Hydrogeologic Evaluation of the Groundwater Resources of Roanoke Island
Dare County, North Carolina

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Executive Summary

Sources of Water:

Dare County operates a water system that provides high-quality potable water to the public. The water system is supplied by a diversity of sources, including fresh and brackish groundwater. Five separate water treatment facilities supply a combined volume of 12.7 million gallons per day (MGD). In addition, 0.7 MGD of treated surface water from the Fresh Pond Water Treatment Plant (WTP) is supplied during periods of high demand through cooperative agreement with the Town of Nags Head. Dare County experiences seasonal variation in water demand associated with seasonal population pressures, and this large variation in water demand presents challenges for public water system operation.

The County's Skyco WTP located at Roanoke Island has a process capacity of 4.3 MGD and is supplied by 9 wells withdrawing from the Principal Aquifer. The Skyco wellfield has been in operation since 1979, and it has proved to be a reliable source of fresh water supply for Dare County. In recent years, local areas of saltwater intrusion have been identified beneath The Island, mostly in the Wanchese area and in the Surficial Aquifer near the center of The Island. As Dare County seeks to expand the Skyco wellfield, there is a need for careful study of the safe yield of the aquifers and the mechanisms for saltwater intrusion. Groundwater Management Associates, Inc. (GMA) was contracted by the Dare County Water Department to conduct a hydrogeologic evaluation of the groundwater resources beneath Roanoke Island. The purpose of the evaluation was to reassess the fresh groundwater resource potential of the Principal Aquifer and to evaluate the vulnerability and mechanisms of saltwater intrusion to the Principal Aquifer.

Scope of Study:

GMA devised a study that included research and field evaluations to gain new understanding about the groundwater resource potential. Research included: 1) review of existing published reports, 2) evaluation of well drilling logs and well construction records, 3) review of available groundwater level data from the Skyco wellfield and from North Carolina Department of Environment and Natural Resources (NCDENR) monitoring wells, 4) evaluation of historical water quality sample data, and 5) review of records of private well replacements in Wanchese where private wells have experienced increases in chloride concentrations. GMA's field evaluations consisted of measurement of water levels at existing Skyco water-supply wells, conducting 1-hour pumping tests on each Skyco well, and performing a 24-hour constant-rate pumping test at Skyco Well #11. GMA compiled the results of these evaluations into a database and a series of maps and cross sections that illustrate the framework of aquifers and their properties. The database and maps are important tools for future management and exploration of the groundwater system at Roanoke Island.

Groundwater Conditions:

Four aquifers were assessed in this study: the Surficial Aquifer, the Upper Principal Aquifer, the Lower Principal Aquifer, and the Yorktown Aquifer. The Surficial Aquifer is the uppermost layer of permeable sediments and occurs from the land surface to a depth of 75 to 100 feet below land surface. These sediments have very complex stratigraphy that is characteristic of dynamic barrier island systems. The Surficial Aquifer sediments include back-barrier estuarine, dune, beach, inlet, and open marine deposits. Complex cut-and fill structures occur within the Surficial Aquifer sediments. Water quality of the Surficial Aquifer is variable and includes local areas of fresh and salty groundwater. Evidence of saltwater in the Surficial Aquifer beneath Roanoke Island includes the area near Shallowbag Bay, the vicinity of Skyco Well #12, and western portions of Wanchese, especially areas within 2500 feet of open water bodies. The Surficial Aquifer is also likely to be salty near finger canals, spoils disposal sites, and other large excavation areas on Roanoke Island. The Surficial Aquifer is not a primary source of drinking water on Roanoke Island, although it is locally used at some private residences.

The Upper Principal Aquifer is a thin (20 to 40 foot thick) marine sand unit that occurs from about 95 to 130 feet below sea level beneath Roanoke Island. The unit is overlain by a discontinuous clay confining layer that separates it from the Surficial Aquifer. The water quality appears to be fresh beneath most of Roanoke Island, but it is vulnerable to saltwater intrusion from the overlying Surficial Aquifer in areas where the confining layer is thin or absent. The Upper Principal Aquifer has been important to private well owners at Roanoke Island, especially near Wanchese. Two Skyco wells, Well #9 and Well #12, included screens that were open to the Upper Principal Aquifer. These two wells experienced the most variable water quality, and the wells have been abandoned due to the increases in chloride content. NCDENR asked Dare County to relocate Well #9 in order to complete an overdue dredging project and use the property as a spoil site. Well #9 was abandoned and Well #6 was constructed to replace the lost yield from Well #9.

The Lower Principal Aquifer is a 50 to 75 foot thick coarse sand that occurs at about 160 feet below land surface and is the primary source of water supply to the Skyco wellfield. The aquifer is well confined in most areas and contains fresh water beneath most of Roanoke Island. However, near Skyco Well #12, no confining layer between the Upper and Lower Principal Aquifers was evident. Saltwater intrusion has been recognized near Skyco Well #12 as a result of the poor confinement of the aquifer. Another area of elevated chloride concentrations has been identified in the Lower Principal Aquifer in Wanchese, close to the Croatan Sound. This elevated chloride area does not appear to be a result of thinning or breaching of the confining layer, but is more likely a result of poor well construction at private residences in the area.

The Yorktown Aquifer underlies the Lower Principal Aquifer, and it is not used beneath Roanoke Island. The aquifer top occurs from about 270 to 300 feet below sea level, and the aquifer averages about 100 feet in thickness. The Yorktown Aquifer is believed to be brackish beneath Roanoke Island, although there is very limited data on the water quality of this aquifer in the area. The aquifer is overlain and underlain by thick clay confining layers. The nature and occurrence of additional water-bearing units of the Yorktown Formation are not addressed in this study due to the lack of data and the lack of use of deeper aquifer zones near Roanoke Island. The Yorktown Aquifer is an important water-supply source to Dare County's reverse osmosis plants at Kill Devil Hills and Rodanthe. As such, the Yorktown has water-resource development potential beneath Roanoke Island, as long as adequate treatment is developed to support the use of this brackish aquifer.

Conclusions:

- Natural recharge to the Principal Aquifer occurs predominantly in up-dip areas of the mainland to the west of Roanoke Island.
- The transmissivity of the Principal Aquifer averages about 15,000 ft^2/day, and individual well yields exceeding 500 gallons per minute are supported by the aquifer.
- Most Skyco wells are exclusively screened into the Lower Principal Aquifer.
- The few Skyco Wells that include screens within the Upper Principal Aquifer are more vulnerable to saltwater intrusion, and some older wells built in this manner had to be abandoned and replaced due to increases in chloride concentrations.
- Existing Skyco wells that occur more than 2500 feet from the sounds appear to be less vulnerable to saltwater intrusion than wells less than 2500 feet from the sounds. We believe that this is because the Surficial Aquifer is less likely to be salty at distances of more than 2500 feet from the sounds. However, there are areas, such as Well #12, where saltwater in the Surficial Aquifer has been recognized more than 2500 feet from the sounds. This area warrants further evaluation to determine the nature and extent of saltwater intrusion into the Surficial and Principal Aquifers.
- Withdrawals from the Skyco wellfield have caused an elongate narrow cone of depression in the Principal Aquifer.
- Water levels in the Principal Aquifer have declined on average by about 12 feet since the Skyco wellfield was constructed, but since 2003 the water levels have stabilized, or are slightly rising. Water levels in close proximity to the Skyco wells fluctuate seasonally by about 20 feet in response to seasonal changes in well use.
- The depressurization of the Principal Aquifer by the Skyco wellfield has induced a downward head gradient between the Surficial Aquifer and the Principal Aquifer.
- Declines in water levels within the Principal Aquifer near Wanchese affected the yield of private wells in the area, prompting Dare County to develop a program of private well replacements.
- In recent years, private wells in the southwestern portion of Wanchese have experienced saltwater intrusion. The mechanisms for saltwater intrusion into the Lower Principal Aquifer at Wanchese appear to be vertical downward migration of water in boreholes of private residential wells with incomplete grout seals. Many private wells have only minimal grout (to a depth of about 20 feet), and the Surficial Aquifer in this area is salty. These older, poorly-grouted wells allow saltwater from the Surficial Aquifer to drain down the borehole into the Upper and Lower Principal Aquifers, thereby causing the well to become salty. Dare County has modified the procedures for private well replacements to include installing Lower Principal Aquifer wells with casings that are fully grouted into the top of the Lower Principal Aquifer to a depth of about 150 feet below land surface. These procedures have been very effective at providing more reliable fresh water to local private residences in Wanchese.
- Current withdrawals from the Skyco wellfield appear to be sustainable. Water levels within the Lower Principal Aquifer remain stable with consistent seasonal variability over the past five years.
- The most significant risk to continued withdrawals at the Skyco wellfield is saltwater intrusion at Wanchese associated with insufficient grout around private wells. In

addition, improperly abandoned private wells likely occur, and these wells serve as conduits for the intrusion of saltwater from the Surficial Aquifer down into the Lower Principal Aquifer.

- The continued use of private wells limits the potential for expansion of withdrawals from the Lower Principal Aquifer by Dare County in the southern portion of Roanoke Island.
- The Lower Principal Aquifer has significant resource potential beneath the northern end of The Island. A prior test well constructed at the Roanoke Island Fire Department (RITW1) demonstrated that the Lower Principal Aquifer beneath Manteo is fully confined, has significant yield potential, and contains fresh water.
- GMA conservatively estimates that the Lower Principal Aquifer beneath the northern portion of Roanoke Island could support an additional 3.25 MGD withdrawal. This estimate assumes that nine new wells would be installed with a minimum well spacing of 3000 feet and a design flow rate of 500 gpm per well. This estimate also assumes that individual wells would be pumped not more than 12 hours per day. Further exploration and testing on the northern portion of Roanoke Island is needed to refine the estimate of additional available supply from the Lower Principal Aquifer. Combining this conceptual northern wellfield with the existing 4.3 MGD supply from the Skyco wellfield would provide a combined total supply of 7.55 MGD from the Principal Aquifer at Roanoke Island.
- The Yorktown Aquifer is unutilized beneath Roanoke Island. The aquifer has significant water resource potential, but the use of the Yorktown Aquifer would likely require treatment by reverse osmosis, as is done at the Northern RO Water Treatment Plant. Chloride concentrations in the Yorktown Aquifer beneath The Island are expected to be lower than occur at the Northern RO wellfield.
- Due to economic factors, Dare County would like to stop using the Town of Nags Head's Fresh Pond WTP as a source of water supply. Considering the expansion potential of the Lower Principal Aquifer beneath Manteo, and considering other water-supply options available to the County, GMA concludes that there are adequate groundwater resources available to replace the approximately 0.7 MGD supply from the Fresh Pond.

