less than high quality fresh water, deeper wells tapping the brackish water aquifers below the clay layer, or an intake in Currituck Sound. The 1,500 foot well drilled at Ocean Sands in 1991 was an attempt to reach permeable zones that could yield saline water in the Yorktown, Castle Hayne or deeper aquifers. Permeable zones were not found deeper than 300 feet in this well and the quality of the water in permeable zones found is unknown at this time (Russnow, Kane & Andrews, Inc., 1991). Although shallow wells and Currituck Sound would on average provide lower salinities, there is a risk that the chloride concentration would be irregular (and therefore more difficult to process). A deeper saline aquifer might provide a more consistent source. However, feedwater with a higher salt concentration requires higher energy costs to extract the fresh water.

The reject, or brine discharge, from an RO plant with brackish feedwater could have a salinity less than seawater. Feedwater at the Dare County RO is processed yielding 75 percent fresh water for storage and distribution to customers. The remaining 25 percent is brackish wastewater, about one quarter as salty as seawater, and is discharged into the Atlantic Ocean.

Pipeline to a Ground Water Supply on the Mainland

A feasibility study was completed in the 1980's on water facilities for the County by the consulting firm Moore, Gardner and Associates (now Black and Veatch) (Moore, Gardner & Associates, 1982). The report discusses an alternative of piping ground water from Poplar Branch on the mainland to Ocean Sands on the Currituck Outer Banks. The 16-inch submerged pipeline would cross Currituck Sound and connect to water towers, one on each end of the pipeline. Black and Veatch estimated the construction cost of the pipeline and the two water towers to be 2.2 million dollars in 1985. Attaching the pipeline to the new bridge should reduce the costs of construction.

This estimate does not include water distribution and other costs on the Outer Banks and water supply development costs on the mainland. The report indicated that further study is needed to determine the environmental impacts of the pipeline crossing the Currituck Sound and the reliability of the ground water source on the mainland.

Interconnecting with the Dare County Water System

The Dare County RO desalination plant has the ability at present to produce six MGD. Design of the plant allocated space in the facility's process area to readily expand to eight MGD. The buried piping and chemical feed facilities will support an ultimate capacity of 12 MGD. Currituck County would need to contact the public officials of Dare County, Kill Devil Hills, and Nags Head to determine the feasibility of obtaining a water allocation from the regional water supply system. Considering economies of scale and the fact that much of the required RO plant supporting infrastructure and brine discharge facilities are already in place, the capital investment and operating unit cost may be considerably less than that for a separate Currituck RO plant. However, if there is significant growth in these service areas there may be less water available for export.

Institutional Options

Regional Water and Sewer System Organization

A few alternatives requiring the formation of a regional water system have been described. The development of a regional system can be established under several organizational structures. These include, but are not limited to: 1) cities or counties; 2) a county service district; 3) a water and sewer authority; 4) a metropolitan water district; and 5) private nonprofit associations.

The structure and powers of each organizational arrangement named above have been summarized by Wicker (1988). A city or county can create and operate a water and sewer system and require installation in new subdivisions. The area of service may extend beyond city or county boundaries.

A county service district is established by the Board of County Commissioners. The county has the powers of ownership and operation. Its jurisdiction lies within the county and is set by the Board. The county service district can also require installation of water or sewer systems in new subdivisions.

A water and sewer authority may be organized by any two or more political subdivisions. An authority can own and operate water and sewer systems, but can not require new subdivisions to connect to the systems. The authority's boundaries are set by the articles of incorporation.

Any two or more political subdivisions, or any political subdivision and any unincorporated area in the same county can form a metropolitan water district. The Health Services Commission adopts a resolution creating the metropolitan water district that has power to own and operate a water and sewer system. It does not have the power to require attachment to the system by new subdivisions, although the metropolitan water district can operate outside its boundaries.

Lastly, private nonprofit associations are created by incorporation and may own and operate water and sewer systems in an area set out in their articles of incorporation. They can not require new subdivisions to connect to the system.

Conservation Measures

Water conservation consists of processes and programs designed to efficiently use the water supply. A water conservation program should be one element of, and not a substitute for, a water supply planning and management program. As part of development of a good water management system, the County should implement a program emphasizing the efficient use of their water resources. Possible elements include:

1. Reduce distribution system losses to less than ten percent and carry out an on-going leak detection and repair program;
2. Install meters for all users and initiate a testing and/or change out program;
3. Distribute literature to all water users that describes water conservation measures;
4. Hand deliver or mail shower head and toilet dam retrofit kits to water users;
5. Adopt a local ordinance requiring installation of

ultra low-flow toilets (using 1.6 gallons per flush or less) and low-flow fixtures in new construction and renovation. Also, the ordinance would not allow the sale or installation of inefficient water devices in the county;

6. Promote xeriscaping, which includes the outdoor use of drought-tolerant plants and efficient lawn watering practices, to reduce outdoor water use;

7. Implement a water pricing structure which encourages conservation; and

8. Develop a county water shortage response plan, including a water shortage response ordinance, with water conservation measures that will give local officials the power to ensure water is equitably distributed during water shortages.