Recommendations:

- Expand public water service to the community of Wanchese. By connecting properties in Wanchese to the public water system, Dare County could provide consistent, safe potable water to Wanchese, and the County could eliminate the need to continue the expensive program of replacing private wells.
- If public water is provided to Wanchese, all existing private wells should be properly abandoned to eliminate the potential of saltwater intrusion into the Principal Aquifer through these wells.
- Expand the wellfield supplying the Skyco plant by exploring and constructing Lower Principal Aquifer wells on the northern portion of Roanoke Island. A viable well site has already been explored at the Roanoke Island fire department (RITW1). GMA recommends that future well sites be selected where the Surficial Aquifer is not salty, thereby reducing the potential for downward vertical migration of saltwater at new well sites. GMA has mapped a target zone for future expansion of the wellfield. This

exploration zone includes a 2500 foot buffer from shorelines and areas of known saltwater in the Surficial Aquifer.

- Future Dare County production wells should not include screens in the Upper Principal Aquifer. Available data suggest that the Upper Principal Aquifer is more vulnerable to saltwater intrusion than wells that are exclusively screened in the Lower Principal Aquifer.
- Avoid constructing new production wells near Shallowbag Bay where the confining layers overlying the Principal Aquifer are thinned or absent. Further study of the water quality and hydraulic properties of the aquifers near Shallowbag Bay is recommended so that Dare County can better understand the potential threat of saltwater intrusion to the Skyco wellfield from this area.
- As the wellfield is expanded, modify pumping strategies for the existing wellfield to provide cycles of pumping and rest periods that minimize the prolonged drawdown within the Principal Aquifer. The goal of wellfield cycling should be to allow for individual rest periods that equal or exceed the duration of pumping. This type of wellfield management strategy will extend the life of the wellfield and minimize the potential for saltwater intrusion.
- Explore the resource potential of the Yorktown Aquifer beneath Roanoke Island as a source of water supply. The Yorktown Aquifer represents an abundant resource for future water supply to Dare County if reverse osmosis treatment were developed at Roanoke Island.
- Provide specifications for proper well construction in the Dare County Well Ordinance. These specifications should present requirements for proper grouting of well casings to prevent interconnection of aquifers with differing water quality.
- Expand the monitoring well network to include wells in the Surficial and Principal Aquifers to monitor for chloride concentrations and water levels near Shallowbag Bay and Broad Creek. This network of monitoring wells would provide a means of monitoring changes in water levels and water quality that could indicate areas of vulnerability to saltwater intrusion.
- Carefully evaluate any future proposed "finger canals" of "borrow pits" that could be pathways for saltwater intrusion into the Surficial Aquifer in the interior of the Island. These types of canals and pits should not be permitted in close proximity to wells.
- Consider the water resource potential of the Surficial Aquifer near the relict dune ridge on the northern end of The Island. The Surficial Aquifer in this area may have untapped fresh resource potential that is protected from saltwater sources by the significant land elevation. A series of shallow test wells could be constructed in the area to determine the viability of using the Surficial Aquifer in the area.
- Dare County should share concerns with the NCDRW about the integrity of the existing monitoring wells at the J3Y site. If these wells are determined to be poorly constructed, or if their condition has deteriorated, the wells may serve as a conduit for saltwater intrusion into the Principal Aquifer. If one or more of these monitoring wells is a conduit for saltwater intrusion, the well(s) should be abandoned.

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1.0) <u>**Background and Purpose**</u>

Dare County operates a water system that provides high-quality potable water to the public. The water system is supplied by a diversity of sources, including fresh and brackish groundwater. Five separate water treatment facilities supply a combined volume of 12.7 million gallons per day (MGD). In addition, treated surface water from the Fresh Pond Water Treatment Plant is supplied during periods of high demand through cooperative agreement with the Town of Nags Head. Dare County experiences seasonal variation in water demand associated with seasonal population pressures, and this large variation in water demand presents challenges for public water system operation. Facilities are designed to meet the peak demands of the summer months, but are operated well below capacity during most of the year. Increased development to support the tourism industry has led Dare County to expand its water supply systems. The need for increased withdrawals from the groundwater system has prompted Dare County to further evaluate the safe yield of the aquifers that are the sources of water.

One area where additional supply is needed is the Skyco Water Treatment Plant (WTP) on Roanoke Island (The Island) (Figure 1). The Skyco WTP has a capacity of 4.3 MGD and is supplied by 9 wells withdrawing from the Principal Aquifer. The Skyco wellfield has been in operation since 1979, and it has proved to be a reliable source of fresh water supply for Dare County. In recent years, local areas of saltwater intrusion have been identified beneath The Island, mostly in the Wanchese area and in the Surficial Aquifer near the center of The Island. As Dare County seeks to expand the Skyco wellfield, there is a need for careful study of the safe yield of the aquifers and the mechanisms for saltwater intrusion. Therefore, Dare County contracted Groundwater Management Associates, Inc. (GMA) to perform a hydrogeologic evaluation of the groundwater resources beneath Roanoke Island.

1.1) Hydrogeologic Setting

Roanoke Island is a coastal island, approximately 10.5 miles long and 2.5 miles wide, which is surrounded by estuarine waters of the Croatan Sound (west), Roanoke Sound (east), Albemarle Sound (north), and Pamlico Sound (south). The Island lies near the eastern edge of the Coastal Plain Physiographic Province. The Coastal Plain is a broad, relatively flat region comprising the eastern third of the State, and it is underlain by marine, estuarine, and terrestrial sediments (up to 10,000 feet thick at Cape Hatteras) that were deposited on top of pre-Mesozoic aged (>250 million years) crystalline basement rocks (Lawrence and Hoffman, 1993). The Coastal Plain sediments include a framework of laterally extensive interbedded permeable strata (aquifers) separated by impermeable strata (confining beds) (Winner and Coble, 1996) (Figure 2).

Local topography is very flat across most of The Island, with local relief of only about 10 feet between the center of The Island and the surrounding estuaries (Figure 3). The northern end of The Island has a high ridge (maximum elevation of 74 feet above mean sea level) that is believed to be a relict dune ridge, similar in nature to Jockey's Ridge at Nags Head. The land surface of The Island largely owes its origin to erosion following several sea level advances and retreats that occurred throughout the Pleistocene Epoch (<1.8 million years ago). These sea level fluctuations created broad and generally flat terraces that slope gently to the east. Streams and rivers have incised these terraces to create the current topographic character of the area.

Extensive studies of the nature of sediment deposition and erosion since the Pleistocene have been conducted in the area, but have predominantly focused on the Outer Banks and the Albemarle River. Mallinson, et al (2005) have studied the shallow sediments in detail and mapped a paleo-channel of the ancestral Albemarle River located approximately 4 miles north of Roanoke Island and extending off-shore beneath Kitty Hawk (Figures 4 and 5). The paleo-channel cuts to a depth of approximately 130 feet below sea level and is backfilled with late Pleistocene to Holocene sediments. A smaller distributary paleo-channel was also identified immediately north of Roanoke Island. This smaller paleo-channel cuts to a depth of about 65 feet below sea level.

The Mesozoic-aged sediments beneath The Island are dominantly clastic in nature, and include sequences of silt and clay interbedded with sand and gravel zones with minor amounts of shell. These sediments are associated with deltaic and marginal marine depositional environments that predominated along the eastern margin of North America from about 145 to 65 million years ago (Sohl and Owens, 1991). These sediments have been hydrostratigraphically subdivided into four major aquifers of the Cretaceous Aquifer System (CAS). The CAS includes (from deep to shallow) the Lower Cape Fear Aquifer, the Upper Cape Fear Aquifer, the Black Creek Aquifer, and the Peedee Aquifer (Winner and Coble, 1996). The CAS is extensively used as a source of water supply in the central portion of the Coastal Plain. However, in the vicinity of Roanoke Island, the CAS is not used because of the occurrence of saltwater and the significant depth (>1500 feet) to these aquifers.

Overlying the CAS is a sequence of Cenozoic-aged (<65 million years) sediments of dominantly marine origin. These include significant beds of sands, shelly clays and fossiliferous sandy limestones. These sediments have been hydrostratigraphically subdivided into five regional aquifers, including (from deep to shallow): the Beaufort Aquifer, the Castle Hayne Aquifer, the Pungo River Aquifer, the Yorktown Aquifer, and the Surficial Aquifer. Many of these aquifers contain fresh water and are important sources for local and regional water supplies. At Roanoke Island, the Pleistocene to Recent aged sediments which regionally comprise the "Surficial Aquifer" have been subdivided to include a confined aquifer which is termed the Principal Aquifer. The nature of the Principal Aquifer is a focus for this hydrogeologic framework study, and will be further discussed in later sections. Table 1 lists the utilized aquifers that occur beneath The Island and describes the characteristics of these aquifers.

Table 1: Regional Aquifer Framework near Roanoke Island, Dare County

Aquifer	Formations and Ages	Character and Use Near Roanoke Island
Surficial	Surficial Sediments (Pleistocene to Recent)	This aquifer occurs as a veneer (70 to 100+ feet thick) of sandy to clayey sediments, locally fossiliferous with shells, bone, and teeth. The aquifer covers the entire County, except in areas where deeply incised streams and rivers cut into underlying units. Clays within the unit tend to serve as confining layers and restrict recharge to underlying aquifers. The aquifer is not currently used as a significant groundwater source. It may be used sporadically for irrigation and private residential water supply.
Principal	Un-named Pleistocene Sediments	This term was assigned by Peek, et al (1972) for the fresh water aquifer used by the Skyco wellfield. It generally occurs from 110 to 215 feet below sea level. GMA has subdivided the aquifer into two separate aquifers, the Upper and Lower Principal Aquifers. The upper aquifer is poorly confined and is vulnerable to local saltwater intrusion. The North Carolina Division of Water Resources has also used the name Upper Yorktown Aquifer to describe this unit (NCDWR, 1997). GMA does not use the name Upper Yorktown because this aquifer is entirely Pleistocene aged and does not include the Yorktown Formation.
Yorktown	Yorktown Formation (Pliocene)	The Yorktown Aquifer is a brackish unit composed of interbedded gravelly shelly sands and clays overlain by a ~60-feet thick confining unit (clay). Locally, the aquifer may include beds of sandy micritic limestone. The top of the Yorktown Aquifer occurs at an elevation of approximately 270 to 300 feet below MSL beneath Roanoke Island. According to the USGS (Winner and Coble, 1996), the Yorktown Aquifer is approximately 450 feet thick near Roanoke Island. Local drilling data demonstrate that the Yorktown Aquifer near The Island has upper and lower units separated by one or more significant clay layers. The upper portion of the Yorktown Aquifer is approximately 100 feet thick beneath Roanoke Island and is underlain by a >100 feet thick clay confining layer for the lower portion of the Yorktown Aquifer. Data on the nature and water quality of the lower portion of the Yorktown Aquifer are lacking in the vicinity of Roanoke Island. The upper portion of the Yorktown Aquifer is the source for the Reverse Osmosis water treatment plants operated at the Northern RO plant and at the Rodanthe, Waves, Salvo plant. The aquifer is not used at Roanoke Island.