The water conservation program should be developed as soon aspossible to begin conserving this valuable resource. DWR has published a water conservation handbook that addresses these concerns in more detail (DWR, 1988).

Capacity Use Investigation

At the request of the Board of Commissioners of Currituck County the Department of EHNR can conduct a capacity use investigation for the area pursuant to the provisions of the North Carolina Water Use Act of 1967 (G.S. 143-215.11 et seq). The purposes of the department's investigation, as specified in the statute, are: to study all factors relevant to the conservation and use of water in the area; to consult with interested persons, groups, and agencies; to determine if the public interest can be better protected by encouraging coordination and requiring limited regulation of water users; and to determine whether effective measures, timely actions, or other alternatives might preclude the need for the designation of a capacity use area. The Environmental Management Commission may declare and delineate capacity use areas where it finds that the use of ground water, surface water, or both, require coordination and limited regulation. A capacity use area is defined as one where:

> "...the aggregate uses of ground water or surface water, or both, in or affecting said area (i) have developed or threaten to develop to a degree which requires coordination and regulation, or (ii) exceed or threaten to exceed, or otherwise threaten or impair, the renewal or replenishment of such waters or any part of them." (G.S. 143-215.13(b))

If the Commission elects to declare a capacity use area, a public hearing on the proposed designation must be held. After designation, the Commission may then adopt regulations within the designated capacity use area, including the issuance of permits for water users. A separate public hearing is required for the proposed regulations.

Currently, a capacity use area exists for a portion of the coastal plain, covering more than 2,500 square miles in all or parts of Beaufort, Pamlico, Washington, Carteret, Craven, Hyde, Martin, and Tyrrell counties. The area was declared capacity use in 1968 as a result of concern about large ground water withdrawals for phosphate mining. Regulations require any person withdrawing more than 100,000 gallons of water per day to obtain a Water Use Permit. While this is the only area that has actually been designated capacity use, several other areas of the state have been studied, and the Eno River Basin in Durham and Orange Counties has been under a voluntary designation since 1988. Under resolution of the Environmental Management Commission, failure to comply with voluntary regulation will result in designation of a capacity use area.

Where water shortages or water use conflicts exist, a capacity use area designation provides a systematic process to allocate water among competing users and to control its use by permits.

SECTION III. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

The hydrogeology of the Currituck County Outer Banks and water use by its inhabitants have been analyzed and the resulting hydraulic parameters have been included in a 2-D finite element, saltwater intrusion, computer model. Using this model, parameters with large ranges of values were defined more narrowly, based on matching the resulting freshwater heads produced by the model to observed heads. Elevation of the clay layer and estimated future recharge are the two parameters having the least precision.

The model produces monthly average water table elevations at each node in the grid and ground water velocity vectors for each element. Also, output from the model delineates the saltwater toe or the intersection of the saltwater-freshwater interface and the bottom of the aquifer. This saltwater toe calculation is useful for estimating zones of saltwater intrusion and upconing.

The large size of the model's elements and the lack of good quality aquifer parameters limit the detail of simulation results. However, general trends of ground water flow and freshwater storage volume changes due to pumping and recharge conditions can be determined.

Ground water flow patterns were described as well as a recommended monitoring well network to track saltwater intrusion and water table elevation changes. Full build-out pumping rates with present well field positions appear to distort greatly the natural ground water flow patterns during summer months. This pumping creates large cones of depression, while mounds are produced by waste disposal field recharge. Wellfields close to the ocean boundary become prone to saltwater intrusion.

Monitoring well traverses across the island near pumping centers should provide the necessary detail to delimit the interface movement. Whereas the water table rebounds quickly in response to increased recharge, the saltwater-freshwater interface moves more sluggishly, requiring years to equilibrate to recharge changes. If the surficial aquifer continues to provide water resources for the Outer Banks, monitoring well construction is essential. It is especially important to provide data on the location of the saltwater-freshwater interface and its thickness. Currituck County officials began monitoring well construction in late 1990 with the installation of 19 shallow monitor wells to track water table elevations.

Ground water quality problems, other than saltwater intrusion, were discussed briefly. There is a lack of data to define water quality conditions adequately. In general, iron, hardness, color, and hydrogen sulfide locally degrade ground water quality. Certainly, because of fairly rapid movement through the aquifer material (up to about one foot/day based on model results), waste disposal system recharge may pose contamination potential. The impact of waste disposal systems on ground water quality was not analyzed in this report. Many PUD wastewater disposal fields on the Outer Banks are required by permit to have monitoring wells installed. Results of sampling by the permittee are filed with the Groundwater Section, Division of Environmental Management.

Ground water capacity, or the ability of the surficial aquifer to support development or ground water pumping, was analyzed using several model runs and a scenario of island build-out for the southern section. The positions of the water table and saltwater-freshwater interface derived from the model determined areas where pumping might create problems (near ocean and sound boundaries), tracked movement of the interface, and calculated changes in aquifer storage. Future-Normal and Future-Dry simulations resulted in saltwater intrusion, especially near Corolla Light and Monteray Shores-Buck Island.

In five to six years with normal recharge, full build-out pumping would induce undesirable shrinkage of freshwater storage in the surficial aquifer. If growth is limited to 50 percent or less of planned development, the aquifer may equilibrate to pumping from the existing wellfields after more than 15 years.

At existing growth rates, 50 percent build-out will be achieved by southern subdivisions as a whole in the year 2000. Corolla Light and Whalehead subdivisions will grow to 50 percent build-out earliest, by 1992 and 1993, respectively. Full build-out conditions will be attained at Corolla Light in 2000 and Ocean Sands in 2018. Prior to full build-out stage it will be necessary to increase the size of Corolla Light and Ocean Sands water and wastewater facilities. Thus, it will be necessary to plan and implement water supply alternatives prior to the year 2000 to avoid potential saltwater intrusion problems in 2005 or 2006.

The ground water modeling shows that Whalehead residents were correct in seeing the necessity for a water resources investigation and planning and implementation of water supply management alternatives. However, their concerns that PUDs to the north and south of Whalehead could significantly affect the ground water beneath them are not supported by this report. It is more likely that Whalehead residents might experience water quality and quantity problems through their own waste disposal practices, natural conditions of the aquifer, or placement of wells too close to the Ocean.

In Section II of this report, various water supply alternatives, including a regional surficial aquifer supply, were discussed. According to model results from a simulation of a regional system with modified well and disposal systems, full build-out can be achieved using the surficial aquifer. An example regional water and wastewater system was modeled with wellfields located near the ground water divide and disposal fields positioned on the Sound side. Normal recharge rates and a full build-out pumping scenario appears to result in equilibration of aquifer storage after more than 15 years. Contraction of the freshwater zone was acceptable. Saltwater did not threaten the drinking water supply around any of the proposed wellfields. Even with a regional system similar to that proposed, monitoring wells designed to observe the location of the saltwater interface are necessary. Build-out to include development of lands not presently platted (see potential units in Table 9) was not modeled.

Desalinization might be used to supply Currituck Outer Bank communities if an appropriate source of brackish water can be located. RO technology could also be used to offset insufficient supplies of freshwater from the surficial aquifer for the busy summer seasons. Its use would be most effective in concert with regional water and wastewater systems.

Other alternatives exist, such as a pipeline to the Dare County Water system or to a mainland Currituck source. Several organizational entities can create regional water and sewer systems to provide service to their citizens. However, only a city, county, or county service district has the power to require connection to the regional system.

Conservation measures are appropriate no matter what decision Currituck County makes. They should be incorporated in any plan to supply the Outer Banks with water.

Lastly, the ability of capacity use designation to control growth and water withdrawal was discussed. If a management plan for the Currituck Outer Banks is not drawn up by 2000, then a capacity use area designation is a regulatory option for the County to consider.

The Division of Water Resources recommends that the following actions be taken to prevent water supply problems in Currituck County Outer Banks:

1. Currituck County should adopt a water conservation strategy for the Currituck Outer Banks to assure the most efficient use of the limited available water supply. The strategy should include requiring efficient plumbing fixtures in all new construction and possibly a phased retrofitting of fixtures in existing structures. The strategy should also include provisions for zoning, tap-on requirements, building restrictions, and other local government measures as needed to assure the protection and efficient use of water resources.

2. Currituck County should install a system of monitoring wells near ground water pumping centers to track the movement of the saltwater-freshwater interface. Regular sampling of monitoring wells is critical to detect saltwater intrusion and to allow the refinement of the ground water model.

3. The Division of Water Resources should periodically

collect data on ground water pumping, wastewater disposal, water use, and water table elevations to allow re-calibration and refinement of the ground water model. The model should be kept current to allow its use by the County to evaluate various development options.

4. Currituck County should consider all issues and constraints relative to the rapid development of the Currituck Outer Banks, including not only water supply but also quality of life, traffic congestion, cost of providing public services, hurricane evacuation, and other relevant growth issues. The County should decide on a development goal for Currituck Outer Banks. The goal could include the full platted build-out or some other ultimate level of development.