Deeper aquifers below the Yorktown have not been explored for water supply in the vicinity of Roanoke Island, and there are no data available on the yield and water quality characteristics of these aquifers. One deep oil exploration hole, drilled at Manteo, demonstrates that Coastal Plain sediments extend to a depth of more than 6000 feet (see Table 2).

The Upper and Lower Principal Aquifers are the most extensively used aquifers at Roanoke Island. The largest user of the Principal Aquifer is Dare County at its Skyco wellfield. The Principal Aquifers are also important to private well owners on Roanoke Island, especially at Wanchese. The use of the Upper and Lower Principal Aquifer will be discussed in more detail in Section 3.

1.2) Previous Studies and Prior Development of Groundwater at Roanoke Island

In 1972, the North Carolina Department of Natural and Economic Resources (NCDNER) conducted a study of the groundwater resources beneath Roanoke Island (Peek, et al, 1972). The study involved drilling several exploratory wells and installing a monitoring well network. The study identified the Principal Aquifer beneath the southern portion of Roanoke Island as a viable source of water supply for Dare County.

Building upon the knowledge gained from the NCDNER study, Dare County began exploring options for regional water supply at Roanoke Island. Initial evaluations of water-supply options concluded that the southern portion of Roanoke Island was the most adequate and available area to develop a regional water-supply source of approximately 8 to 10 million gallons per day (HVO, 1973). These initial evaluations further indicated that 14 wells could be constructed as a source of water supply from Roanoke Island (HVO, 1974).

Dare County proceeded with construction of the Skyco wellfield, and eight wells were constructed by 1984. Following initial construction and operation of the Skyco wellfield, it was recognized that water levels in the Wanchese area had declined, and a number of private wells suffered a loss of yield due to the lower water levels (Quible, 1989). From the early 1970's through the early 1980's, the North Carolina Division of Environmental Management (NCDEM) constructed a series of monitoring wells on Roanoke Island to monitor the water levels in the aquifers used by the Skyco wellfield (NCDWR, 1994). By 1984, Dare County enacted a program of "replacing wells with deeper wells" (Quible, 1989). In addition, there were recommendations for connection of Wanchese to the public water system to eliminate the need for continuing with well replacements. However, these recommendations were met with resistance from the Wanchese community, and public water service has not been provided.

By the early 1990's, the NCDWR, at the direction of the Environmental Management Commission, began a program of data gathering and evaluations of the water resources beneath Roanoke Island. NCDWR produced a report in October of 1992 that included evaluations of data from NCDEM monitoring wells and Skyco production wells. This study was followed by annual to semi-annual monitoring reports (ending in 1997), wherein water levels and chloride data were collected and interpreted by the NCDWR. These studies concluded that the withdrawals from the Skyco wellfield are capable of providing significant portions of Dare

County's water demands (NCDWR, 1997). Dare County has continued to monitor water levels and chloride concentrations on a monthly basis at NCDEM monitoring wells.

In 1998, a County-Wide Hydrogeological Study and Groundwater Resource Evaluation was conducted in behalf of Dare County (Missimer, 1998). This study included evaluation of the historic pumpage, water quality, and monitoring well data. A hydraulic computer model was developed to predict the drawdown impacts associated with expansion of the Skyco wellfield. The hydraulic computer model used limited historical data on aquifer properties and hydrostratigraphy. The modeling simulated the response of the aquifer to a combined withdrawal rate of 5.5 million gallons per day (MGD) from an expanded Skyco wellfield. The model indicated that this withdrawal rate could result in up to 5 additional feet of drawdown to residential wells in Wanchese during the summer season (Missimer, 1998). Missimer recommended that three additional water-supply wells be constructed to increase the capacity of the Skyco wellfield to 7.0 MGD. This expansion would need to be coupled with connection of the residents of Wanchese to the public water system to avoid domestic well problems caused by seasonal drawdown effects. These recommended expansions of the wellfield have not been conducted, due in part to continued unwillingness of the Wanchese community to connect to the public water system.

Between 1998 and 2006, Dare County continued to operate the Skyco wellfield as a major source of public water supply. Three wells (Well 1, Well 9, and Well 12) were abandoned during this time period. Wells 1 and 12 were abandoned due to increased chloride concentrations. Although Well 9 did not experience an increase in chloride concentrations, Well 9 was abandoned due to its proximity to a dredge spoil disposal area. Two wells (Well 2 and Well 6) were constructed in 2004 to replace existing Wells 1 and 9. In April of 2006, Camp, Dresser, and McKee (CDM) published a "Dare Countywide Hydrogeologic Study and Groundwater Resource Evaluation Update". CDM postulated that the degradation in water quality at Wells 1 and 12 were a result of breaches in the well casings that were allowing entry of poor-quality water. During this time period, Dare County continued its program of private well replacement in Wanchese. Reasons for private well replacements included: loss of yield (static water levels below 15 feet depth), increases in chloride concentrations above 250 mg/L, and sand production.

CDM also reported the results of a test well (RITW-1) installed at the Roanoke Island Fire Department (CDM, 2006). The Lower Principal Aquifer at Well RITW-1 had low chloride (23 mg/L) and moderately high transmissivity (6800 ft^2/day). Based upon the findings of RITW-1, CDM concluded that the Lower Principal Aquifer has potential for use as a public water supply source beneath the northern end of The Island.

In 2007, Dare County constructed a new water-supply well (Well 14) located north of the Roanoke Island Visitor Center across US Highway 64. Well 14 replaces the abandoned Well #12, and brings the wellfield back to a total of 10 wells. Dare County plans to bring Well 14 into operation in 2008. Dare County plans to expand withdrawals from the Principal Aquifer at Roanoke Island. These plans have led Dare County to further evaluate the yield potential of the Principal Aquifer beneath Roanoke Island.

2.0) Scope of Work

GMA developed a scope of work designed to determine the fresh water resource potential of the Principal Aquifer, and to identify the areas and mechanics of saltwater intrusion recognized at two Skyco wells (Well 1 and Well 12), and at several private wells in the Wanchese area. The scope of work included:

- Review of existing well information from the Skyco wellfield, including: well construction records, driller's notes, geophysical logs, laboratory data, and pumping test data from all production wells and test wells.
- Review of reports prepared by consultants on behalf of the Dare County Water Department.
- Review of available data on State or United States Geological Survey (USGS) test wells at or near Roanoke Island.
- Review of available publications (USGS, NCDWR) on the regional and local hydrogeologic setting and framework.
- Review of records maintained by the Dare County Water Department on the occurrence of saltwater intrusion at private wells on Roanoke Island. This included review of data on any replacement wells recently installed at private residences by the Dare County Water Department.
- GMA visited and inspected each existing active water-supply well in the Skyco wellfield. This inspection entailed observation of the wellhead equipment, water level access ports, and flow meter equipment. GMA worked with Dare County Water Department to shut off the wells for several hours prior to our inspections so that a non-pumping water level could be obtained. Additionally, GMA worked with Dare County Water Department to perform 1-hour pumping tests to determine the individual pumping rate and specific capacity of each well.
- Development of a database of existing available well information, including GMA's inspection and well test results.
- GMA worked with Dare County Water Department to conduct an extended constant-rate pumping test centered on Skyco #11. The test was designed to determine the transmissivity, storage coefficient, and degree of leakance of the Principal Aquifer. Nearby wells were turned off to avoid drawdown interference during the test. GMA utilized pressure transducers and hand measurements to monitor water levels at observation wells at sites Skyco #6, Skyco #10, Skyco #11, Skyco #12, and at the test well site Skyco #14. Analysis of aquifer test data provided estimates of hydraulic properties of the aquifer.

3.0) Hydrostratigraphic Framework Beneath Roanoke Island

3.1) Data Collection and Database Development

GMA reviewed data from more than 50 borings and wells in Dare County. Data sources included Dare County Water Department, consultation with local well drilling contractors, hydrostratigraphic data available on the internet from the North Carolina Division of Water Resources, prior publications by consultants to Dare County Water Department, publications from the North Carolina Geological Survey, and publications by the United States Geological Survey. Data reviewed included well construction records, geophysical logs, aquifer test data, water level monitoring data, water quality data, seismic surveys, and sediment descriptions from core holes. These data were interpreted and integrated into a spreadsheet database (Table 2). The database is a compilation of well details and aquifer data that is an important tool for future water resource evaluations and groundwater management strategies. Figure 6 illustrates GMA's interpretation of aquifers and confining layers from a typical geophysical log used in the study.

Table 2. Hydrostratigraphic Framework Database

Lat	Long	Well ID	Name	Status	Date	LS Elev	Depth	Screen Interval	Aquifer Monitored	Geophysical Logs?	Elev of UPCL	Elev of UPA	Elev of LPCL	Elev of LPA	Elev of UYTCL	Elev ofU YTA	Elev of LYTCL
35.8688	75.92003	ELTW1		?													
35.90417	75.59556	J3A	Whalebone #6	Monitoring Well	1972	5	500			Y	-93	-145	-155	-175	-215	-307	-375
35.89833	75.62083	J3H	Causeway #5	Monitoring Well	1973	3	357			Y	-97	-132	-157	-177	-212	-312	
35.88096	75.66577	J3O	Skyco Road	Monitoring Well	1972	5	504			Y	-88			-120	-235	-305	
35.83979	75.65382	J3Y	Eason	Monitoring Well	1983	4	402			Y	-85	-116	-134	-166	-216	-296	
		J3 Y8	Eason	Monitoring Well	1983	4	14.6	9.6-14.6	Surficial								
		J3 Y5	Eason	Monitoring Well	1983	4	181	171-181	LPA								
35.8423	75.63989	J3X	Wanchese Research Station	Monitoring Well	1972	9	500			Y	-87	-120	-137	-159	-220	-291	-411
35.84602	75.64805	J3X2	Convict Pit RS	Monitoring Well		8	501			Y	-103	-113	-132	-154	-217	-292	-412
35.84602	75.64805	J3 X17	Convict Pit RS	Monitoring Well	1984	8	172.3	162.3-172.3	LPA								
35.84602	75.64805	J3 X20	Convict Pit RS	Monitoring Well	1984	8	10.6	5.6-10.6	Surficial								
35.8423	75.63989	J3 X13	Wanchese Community Center	Monitoring Well	1983	9	180.3	170.3-180.3	LPA								
35.8423	75.63989	J3 X9	Wanchese Community Center	Monitoring Well	1983	9	17.6	12.6-17.6	Surficial								
35.88097	75.66578	J3 F4	Skyco, Toler Road	Monitoring Well	?		Unknown	Unknown	Surficial								
35.88096	75.66581	J3 F3	Skyco, Toler Road	Monitoring Well	1972		208	198-208	LPA								
35.87109	75.78605	J5M	Spencers Creek	Monitoring Well	1973	3				Y	-70	-79	-100	-120	-177	-227	
35.87111	75.86194	J5 M3	Hwy 64, Gateway Intersection	Monitoring Well													
35.87089	75.78603	J5 M2	Hwy 64, Gateway Intersection	Monitoring Well													
35.89358	75.7669	MANN	Missimer-Manns Harbor	Monitoring Well	1998	4	356	SW 135-195 DW 250-350	LPA YTA	Y	-71	-81	-106	-126	-186	-241	-358
35.88739	75.76659	J5J	Manns Harbor	Monitoring Well	1972	6	500			Y	-70	-79	-109	-131	-171	-231	-382
35.88735	75.7666	J5 J2	Manns Harbor, Whites Trailer	Monitoring Well													
35.92389	75.67722	I4U	Rapp Oil Etheridge #1	Borehole	1969	11	6081			Induct/SP							
35.91833	75.70157	I4 V3	Manteo Airport	Monitoring Well	1972	12	158.5	148.5-158.5	LPA	Y							
35.91832	75.70153	I4 V5	Manteo Airport	Monitoring Well	1984	12	17	12-17	Surficial								
35.91839	75.70164	I4W	Manteo Airport	Monitoring Well	1972	12	155.9			Y	-88	-97	-119	-128	-183	-273	-378
35.82372	75.56948	K2E	Bodie Island Lighthouse RS	Monitoring Well	1983	3	500			Y	-129	-144	-180	-193	-225	-327	-402
35.9301	75.71167	NEVC	Center	Borehole													
35.9161	75.67647	RITW1	Roanoke Island TW1, Fire Dept	Monitoring Well	2003	7	213	140-180	LPA	Y	-83	-115	-128	-134	-173		
35.87139	75.75519	MHFM		?													
35.87245	75.75418	MLD03	NCGS Rotosonic Core	Core	2005	3	220			N	-74	-94	-117	-132	-192		
35.85249	75.64493	OW1	Dare Co. OW1	Monitoring Well	1978	4	210	200-210	LPA	Y	-102	-120	-132	-156	-222		
35.89381	75.63887	OW2	Dare Co. OW2	Monitoring Well	1978	3	240	208-218	LPA	Y	-101	-117	-129	-151	-221		
35.84983	75.65593	Well 1	Skyco Well 1	Abandoned	1973	7	236	132-236	UPA LPA	N	?	?	?	-125	-221		
		Well 2	Skyco Well 2	Active	2004	4	222	167-217	LPA								
35.8541	75.64017	Well 4	Skyco Well 4	Active	1978	3	250	170-220	LPA	N	-97	?	?	-157	-237		
35.86035	75.64866	Well 5	Skyco Well 5	Active	1977	5	235	168-218	LPA	Y	-109	-122	-131	-151	-223		
35.87822	75.65853	Well 6	Skyco Well 6	Active	2004	5	225	150-220	LPA	Y	-101	-120	-129	-147	-229		
35.86483	75.65019	Well 7	Skyco Well 7	Active	1978	4	250	165-215	LPA	Y	-102	-127	-134	-156	-220		
35.87116	75.65181	Well 8	Skyco Well 8	Active	1978	3	250	162-250	LPA	Y	-105	-112	-134	-150	-217		
35.87662	75.66031	Well 9	Skyco Well 9	Abandoned	1973	5	200	120-190	UPA LPA	N	?	?	-135	-145			
35.88116	75.66754	Well 10	Skyco Well 10	Active	1978	5	250	141-192	LPA	Y	-91	-113	-129	-135	-228		
35.88369	75.66352	Well 11	Skyco Well 11	Active	1983	4	223	187-223	LPA	Y	-83	-108	-149	-160	-223		
		OW11	Skyco Obs Well 11	Monitoring Well	1983		220	210-220	LPA								
35.88632	75.66008	Well 12	Skyco Well 12	Abandoned	1978	4	244	140-190	UPA LPA	Y	-96	-108		-136	-213		
		OW12	Skyco Obs Well 12	Monitoring Well	1978				LPA								
35.87503	75.65091	Well 13	Skyco Well 13	Active	1983	4	225	180-225	LPA	Y	-92	-116	-128	-144	-216		
		OW13	Skyco Obs Well 13	Monitoring Well	1983				LPA								
		Well 14	Skyco Well 14	Inactive	2007	5	200	150-200	LPA	Y	-85	-107	-129	-151	-218		
		OW14	Skyco Obs Well 14	Monitoring Well	2000	5	180	130-180	UPA LPA	Y	-85	-109	-149	-154	-219		
35.84219	75.65511	Reber	Well	Residential	2007	5	225	215-225	LPA	Y	-66	-99	-142	-163			

Hydrostratigraphic Units
SA = Surficial Aquifer
UPCL = Upper Principal Confining Layer
UPA = Upper Principal Aquifer
LPCL = Lower Principal Confining Layer
LPA = Lower Principal Aquifer
UYTCL = Upper Yorktown Confining Layer
UYTA = Upper Yorktown Aquifer

3.2) Hydrostratigraphy

3.2.1) Mapping of Aquifers

Aquifer and confining layer elevations from each boring were plotted on maps of Roanoke Island. These data were contoured to depict the top and bottom elevations for each aquifer encountered (down to and including the Yorktown Aquifer). In addition, GMA developed maps of the thickness of each aquifer mapped. Figures 7 through 15 present the elevation and thickness maps developed. These maps provide important tools for understanding the depths and thicknesses of aquifers near Roanoke Island. Elevation maps indicate that the aquifers and confining layers dip to the east-southeast. Upon completion of mapping, GMA developed two cross sections that depict the aquifer depths and thicknesses in profile views. Figure 16 illustrates the cross section traces, and Figures 17 and 18 illustrate east-west and north-south cross sections, respectively. These maps and cross sections of aquifers in the vicinity of Roanoke Island depict a complex hydrogeologic system.

3.2.2) Hydrostratigraphic Findings

The Surficial Aquifer is an assemblage of mostly coarse-grained marine to estuarine sediments with minor clay content. These sediments have very complex lithologic facies that are characteristic of dynamic barrier island systems. The sediments include back-barrier estuarine, dune, beach, inlet, and open marine deposits. Complex cut-and fill structures occur within the Surficial Aquifer sediments. Water quality of the Surficial Aquifer is variable and includes local areas of fresh and salty groundwater. Fresh groundwater occurs beneath the mainland near Manns Harbor, beneath interior portions of Roanoke Island, and beneath the barrier island chain. Saltwater areas of the Surficial Aquifer on The Island occur beneath and adjacent to the Croatan, Albemarle, and Roanoke Sounds.

The Upper Principal Aquifer is a thin (20 to 40 foot thick) marine sand unit that occurs from about 95 to 130 feet below sea level beneath Roanoke Island. The unit is overlain by a discontinuous clay confining layer that separates it from the Surficial Aquifer. The water quality appears to be fresh beneath most of Roanoke Island, but it is vulnerable to saltwater intrusion from the overlying Surficial Aquifer in areas where the confining layer is thin or absent. The Upper Principal Aquifer has been important to private well owners at Roanoke Island, especially near Wanchese. A few Skyco wells (e.g., Well #9 and Well #12) included screens that were open to both the Upper Principal and Lower Principal Aquifers. These two wells experienced the most variable water quality, and the wells have been abandoned due to the increases in chloride content.

The Lower Principal Aquifer is a shelly coarse sand unit that averages 50 to 75 feet in thickness. The Lower Principal Aquifer is the primary source of water supply to the Skyco wellfield. The aquifer is well confined in most areas and contains fresh water beneath most of Roanoke Island. However, near Skyco Well #12, no confining layer between the Upper and Lower Principal Aquifers was evident. Saltwater intrusion, as illustrated in Figures 17 and 18, has also been recognized near Skyco Well #12. Another area of elevated chloride concentrations has been identified in the Lower Principal Aquifer in Wanchese, close to the Croatan Sound. This elevated chloride area does not appear to be a result of thinning or breaching of the confining layer, but is more likely a result of poor well construction at private residences in the area, as further discussed in Section 5.

The Yorktown Aquifer is not used beneath Roanoke Island. The aquifer top occurs from about 270 to 300 feet below sea level, and the aquifer averages about 100 feet in thickness. The Yorktown Aquifer is brackish beneath Roanoke Island (Figure 17). The aquifer is overlain and underlain by thick clay confining layers. The nature and occurrence of additional water-bearing units of the Yorktown Formation are not addressed in this study due to the lack of data and the lack of use of deeper aquifer zones near Roanoke Island. The Yorktown Aquifer is an important water-supply source to Dare County's reverse osmosis plants at Nags Head and Rodanthe. As such, the Yorktown has water resource development potential beneath Roanoke Island, as long as adequate treatment is developed to support the use of this brackish aquifer.

3.3) Historical Water Level and Chloride Data

Water levels within the Principal Aquifer have been consistently monitored at Roanoke Island since 1972. Figure 19 presents the water level record from July 1972 through January 2008 for the NCDENR Skyco Road monitoring well. This figure illustrates that water levels in the Principal Aquifer occurred at about 4 feet above sea level until the summer of 1980. From 1980 until about 2003, water levels in the aquifer declined to an average of about 8 feet below sea level in response to initiation and operation of the Skyco wellfield. Water levels varied seasonally by about 20 feet in response to changes in withdrawal rates from the Skyco wellfield. Water levels during higher pumping periods of the summer months occurred at about 18 feet below sea level. Since about 2003, water levels in the Lower Principal Aquifer have rebounded slightly, and water levels during summer months have been about 14 to 16 feet below sea level.

Dare County Water currently monitors water levels and chloride concentrations at NCDENR monitoring wells on Roanoke Island on a monthly basis. The water level data document seasonal variability related to pumping from the Skyco wellfield. Water levels within the Principal Aquifer at the Manteo Airport vary about 5 feet between the summer and winter seasons. Greater water-level variability is evident closer to the Skyco wellfield, where water levels vary seasonally by about 20 feet. Water levels in the Principal Aquifer were generally declining at a rate of about 0.4 feet/year until 2003. Since 2003, water levels have remained relatively stable or have been rising slightly. Appendix A includes water level records for the NCDENR monitoring wells since 1993.

Chloride concentrations (Figure 23) at NCDENR monitoring wells open to the Principal Aquifer have remained fresh since 1993, with exception of the Eason Hickman Road well (Well #J3Y). Well J3Y5 (open to the Lower Principal Aquifer) contained relatively fresh groundwater until March of 1995, at which point the chloride concentrations jumped to more than 4000 mg/L. Dare County discontinued monitoring of the well in June of 1997 because chloride concentrations remained high. The source of increased chloride at the Eason Hickman Road well site is not understood. Because elevated chloride concentrations were also identified in the very shallow portion (10 to 15 feet depth) of the Surficial Aquifer, GMA suspects that deeper portions of the Surficial aquifer at the Eason Hickman Road site are salty. GMA believes that saltwater likely migrated downward from the Surficial into the Principal Aquifer at the Eason Hickman Road site. This migration could have resulted from leakance across the confining layer for the Principal Aquifers, or from a poorly sealed casing at well J3Y5. Well J3Y5 (and other monitoring wells at this location) should be investigated by the NCDWR to determine if the well casing seal has failed. If well J3Y5 is poorly sealed, GMA recommends that the well be permanently abandoned to prevent continued migration of saltwater into the Principal Aquifers.