5. After adopting a development goal for the Currituck Banks, Currituck County should plan for an adequate water supply to serve the development goal. The County is responsible for conducting whatever additional studies are needed and selecting a water supply alternative from those available.

6. Finally, Currituck County or some other entity should implement a water supply alternative to serve the development goal for the Currituck Banks, phasing in the construction of the system as needed to keep up with population growth. That implementation should begin prior to the year 2000 to avoid potential water supply problems.

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Division of Water Resources

Appendix A: Data Sets

Finite Element Differential Equations
Example Input Data Set
Example Output Data Set
Field Data from January and August 1990, and March 1991
DWR Regional Water and Wastewater Systems

Differential Equations:

Freshwater Head:

$$\frac{\partial}{\partial_{\chi 1}}\left(K^{f}_{\chi 1} b^{f} \frac{\partial \phi^{f}}{\partial_{\chi 1}}\right) + \frac{\partial}{\partial_{\chi 2}}\left(K^{f}_{\chi 2} b^{f} \frac{\partial \phi^{f}}{\partial_{\chi 2}}\right) + N + q^{f}_{p} - \frac{K'}{b'_{0}}\left(\phi^{f} - \phi_{0}\right)$$

$$= \frac{n\,\gamma^{f}}{\Delta_{\gamma}} \frac{\partial \phi^{f}}{\partial t} - \frac{n\gamma^{s}}{\Delta_{\gamma}} \frac{\partial \phi^{s}}{\partial t}$$

Saltwater Head:

$$\frac{\gamma^{s}}{\gamma^{f}}\left[\frac{\partial}{\partial_{\chi 1}}\left(K^{s}_{\chi 1} b^{s} \frac{\partial \phi^{s}}{\partial_{\chi 1}}\right) + \frac{\partial}{\partial_{\chi 2}}\left(K^{s}_{\chi 2} b^{s} \frac{\partial \phi^{s}}{\partial_{\chi 2}}\right)\right] = n\,\frac{\gamma^{s}}{\gamma^{f}} \frac{\gamma^{s}}{\Delta_{\gamma}} \frac{\partial \phi^{s}}{\partial t} - \frac{n\gamma^{s}}{\Delta_{\gamma}} \frac{\partial \phi^{f}}{\partial t}$$

Saltwater-Freshwater Interface:

$$\zeta = \frac{\gamma^{s} \phi^{s} - \gamma^{f} \phi^{f}}{\Delta_{\gamma}}$$

Symbol Definitions:

$K_{\chi 1, \chi 2}$ = Hydraulic conductivity components (feet/day)

b^{f}, b^{s} = Thickness of freshwater or saltwater layer (feet)

ϕ^{f}, ϕ^{s} = Freshwater or saltwater head (feet)

N = Interpolation or shape function

q^{f}_{p} = Freshwater source or sink (cubic feet/day)

K' = Vertical hydraulic conductivity in the leaky aquifer (feet/day)

b'_{0} = Thickness of leaky aquifer (feet)

ϕ_{0} = Elevation of top of leaky aquifer (feet)

n = Porosity

γ^{f}, γ^{s} = Specific weight of freshwater or saltwater (pounds/cubic foot)

$\Delta_{\gamma} = \gamma^{s} - \gamma^{f}$

t = Time (days)

ζ = Zeta -- Elevation of saltwater-freshwater interface (feet)