3.4) Historical Aquifer Test Data Analysis

GMA evaluated original well aquifer test data from the Skyco wellfield. Most wells had records of 24-hour constant rate pumping tests performed at the time that the wells were installed. GMA evaluated each of these well tests using the Cooper-Jacob (1946) method of pumping test data analysis. From these analyses, GMA calculated estimates of the transmissivity of the Lower Principal Aquifer. Appendix B includes the aquifer test data analytical plots, and Table 3 includes the transmissivity estimates derived from the data analyses.

Table 3. Aquifer Test Analytical Results from Original Skyco Well Pumping Tests.

Well #	Screen Depth	Aquifer	Rate (gpm)	T (ft^2/day)	Q/s (gpm/ft)
Skyco #1	132-236	UPA LPA	650	10400	13.03
Skyco #2	167-217	LPA	600	6900	16.17
Skyco #4	170-220	LPA	503	NA	8.97
Skyco #5	168-218	LPA	503	7800	10.4
Skyco #6	150-220	LPA	600	12500	13.04
Skyco #7	165-215	LPA	703	NA	10.66
Skyco #8	162-250	LPA	503	9050	6.19
Skyco #9	120-190	UPA LPA	955	12700	20.76
Skyco #10	141-192	LPA	554	9500	7.99
Skyco #11	187-223	LPA	NA	NA	NA
Skyco #12	140-190	UPA LPA	900	11250	19.15
Skyco #13	180-225	LPA	NA	NA	NA
Skyco #14	150-200	LPA	495	9000	10.94

Depths are in feet below land surface
UPA = Upper Principal Aquifer
LPA = Lower Principal Aquifer
NA = Not Applicable
T = Transmissivity
Q/s = Specific Capacity (at 24-hours of pumping)

4.0) <u>Field Evaluations</u>

After compiling and interpreting historical data, GMA proceeded with direct field evaluations of the Skyco wellfield. These evaluations included short-duration well performance tests at each existing Skyco production well, and an extensive 24-hour constant rate aquifer test at Skyco #11.

4.1) Individual Well Performance Tests

A GMA geologist visited each active water-supply well serving the Skyco plant and performed short-duration pumping tests to evaluate current well yields. Prior to each well test, Dare County ceased pumping from the well to allow it to recover to a near static water level condition. GMA worked with Dare County to pump individual wells at a constant rate for approximately 1 hour duration. During each well test, GMA monitored the pumping rate and water levels in the pumped well to determine the specific capacity of each well. Specific capacity is an expression of the yield of a well relative to the amount of drawdown that occurs at a specified time at a specific pumping rate. Specific capacity is commonly expressed in gallons per minute per foot of drawdown. Table 4 presents the results of the 1-hour specific capacity for each well tested. Appendix C includes the well test data.

Table 4. One-hour Specific Capacity of Skyco Wells

Well #	Original 1-hour Specific Capacity (gpm/ft)	Observed 1-hour Specific Capacity (gpm/ft) (2007-08)	Percentage Change in Specific Capacity
Well 2	16.17 (2004)	19.55	20.1%
Well 4	9.57 (1978)	8.8	-8.0%
Well 5	11.91 (1977)	8.77	-26.4%
Well 6	13.12 (2004)	17.48	33.2%
Well 7	10.65 (1978)	5.21	-51.1%
Well 8	8.86 (1978)	8.26	-6.7%
Well 9	21.88 (1974)	Abandoned	
Well 10	9 (1978)	6.25	-30.6%
Well 11	20.15 (1983)	5.69	-71.8%
Well 12	20.51 (1978)	Abandoned	
Well 13	12.95 (1983)	NA	
Well 14	11.49 (2007)	NA	

Specific capacity of a well is a function of the pumping rate, the duration of pumping, the aquifer transmissivity, the aquifer storativity, and the head loss in the pumped well resulting from inefficient flow through the well screen (also called well loss). Because aquifer properties (transmissivity and storativity) are constants, comparison of original specific capacity (when a well was new) with current specific capacity can reveal changes in well efficiency.

GMA compared the 1-hour specific capacity for each well with the observed 1-hour specific capacity from the individual tests performed to determine if changes in efficiency have occurred. Efficiency of a well can decrease over time due to plugging of the well's gravel pack and/or screen. As shown in Table 4, Skyco wells #5, #7, #10, and #11 have experienced significant decreases in significant capacity. These declines in specific capacity limit the volume of water that can be withdrawn from the well and cause Dare County to use more electricity to pump water from the wells than when the wells were new. Rehabilitation of the wells could increase the efficiency of the wells, thereby improving the yields of the wells and reducing the expense of continuing to operate the well pumps.

4.2) Groundwater Elevation Data

GMA integrated water level data from the Skyco wellfield with data from NCDWR monitoring wells to determine the non-pumping water levels in the Lower Principal Aquifer. Figure 20 depicts a contour map of non-pumping water level conditions from Fall/Winter of 2007. A relatively shallow cone of depression is evident in the aquifer, with groundwater elevations ranging from about two to eleven feet below sea level. The cone of depression is centered on the Skyco wells.

The thinning/absence of the confining layer above the Lower Principal Aquifer near Skyco OW12, and extending toward Shallowbag Bay, appears to have an associated area of locally higher head in the Lower Principal Aquifer. This shallower groundwater elevation, coupled with evidence of locally increased chloride concentrations in the aquifer, suggest that the Lower Principal Aquifer is open to direct recharge from the Surficial Aquifer in the vicinity of Shallowbag Bay.

4.3) Constant Rate Aquifer Test at Skyco #11

GMA worked with Dare County to develop a plan of aquifer testing to provide a direct measure of the hydraulic properties of the Principal Aquifer serving the Skyco wellfield. This plan involved conducting a 24-hour constant rate pumping test at Skyco #11. Testing was performed in January of 2008 when water system demands were low, and Dare County was able to turn off the northern wells within the wellfield to minimize local drawdown from well interference. The constant rate aquifer test involved the following procedures:

- Shut down Skyco Wells #6, #8, #10, #11, and #13 for several days prior to pumping from Well #11 to allow water levels to recover to a near-static condition.
- Deploy a pressure transducer/data logger in Well #11 to record non-pumping water levels for approximately two weeks preceding the pumping test.
- Deploy pressure transducers/data loggers in observation wells at Skyco OW#6 and Skyco OW#12 to provide automatic water level measurements at these sites during the pumping test.
- On January 16, 2008, Skyco Well #11 was pumped at a constant rate of 482 gallons per minute and continued for a duration of 24 hours.
- Throughout the period of pumping from Skyco Well #11, GMA monitored the pumping rate and gathered water level data from seven wells. At the end of pumping for 24 hours, GMA monitored recovering water levels for a period of two hours.

GMA performed evaluations of the aquifer test data using a variety of standard methods of aquifer test data analyses. These methods included:

- The Theis (1935) and Cooper-Jacob (1946) methods for fully confined aquifers,

- The Hantush-Jacob (1955) method for leaky confined aquifers with no storage in the aquitard, and
- The Neuman-Witherspoon (1969) method for a confined two-aquifer system with leakance between the two aquifers.

Appendix D includes aquifer test data sheets and data analytical plots. Table 5 presents a summary of the aquifer test analysis results. Figure 21 illustrates the drawdown recognized at the end of the 24-hour pumping test. The drawdown area is not a perfect circle, and is slightly elongated in a north-south orientation. The slight elongation of the drawdown cone is likely a function of variations in aquifer transmissivity and degree of leakance of the Principal Aquifer.

Data from most well sites conform closely to the Theis and Cooper-Jacob solutions, indicating fully confined conditions near these wells. There is some evidence of leaky aquifer conditions (for example PW6), so we also evaluated the aquifer test data using leaky confined aquifer solutions. Data from the vicinity of OW11 most closely matches the Neuman-Witherspoon Method for a two aquifer system with a leaky confining layer. This is probably the result of partial penetration of the pumping well (PW11) and observation well (OW11) coupled with the fact that OW11 is only 49 feet away from the pumped well and is probably affected by vertical flow toward the pumped well. Based upon the extensive aquifer testing performed at PW11, we conclude that the average transmissivity of the Lower Principal Aquifer near Skyco Well #11 is 15,000 ft^2/day, and the average storage coefficient is 0.0005.

GMA developed a contour map of transmissivity of the Principal Aquifer to provide a spatial analysis of aquifer properties beneath The Island (Figure 22). The map integrates the results of the 24-hour pumping test at Skyco Well #11 along with data from original well tests on Skyco production wells. Transmissivity of the aquifer varies from 6,900 to 17,000 ft^2/day. The variability of transmissivity of the Principal Aquifer beneath The Island is a function of changes in permeability of the sediments, changes in thickness of the aquifer, and the degree of confinement between the Upper and Lower Principal Aquifers. The northern portion of the Skyco wellfield (near Skyco Wells #6, 10, 11, 12, and 14) exhibit the higher transmissivity. This area also appears to be the region where the confining layer between the Upper and Lower Principal Aquifers is thin or absent.

Table 5. Summary of Aquifer Test Analytical Results for 24-hour Pumping Test at Skyco Well #11

Well Number	Theis Method	Cooper-Jacob Method	Hantush-Jacob Method	Neuman-Witherspoon Method
Skyco #6	T = 15,280 ft^2/day S = 0.00058	T = 25,300 ft^2/day S = 0.0004 (Poor match due to leakance or well interference?)	T = 13,550 ft^2/day S = 0.00055 r/B = 0.598	NA
Skyco #10	T = 14,830 ft^2/day S = 0.00088	T = 14,860 ft2/day S = 0.00084	NA	NA
Skyco #11 (OW)	NA Poor curve match due to partial penetration and leakance?	Early Data: T_1 = 7400 ft^2/day S_1 = 0.00016 Later Data: T_2 = 15,220 ft^2/day S_2 = 0.000003	NA	T = 3015 ft^2/day S = 0.0006 r/B = 0.5 T' = 12,600 ft^2/day S' = 0.002
Skyco #12 (OW)	T = 15,120 ft^2/day S = 0.00036	T = 15,300 ft^2/day S = 0.00033	T = 13,730 ft^2/day S = 0.0004	NA
Skyco #14 (OW)	T = 15,880 ft^2/day S = 0.0005	T = 17,000 ft^2/day S = 0.0004	T = 16,370 ft^2/day S = 0.0005	NA

NA = Method Not Applied

5.0) <u>Conclusions</u>

GMA has completed a hydrogeologic framework study of Roanoke Island. The Skyco wellfield is an important source of water to Dare County that should provide sustainable fresh groundwater for the foreseeable future. However, development and use of a fresh water aquifer in a coastal environment presents significant challenges. Diligent management of the wellfield and an aggressive wellhead protection program are important for the successful continued use of the aquifer.