Example Input Data Set

```
{title}
Currituck Saltwater Intrusion Model, Jan 89 to Mar 91, K=68
{I/O switches}
          0          1          1          1          1          0          0
     {# nodes} {# elements}                                                       {# wells}      {# elem. recharged}
        179        300          7          0         49          0         51         21          0        300
          {days/timestep} {# timesteps}
          0      30.42         49         10      0.005       1.00
     {specific weights}
      62.43      63.99       0.10

     {element data -- bounding nodes, K, porosity}
          1        173        167        168      68.00      68.00      68.00      68.00       0.25
          2        173        168        174      68.00      68.00      68.00      68.00       0.25
          3        174        168        175      68.00      68.00      68.00      68.00       0.25
          4        174        175        176      68.00      68.00      68.00      68.00       0.25
          5        175        170        176      68.00      68.00      68.00      68.00       0.25
          6        176        170        177      68.00      68.00      68.00      68.00       0.25
          7        170        171        177      68.00      68.00      68.00      68.00       0.25
          8        177        171        178      68.00      68.00      68.00      68.00       0.25
          9        178        171        172      68.00      68.00      68.00      68.00       0.25
         10        178        172        179      68.00      68.00      68.00      68.00       0.25
         ...

     {nodal data -- location by State plane coordinates, elevation of clay layer}
          1 2948350.00 923800.00     -65.00    1000.10          0
          2 2946900.00 926500.00     -65.00    1000.10          0
          3 2946600.00 926350.00     -65.00    1000.10          0
          4 2947400.00 926650.00     -65.00    1000.10          0
          5 2947875.00 926800.00     -65.00    1000.10          0
          6 2948900.00 924000.00     -65.00    1000.10          0
          7 2946050.00 927450.00     -65.00    1000.10          0
          8 2945500.00 929050.00     -65.00    1000.10          0
          9 2945950.00 929200.00     -65.00    1000.10          0
         10 2946400.00 929400.00     -65.00    1000.10          0
         ...

     {recharge rate data by element by timestep}
          1         -1
   0.001009   0.000000   0.002331   0.003098   0.000000   0.000000   0.000000   0.000000   0.000000   0.000000 ...
              0.007488   0.000000   0.000000   0.000000   0.000000   0.000000   0.000000   0.000000   0.000000
              0.010028   0.000000   0.000285   0.000000   0.000000   0.000000   0.000000   0.000000   0.000000
              0.007138   0.000869   0.000000   0.000000   0.000000   0.000000   0.000000   0.000000   0.000000
          5
          6         -1
   0.003262   0.001456   0.007331   0.010598   0.000717   0.000000   0.000000   0.010713   0.000000   0.012078 ...
              0.009988   0.002806   0.004459   0.000827   0.004433   0.000000   0.000000   0.000000   0.000000
              0.012528   0.000000   0.009985   0.000000   0.000000   0.000000   0.000000   0.001917   0.001535
              0.009638   0.005869   0.002480   0.000000   0.000000   0.000000   0.000000   0.001917   0.001535
          6
          7          0
   0.003220   0.001443   0.007321   0.010580   0.000694  -0.000030  -0.000074   0.010611  -0.000102   0.012023 ...
              0.009975   0.002796   0.004442   0.000804   0.004403  -0.000074  -0.000102  -0.000102  -0.000055
```

```
          0.012515  -0.000010  0.009968  -0.000023  -0.000030  -0.000074 -0.000102  0.001815  0.001480
          0.009625  0.005859   0.002463  -0.000023  -0.000030  -0.000074 -0.000102  0.001815  0.001480
       8  0
0.005516  0.002912  0.012331   0.018098  0.001435   0.000000   0.000000  0.021427   0.000000  0.024156 ...
          0.012488  0.005612   0.008918  0.001654   0.008867   0.000000  0.000000   0.000000  0.000000
          0.015028  0.000000   0.019685  0.000000   0.000000   0.000000  0.000000   0.003833  0.003070
          0.012138  0.010869   0.004959  0.000000   0.000000   0.000000  0.000000   0.003833  0.003070
     ...

  {elements where no-flow boundary exists}
     298       1       6
       0       0       0       0       0       0       0       0       0       0        ...
               0       0       0       0       0       0       0       0       0
               0       0       0       0       0       0       0       0       0
               0       0       0       0       0       0       0       0       0
     300       6      13
       0       0       0       0       0       0       0       0       0       0        ...
               0       0       0       0       0       0       0       0       0
               0       0       0       0       0       0       0       0       0
               0       0       0       0       0       0       0       0       0
     ...

  {elements with coastal boundary condition}
     300      13       12    68.00