GMA's analysis of the groundwater conditions beneath The Island has provided new understanding of the groundwater system, and the mechanisms for saltwater intrusion into some wells. Fundamental conclusions of this study are summarized below.

Geologic Framework

- GMA mapped the depths and thicknesses of four aquifers that occur beneath the Island, including the Surficial, Upper Principal, Lower Principal, and Yorktown Aquifers. Each of these aquifers are used in Dare County as sources of water supply. The aquifers vary in hydraulic properties, hydraulic head, degree of confinement, and water quality characteristics.
- The Surficial Aquifer is an unconfined sequence of predominantly marine sediments that extends from the land surface to an average depth of about 80 feet below land surface. The sediments have an extremely complex stratigraphy representing numerous cut-and-fill structures associated. A series of large-scale paleo-channels associated with the ancestral Roanoke-Albemarle River occurs to the north of The Island. The aquifer is used locally at Roanoke Island by private residences. The Surficial Aquifer is open to direct recharge on The Island, and it is very vulnerable to saltwater intrusion. In areas adjacent to the sounds, the Surficial Aquifer commonly contains saltwater. The Surficial Aquifer also may contain saltwater beneath tidal marshes and in areas where finger canals have been cut into the interior of The Island. Due to these factors, the Surficial Aquifer is not considered to be a reliable source of fresh water. One exception may be the northern end of The Island where the Surficial Aquifer underlies a relict dune ridge, although this area was not assessed in detail during GMA's study.
- The source aquifer for the Skyco wellfield is a Pleistocene-aged sequence of marine sediments that contains fresh groundwater. This aquifer is assigned the name "Principal Aquifer" to avoid confusion with the regionally mapped Yorktown Aquifer, which is Pliocene aged. The Principal Aquifer is fully confined beneath most of The Island. However, GMA has identified one area, south of Shallowbag Bay, where the confining layer is very thin or absent, and the Principal Aquifer is open to direct recharge from the overlying Surficial Aquifer, which is salty in the area. The Principal Aquifer includes an Upper and Lower unit separated by a laterally discontinuous confining layer. The Principal Aquifer generally occurs from about 120 down to about 225 feet depth beneath The Island.
- Underlying the Principal Aquifer is the Yorktown Confining Layer, a thick clay (average of 60 feet) that is laterally continuous. Analysis of available data suggests that the

Yorktown Confining Layer effectively restricts the vertical movement of water between the Principal Aquifer and the Yorktown Aquifer.

- The Yorktown Aquifer is a Pliocene-aged sequence of marine sediments, including sand, gravel, shell, and local limestone facies. The Yorktown is an important aquifer to Dare County because it is the source of water for the reverse osmosis Water Treatment Plants on the Outer Banks. The Yorktown is not utilized beneath Roanoke Island because the aquifer is slightly brackish and would require more extensive treatment than water from the Principal Aquifer.

Hydrologic Characteristics

- Recharge to the Principal Aquifer occurs predominantly in up-dip areas of the mainland to the west of The Island.
- The transmissivity of the Principal Aquifer averages about 15,000 ft^2/day, and individual well yields exceeding 500 gallons per minute are supported by the aquifer.
- Most Skyco wells are exclusively screened into the Lower Principal Aquifer.
- The few Skyco Wells that include screens within the Upper Principal Aquifer are more vulnerable to saltwater intrusion, and some older wells built in this manner had to be abandoned and replaced due to increases in chloride concentrations. Figure 23 illustrates areas of saltwater intrusion recognized in the Lower Principal Aquifer.
- Existing Skyco wells that occur more than 2500 feet from the sounds appear to be less vulnerable to saltwater intrusion than wells less than 2500 feet from the sounds. We believe that this is because the Surficial Aquifer is less likely to be salty at distances of more than 2500 feet from the sounds. However, there are areas, such as Well #12, where saltwater in the Surficial Aquifer has been recognized more than 2500 feet from the sounds. This area warrants further evaluation to determine the nature and extent of saltwater intrusion into the Surficial and Principal Aquifers.
- Withdrawals from the Skyco wellfield have caused an elongate narrow cone of depression in the Principal Aquifer.
- Water levels in the Principal Aquifer have declined on average by about 12 feet since the Skyco wellfield was constructed, but since 2003 the water levels have stabilized, or are slightly rising. Water levels in close proximity to the Skyco wells fluctuate seasonally by about 20 feet in response to seasonal changes in well use.
- The depressurization of the Principal Aquifer by the Skyco wellfield has induced a downward head gradient between the Surficial Aquifer and the Principal Aquifer.
- Declines in water levels within the Principal Aquifer near Wanchese affected the yield of private wells in the area, prompting Dare County to develop a program of private well replacements.
- In recent years, private wells in the southwestern portion of Wanchese have experienced saltwater intrusion (Figure 23). The mechanism for saltwater intrusion into the Lower Principal Aquifer at Wanchese appears to be vertical downward migration of water in boreholes of private residential wells with incomplete grout seals, as illustrated in Figure 24. Many private wells have only minimal grout (to a depth of about 20 feet), and the Surficial Aquifer in this area is salty. These older, poorly-grouted wells allow saltwater from the Surficial Aquifer to drain down the borehole into the Principal Aquifer, thereby causing the well to become salty. Dare County has modified the procedures for private

well replacements to include installing Lower Principal Aquifer wells with casings that are fully grouted into the top of the Lower Principal Aquifer to a depth of about 150 feet below land surface. These procedures have been very effective at providing more reliable fresh water to local private residences in Wanchese.

Water Resource Development

- Current withdrawals from the Skyco wellfield appear to be sustainable. Water levels within the Principal Aquifer remain stable with consistent seasonal variability over the past five years.
- The most significant risk to continued withdrawals at the Skyco wellfield is saltwater intrusion at Wanchese associated with insufficient grout around private wells. In addition, improperly abandoned private wells likely occur, and these wells serve as conduits for the intrusion of saltwater from the Surficial Aquifer down into the Principal Aquifer.
- The continued use of private wells limits the potential for expansion of withdrawals from the Principal Aquifer by Dare County in the southern portion of The Island.
- The Principal Aquifer has significant resource potential beneath the northern end of The Island. A prior test well constructed at the Roanoke Island Fire Department (RITW1) demonstrated that the Principal Aquifer beneath Manteo is fully confined, has significant yield potential, and contains fresh water.
- GMA conservatively estimates that the Principal Aquifer beneath the northern portion of Roanoke Island could support an additional 3.25 MGD withdrawal. This estimate assumes that nine new wells would be installed with a minimum well spacing of 3000 feet and a design flow rate of 500 gpm per well. This estimate also assumes that individual wells would be pumped not more than 12 hours per day. Further exploration and testing on the northern portion of Roanoke Island is needed to refine the estimate of additional available supply from the Principal Aquifer. Combining this conceptual northern wellfield with the existing 4.3 MGD supply from the Skyco wellfield would provide a combined total supply of 7.55 MGD from the Principal Aquifer at Roanoke Island.
- The Yorktown Aquifer is unutilized beneath Roanoke Island. The aquifer has significant water resource potential, but the use of the Yorktown Aquifer would likely require treatment by reverse osmosis, as is done at the Northern RO Water Treatment Plant. Chloride concentrations in the Yorktown Aquifer beneath The Island are expected to be lower than occur at the Northern RO wellfield.

6.0) Recommendations

Based upon the findings of this hydrogeologic assessment of Roanoke Island, GMA makes the following recommendations:

- Expand public water service to the community of Wanchese. By connecting properties in Wanchese to the public water system, Dare County could provide consistent, safe potable water to Wanchese, and the County could eliminate the need to continue the expensive program of replacing private wells.

- If public water is provided to Wanchese, all existing private wells should be properly abandoned to eliminate the potential of saltwater intrusion into the Principal Aquifer through these wells.
- Expand the wellfield supplying the Skyco plant by exploring and constructing Lower Principal Aquifer wells on the northern portion of Roanoke Island. A viable well site has already been explored at the Roanoke Island fire department (RITW1). GMA recommends that future well sites be selected where the Surficial Aquifer is not salty, thereby reducing the potential for downward vertical migration of saltwater at new well sites. Figure 25 was developed to provide a target zone for future expansion of the wellfield. This exploration zone includes a 2500 foot buffer from shorelines and areas of known saltwater in the Surficial Aquifer.
- Future Dare County production wells should <u>not</u> include screens in the Upper Principal Aquifer. Available data suggest that the Upper Principal Aquifer is more vulnerable to saltwater intrusion than wells that are exclusively screened in the Lower Principal Aquifer.
- Avoid constructing new production wells near Shallowbag Bay where the confining layers overlying the Principal Aquifer are thinned or absent. Further study of the water quality and hydraulic properties of the aquifers near Shallowbag Bay is recommended so that Dare County can better understand the potential threat of saltwater intrusion to the Skyco wellfield from this area.
- As the wellfield is expanded, modify pumping strategies for the existing wellfield to provide cycles of pumping and rest periods that minimize the prolonged drawdown within the Principal Aquifer. The goal of wellfield cycling should be to allow for individual rest periods that equal or exceed the duration of pumping. This type of wellfield management strategy will extend the life of the wellfield and minimize the potential for saltwater intrusion.
- Explore the resource potential of the Yorktown Aquifer beneath Roanoke Island as a source of water supply. The Yorktown Aquifer represents an abundant resource for future water supply to Dare County if reverse osmosis treatment were developed at Roanoke Island.
- Provide specifications for proper well construction in the Dare County Well Ordinance. These specifications should present requirements for proper grouting of well casings to prevent interconnection of aquifers with differing water quality.
- Expand the monitoring well network to include wells in the Surficial and Principal Aquifers to monitor for chloride concentrations and water levels near Shallowbag Bay and Broad Creek. This network of monitoring wells would provide a means of monitoring changes in water levels and water quality that could indicate areas of vulnerability to saltwater intrusion.
- Carefully evaluate any future proposed "finger canals" of "borrow pits" that could be pathways for saltwater intrusion into the Surficial Aquifer in the interior of the Island. These types of canals and pits should not be permitted in close proximity to wells.
- Consider the water resource potential of the Surficial Aquifer near the relict dune ridge on the northern end of The Island. The Surficial Aquifer in this area may have untapped fresh resource potential that is protected from saltwater sources by the significant land

elevation. A series of shallow test wells could be constructed in the area to determine the viability of using the Surficial Aquifer in the area.

- Dare County should share concerns with the NCDRW about the integrity of the existing monitoring wells at the J3Y site. If these wells are determined to be poorly constructed, or if their condition has deteriorated, the wells may serve as a conduit for saltwater intrusion into the Principal Aquifer. If one or more of these monitoring wells is a conduit for saltwater intrusion, the well(s) should be abandoned.