     294      12       21    68.00
     283      21       20    68.00
     270      20       31    68.00
     255      31       38    68.00
     243      38       46    68.00
     230      46       54    68.00
     216      54       63    68.00
     199      63       74    68.00
     181      74       84    68.00
     ...


  {sea-level elevations for each timestep}
     13
    0.31    -0.13    -0.04    0.19    0.36    0.36    0.29    0.33    0.52    0.77    ...
            -0.10    -0.01    0.17    0.31    0.31    0.26    0.32    0.51    0.69
            -0.11    -0.02    0.18    0.33    0.33    0.27    0.32    0.52    0.73
            -0.11    -0.02    0.18    0.33    0.33    0.27    0.32    0.52    0.73
     12
    0.31    -0.13    -0.04    0.19    0.36    0.36    0.29    0.33    0.52    0.77    ...
            -0.10    -0.01    0.17    0.31    0.31    0.26    0.32    0.51    0.69
            -0.11    -0.02    0.18    0.33    0.33    0.27    0.32    0.52    0.73
            -0.11    -0.02    0.18    0.33    0.33    0.27    0.32    0.52    0.73
     21
    0.31    -0.13    -0.04    0.19    0.36    0.36    0.29    0.33    0.52    0.77    ...
            -0.10    -0.01    0.17    0.31    0.31    0.26    0.32    0.51    0.69
            -0.11    -0.02    0.18    0.33    0.33    0.27    0.32    0.52    0.73
            -0.11    -0.02    0.18    0.33    0.33    0.27    0.32    0.52    0.73
    ...
```

```
{sound elevations for each timestep}
  173
 0.89      0.89     0.89     0.89      0.89      0.89      0.89      0.89      0.89      0.89      ...
           0.89     0.89     0.89      0.89      0.89      0.89      0.89      0.89      0.89
           0.89     0.89     0.89      0.89      0.89      0.89      0.89      0.89      0.89
           0.89     0.89     0.89      0.89      0.89      0.89      0.89      0.89      0.89
  167
 0.89      0.89     0.89     0.89      0.89      0.89      0.89      0.89      0.89      0.89      ...
           0.89     0.89     0.89      0.89      0.89      0.89      0.89      0.89      0.89
           0.89     0.89     0.89      0.89      0.89      0.89      0.89      0.89      0.89
           0.89     0.89     0.89      0.89      0.89      0.89      0.89      0.89      0.89
  163
 0.89      0.89     0.89     0.89      0.89      0.89      0.89      0.89      0.89      0.89      ...
           0.89     0.89     0.89      0.89      0.89      0.89      0.89      0.89      0.89
           0.89     0.89     0.89      0.89      0.89      0.89      0.89      0.89      0.89
           0.89     0.89     0.89      0.89      0.89      0.89      0.89      0.89      0.89
 ...

{nodal position for wells and pumping rates in cu. ft./day for each timestep}
  112       6
    0      0.00     0.00     0.00   -200.53   -467.91   -935.83  -1002.67  -1270.05   -735.29      ...
        -133.69  -133.69  -267.38   -868.98   -668.45  -1203.21  -1336.90  -1069.52   -534.76
        -270.59  -209.09  -356.68   -479.68   -630.35  -1540.51  -2124.73  -2121.66  -1146.93
        -317.65  -245.45  -418.72   -563.10   -739.97  -1808.42  -2494.25  -2490.64  -1346.39
  110       6
    0      0.00     0.00     0.00   -200.53   -467.91   -935.83  -1002.67  -1270.05   -735.29      ...
        -133.69  -133.69  -267.38   -868.98   -668.45  -1203.21  -1336.90  -1069.52   -534.76
        -270.59  -209.09  -356.68   -479.68   -630.35  -1540.51  -2124.73  -2121.66  -1146.93
        -317.65  -245.45  -418.72   -563.10   -739.97  -1808.42  -2494.25  -2490.64  -1346.39
  107       7
    0      0.00     0.00     0.00    152.41    355.61    711.23    762.03    965.24    558.82      ...
         101.60   101.60   203.21    660.43    508.02    914.44   1016.04    812.83    406.42
         205.65   158.91   271.08    364.56    479.06   1170.79   1614.80   1612.46    871.66
         241.41   186.55   318.22    427.96    562.38   1374.40   1895.63   1892.89   1023.26
  ...

{initial freshwater and saltwater heads, and thicknesses of freshwater and saltwater}
  1 0.955549     0.89 2.688775  63.2668
  2  1.33791 0.820378  21.2288  45.1091
  3 0.875498     0.89      0.1 66.47035
  4 1.475555 0.665345 33.23415  33.2414
  5  1.30499 0.486782 33.56225  32.7427
  6  1.33281 0.569715 31.30135 35.03145
  7 0.962101     0.89 2.957515  63.0046
  8  1.91264 0.831739  44.3377 22.57495
  9 2.102655 0.736333  56.0453  11.0574
 10 2.104035 0.556699 63.47065 3.633415
 ...
```

```
{program switch to classify elements and shorten calculation time}
    0     0     0     0     0     0     0     0     0     0     ...
    0     0     0     0     0     0     0     0     0     0
    0     0     0     0     0     0     0     0     0     0
    0     0     0     0     0     0     0     0     0     0
    0     0     0     0     0     0     0     0     0     0
   ...

{output switch for each node}
    1     1     1     1     1     1     1     1     1     1     ...
    1     1     1     1     1     1     1     1     1     1
    1     1     1     1     1     1     1     1     1     1
    1     1     1     1     1     1     1     1     1     1
    1     1     1     1     1     1     1     1     1     1
```