7.0) Report Certification

This hydrogeologic evaluation report was prepared by Groundwater Management Associates, Inc., a professional corporation licensed to practice geology and engineering in North Carolina.

James K. Holley, P.G.
Senior Hydrogeologist

NORTH CAROLINA LICENSED GEOLOGIST SEAL 1060 JAMES K. HOLLEY

Dr. Richard K. Spruill, P.G.
Principal Hydrogeologist

8.0) List of References

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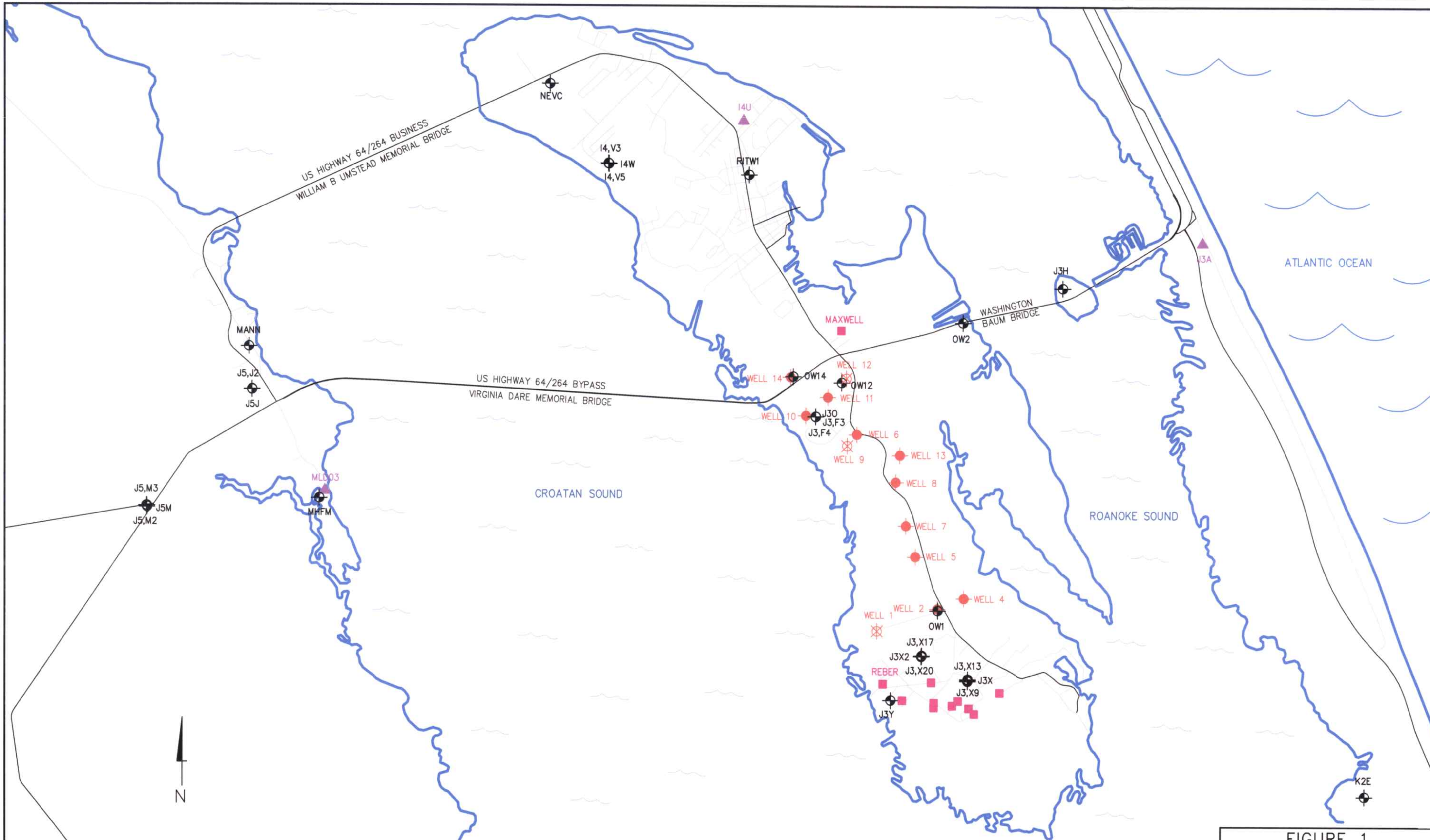


FIGURE 1

-LEGEND-

- DARE COUNTY WATER-SUPPLY WELL
- ABANDONED WATER-SUPPLY WELL
- MONITORING WELL
- BORING/COREHOLE
- RESIDENTIAL WELL
- OW=OBSERVATION WELL

MAP OF ROANOKE ISLAND SHOWING THE LOCATION OF WELLS USED FOR THE STUDY

ROANOKE ISLAND, DARE COUNTY, NC

PROJECT 103501

DATE 6/11/2008

SCALE IN FEET

0 2500' 5000'

1"=5000'

GMA

Groundwater Management Associates, Inc.

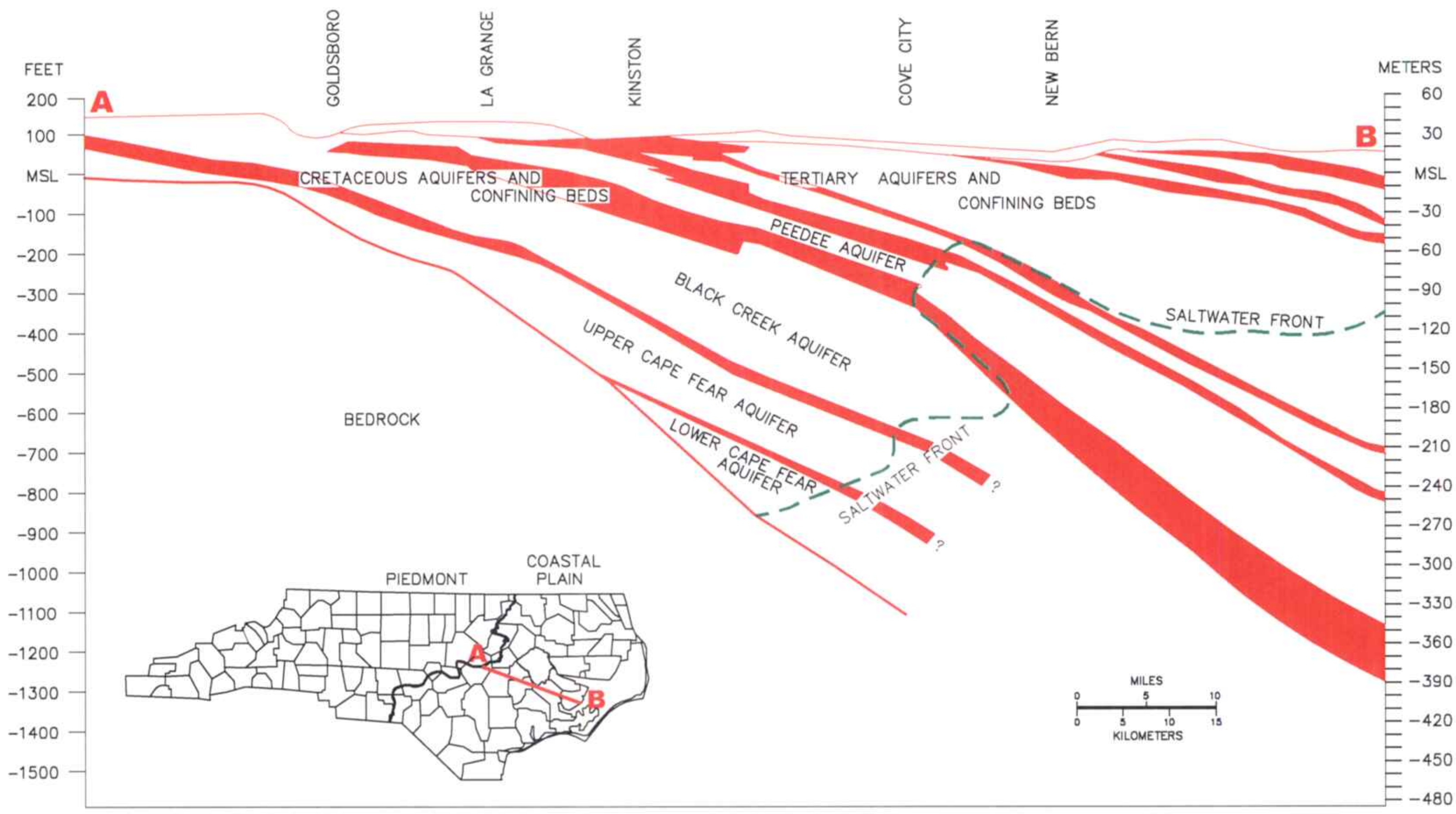
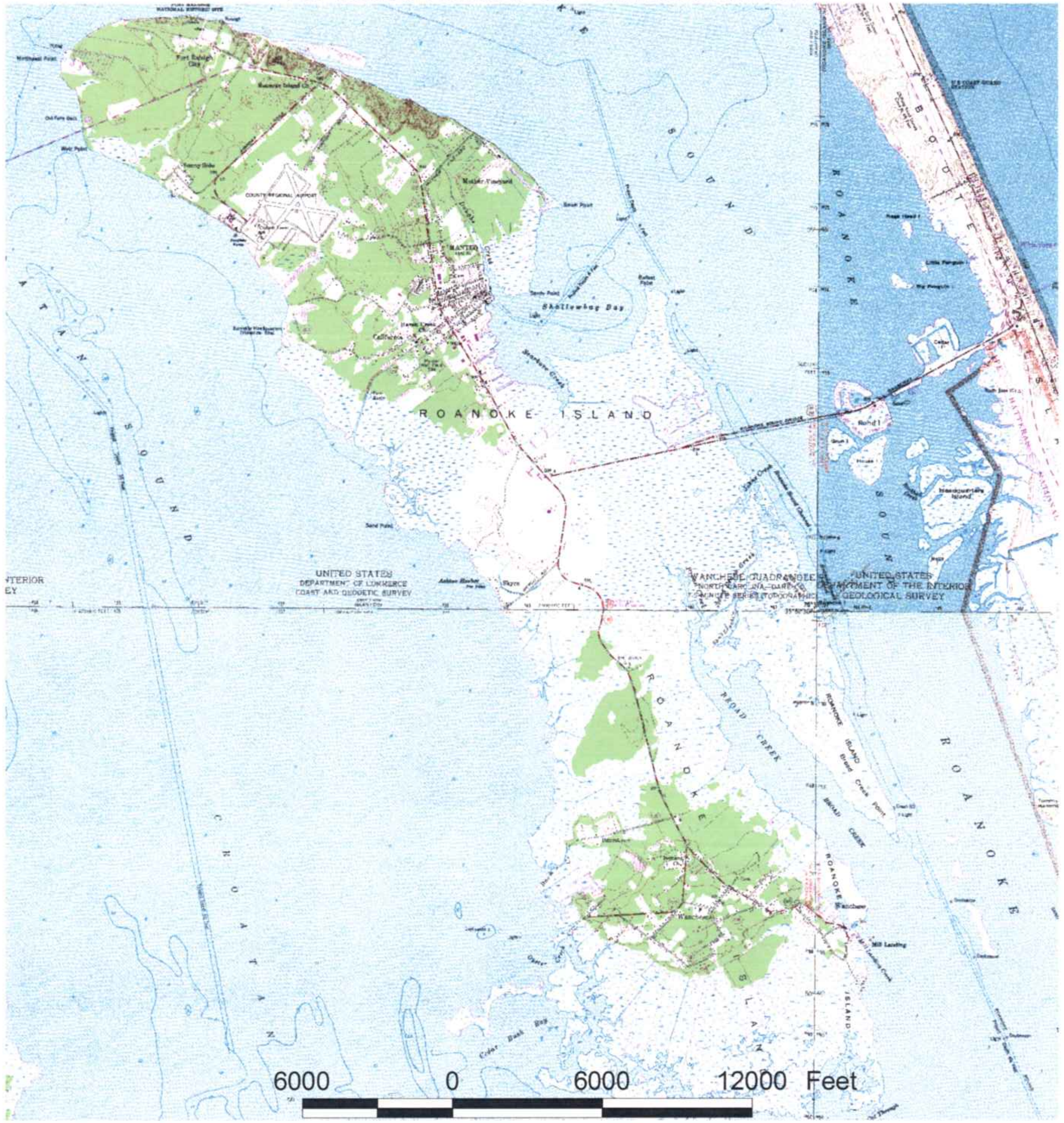