Example Output Data Set

Model Output (Heads and Velocities):

Currituck Saltwater Intrusion Model, Jan 89 to Mar 91, K=68

```
 TIME COUNTER , JT=  2        SIMULATION TIME=        .30420000E+02
 ITERATION NO 1
 ERROR= .418438E+00
 ITERATION NO 2
 ERROR= .942283E-02
 ITERATION NO 3
 ERROR= .124922E-03


           {freshwater   {saltwater   {freshwater    {saltwater  {elevation of
             head}          head}      thickness}    thickness}    interface}

   NODE      HF            HS            BF            BS             ZETA
     1    .945261E+00   .890000E+00   .226678E+01   .636785E+02   -.132152E+01
     2    .120427E+01   .696202E+00   .208405E+02   .453638E+02   -.196362E+02
     3    .874442E+00   .890000E+00   .100000E+00   .665126E+02    .151264E+01
     4    .115881E+01   .358876E+00   .328128E+02   .333460E+02   -.316540E+02
     5    .875673E+00   .691848E-01   .330815E+02   .327942E+02   -.322058E+02
     6    .104133E+01   .287751E+00   .309110E+02   .351303E+02   -.298697E+02
     7    .946452E+00   .890000E+00   .231561E+01   .636308E+02   -.136916E+01
     8    .156583E+01   .498254E+00   .437910E+02   .227748E+02   -.422252E+02
     9    .161561E+01   .262670E+00   .554964E+02   .111192E+02   -.538808E+02
    10    .153645E+01   .274779E-02   .629114E+02   .362508E+01   -.613749E+02
   ...
   176    .207951E+01  -.400597E+00   .159795E+02   .100000E+00   -.139000E+02
   177    .224896E+01  -.665273E+00   .161490E+02   .100000E+00   -.139000E+02
   178    .208327E+01  -.649580E+00   .159833E+02   .100000E+00   -.139000E+02
   179   -.117808E+00  -.130000E+00   .500090E+00   .133821E+02   -.617900E+00


 DIRECTION AND MAGNITUDES OF DISCHARGE VELOCITIES

          {centroid location}   {freshwater velocity, azimuth}

 ELEMENT   CTRX         CTRY       VELF    ANG       AREA {of element}

    1        2931267.   976117.   .117   190.      910000.
    2        2931250.   977100.   .118   190.      577500.
    3        2931867.   976225.   .009   134.      947500.
    4        2931850.   977108.   .045   197.      840625.
    5        2932550.   976175.   .029    16.      935625.
    6        2932442.   977150.   .025   221.      851875.
    7        2933042.   976283.   .104    13.      560625.
    8        2932867.   977333.   .028   334.      738750.
    9        2933408.   976467.   .255    11.      528750.
   10        2933308.   977433.   .308    13.      697500.
  ...
  297        2947875.   925750.   .039    11.      748125.
  298        2948375.   924867.   .012   181.      872500.
```

```
 299       2948392.   925933.   .112   22.      837500.
 300       2948917.   925075.   .134   20.      881250.


MASS BALANCE CALCULATIONS -- (CU. FT.)

      {recharge}    {pumping}    {disposal}   {discharge}    {storage}

TIME     TOTR           TOTP           TOTD         TOTOS        TOTS

 2    .797719E+07 -.150473E+06  .571796E+05  .210865E+07  .185127E+10



TOTALED PUMPING, DISPOSAL, RECHARGE & RATIO {consumption/recharge}

-.150473E+06  .571796E+05  .797719E+07      .116950E-01 {1.2%}



{change in storage volume}
                             CHANGE FROM PREVIOUS TIMESTEP
  D STOR VOL

 -.358817E+08                        -1.90%
```

Model Output (Toes):

```
SALTWATER TOES:
 TIMESTEP:   2

    2     0
    {x-coord.}    {y-coord.} {interface passes between node 167 and
                             168; 130 feet from 167 & 580 feet from
                             168}
    2931351.      975082.     167    130.          168    580.
    2930944.      977448.     168   2174.          173    492.
    2     0
    2930944.      977448.     173    492.          168   2174.
    2930858.      977912.     174    344.          173    109.
    2     0
    2933850.      975586.     171    312.          172     52.
    2933787.      975871.     172    294.          178   2631.
    2     0
    2933787.      975871.     178   2631.          172    294.
    2933192.      978388.     179     59.          178    426.
    2     0
    2930999.      972815.     163     75.          162    435.
    2931277.      974681.     162   1787.          167    320.
    2     0
    2931327.      974788.     159   1902.          167    226.
    2931277.      974681.     167    320.          162   1787.
    2     0
    2931327.      974788.     167    226.          159   1902.
    2931351.      975082.     168    580.          167    130.
    2     0
    2936900.      953571.     107    304.          108    759.
    2936932.      950874.     108   2191.           98     76.
    2     0
    2933898.      975438.     165   1963.          172    162.
    2933850.      975586.     172     52.          171    312.
    2     0
    2934334.      973590.     165    473.          166     43.
    2933898.      975438.     172    162.          165   1963.
    2     0
    2932104.      970274.     155    386.          162   2713.
    2930999.      972815.     162    435.          163     75.
    2     0
    2932275.      969921.     155     78.          154    389.
    2932104.      970274.     162   2713.          155    386.
    2     0
    ...
```

Field Data from January, August 1990, and March 1991

Currituck County Outer Banks Surveys
Topography, Water Table Elevation, and Approximate Distance from Ocean
(measurements in feet)

Pine Island Traverses

1/24/90

Sta. #	Topo.	Water Table	Dist. from Ocean
	.89*	.89*	2800
A1	2.80	2.80	1900
A2	4.28	3.09	1650
A3	5.49	3.61	1400
A4	4.98	2.38	1100
A5	5.37	1.82	800
A6	5.97	1.87	600
A7	11.98	2.08	375
A8	16.53	2.13	150
A9	20.39	1.99	100
	0.31*	0.31*	0

8/22/90

Sta. #	Topo.	Water Table	Dist. from Ocean
	0.89*	0.89*	2800
4	5.37	2.17	1450
3	5.04	2.08	1050
2	6.62	2.32	525
1	10.32	2.59	300
	0.31*	0.31*	0

3/21/91

Sta. #	Topo.	Water Table	Dist. from Ocean
	0.89*	0.89*	2800
1A	5.29	2.17	1525
1B	4.86	2.56	1100
1C	6.53	2.30	625
1D	11.32	2.48	300
	0.31*	0.31*	0

Ocean Sands Traverses

1/25/90

Sta. #	Topo.	Water Table	Dist. from Ocean
	0.89*	0.89*	3950
B1	13.27	7.27	2400
B2	8.05	6.55	2300
B3	11.87	6.75	2150
B4	12.72	7.02	2000
B5	7.77	6.07	1900
B6	9.74	6.26	1700
B7	10.57	4.65	1450
B8	8.91	4.06	1100
B9	9.85	5.00	800
B10	8.86	5.32	550
B11	11.41	4.84	200
	0.31*	0.31*	0

8/21/90

Sta. #	Topo.	Water Table	Dist. from Ocean
	0.89*	0.89*	3950
5	10.37	4.77	2400
4	7.84	4.46	2050
3	6.67	3.56	1650
2	9.72	2.87	1150
1	8.79	3.76	500
	0.31*	0.31*	0

3/21/91 Sta. #	Topo.	Water Table	Dist. from Ocean
	0.89*	0.89*	3950
2A	8.89	3.60	2250
2B	8.70	3.82	1300
2C	9.68	3.93	1100
2D	9.12	4.84	450
	0.31*	0.31*	0

Whalehead Traverses

8/21/90 Sta. #	Topo.	Water Table	Dist. from Ocean
	0.89*	0.89*	2250
5	7.28	3.72	2076
4	9.36	7.35	1551
3	10.32	7.77	1138
2	11.18	7.01	800
1	12.18	4.93	450
	0.31*	0.31*	0

3/21/91 Sta. #	Topo.	Water Table	Dist. from Ocean
	0.89*	0.89*	2250
3A	5.56	2.90	2150
3B	8.92	6.90	1675
3C	12.05	7.24	925
3D	10.34	5.79	575
	0.31*	0.31*	0

Ocean Hill Traverse

3/21/91 Sta. #	Topo.	Water Table	Dist. from Ocean
	0.89*	0.89*	2900
4A	3.51	2.03	2550
4B	6.46	4.59	1850
4C	8.07	6.28	1100
4D	8.30	6.36	750
	0.31*	0.31*	0

Carova Traverse

3/21/91 Sta. #	Topo.	Water Table	Dist. from Ocean
	0.89*	0.89*	4200
5A	3.72	1.01	3450
5B	3.73	1.07	2200
5C	5.96	2.83	1350
5D	4.80	3.19	1000
	0.31*	0.31*	0

* Elevation set to average sound or ocean elevation.

DWR Regional Water and Wastewater Systems

Currituck County Outer Banks

Wellfields and Disposal Areas Numbered from North to South
Refer to Figure 26 for Locations

Wellfield Number	Average Discharge (in GPD)	Maximum Discharge (in GPD)
1	39,000	89,000
2	39,000	89,000
3	39,000	89,000
4	39,000	89,000
5	78,000	179,000
6	78,000	179,000
7	78,000	179,000
8	78,000	179,000
9	78,000	179,000
10	157,000	357,000
11	78,000	179,000
12	78,000	179,000
13	78,000	179,000
14	78,000	179,000
15	78,000	179,000
16	157,000	357,000
17	78,000	179,000
18	78,000	179,000
19	78,000	179,000
20	78,000	179,000
21	78,000	179,000
22	78,000	179,000

Disposal Area Number	Average Recharge (in GPD)	Maximum Recharge (in GPD)
1	47,000	107,000
2	47,000	107,000
3	47,000	107,000
4	94,000	213,000
5	94,000	213,000
6	94,000	213,000
7	94,000	213,000
8	47,000	107,000
9	94,000	213,000