FIGURE 2. Hydrogeologic section through the central Coastal Plain showing the Cretaceous aquifers and confining beds and the position of the saltwater front. (Adopted from Winner and Coble, 1996, Plate 6)

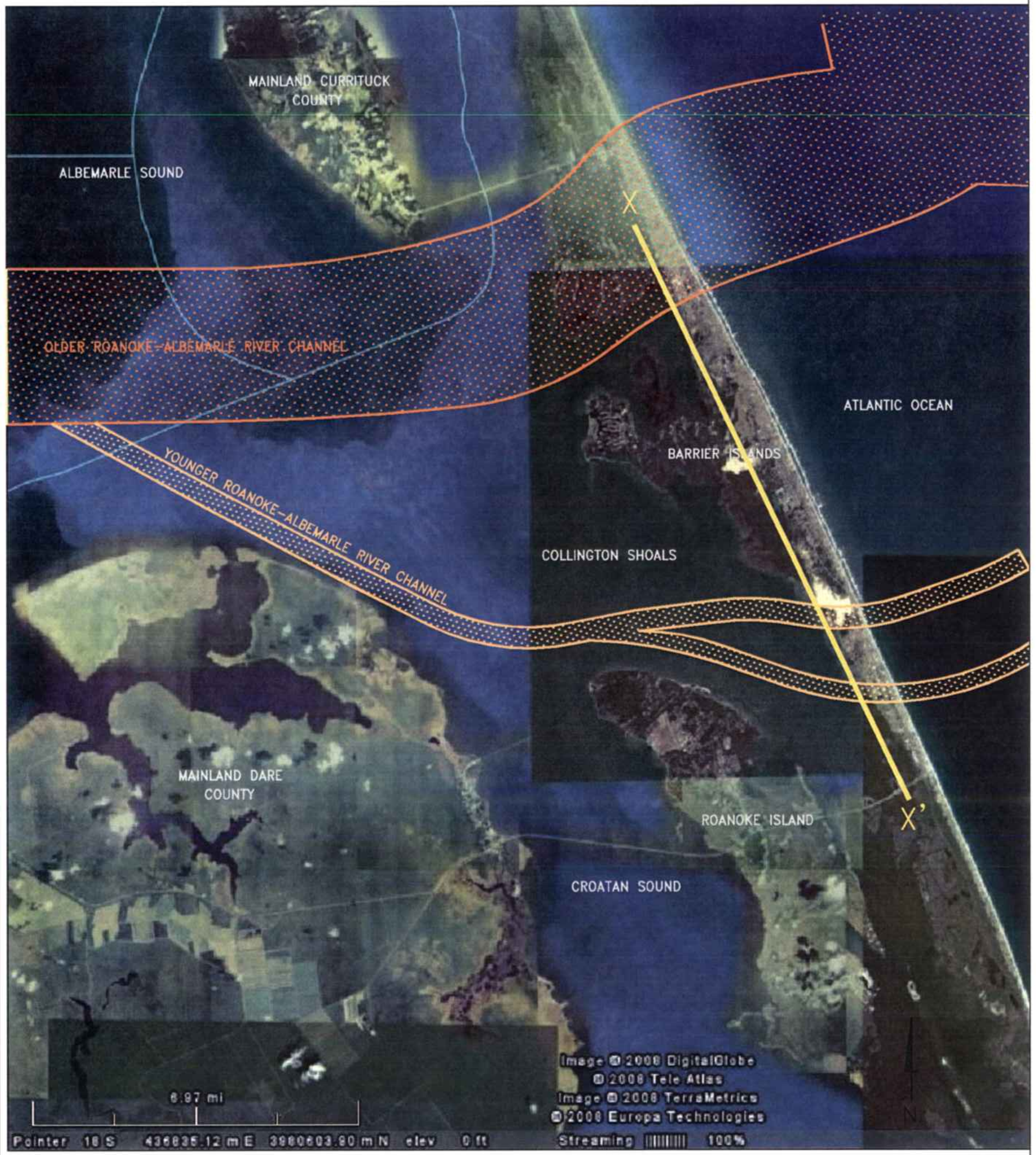
TOPOGRAPHIC MAP OF ROANOKE ISLAND



MANTEO/ROANOKE ISLAND/WANCHESE/OREGON INLET
QUADRANGLES
NORTH CAROLINA - DARE COUNTY
7.5 MINUTES SERIES (TOPOGRAPHIC)
CONTOUR INTERVAL=5 FEET
PHOTO REVISED 1983

N W E S

DARE COUNTY WATER - ROANOKE ISLAND	FIGURE 3
GMA — GROUNDWATER MANAGEMENT ASSOCIATES, INC. 4300 SAPPHIRE COURT, SUITE 100 GREENVILLE, NORTH CAROLINA 27834	5/8/2008 PROJECT 113501

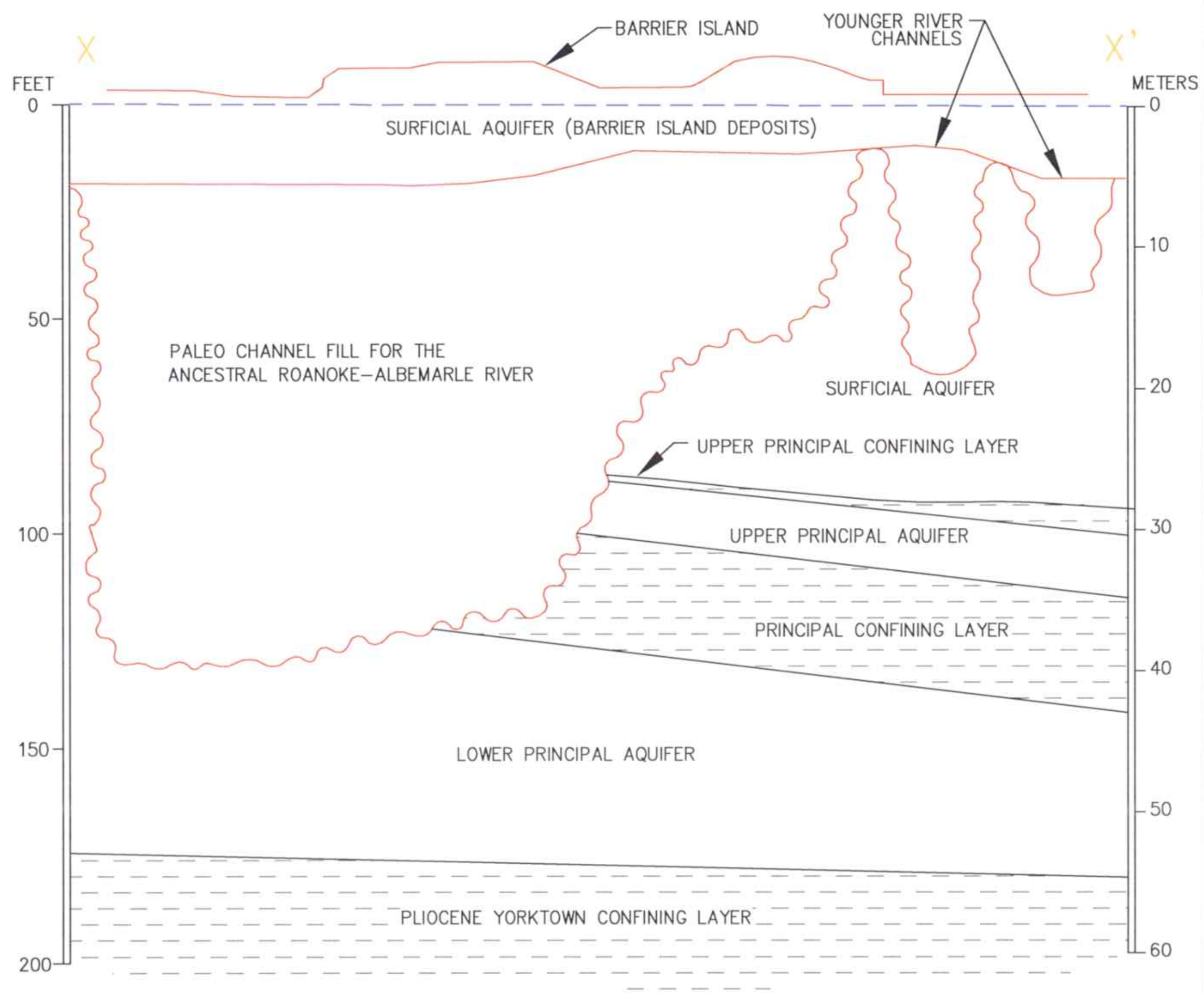


LEGEND

MODIFIED FROM MALLINSON, ETAL, 2005.
X–X' CROSS–SECTION TRACE FOR FIGURE 5

GMA
GROUNDWATER MANAGEMENT ASSOCIATES, INC.

File: DRAWINGS\103501 IMAGE	ANCESTRAL ROANOKE–ALBEMARLE RIVER CHANNELS	Date: 5/15/2008
Project No. 103501	ROANOKE ISLAND, DARE COUNTY, NC	Figure 4



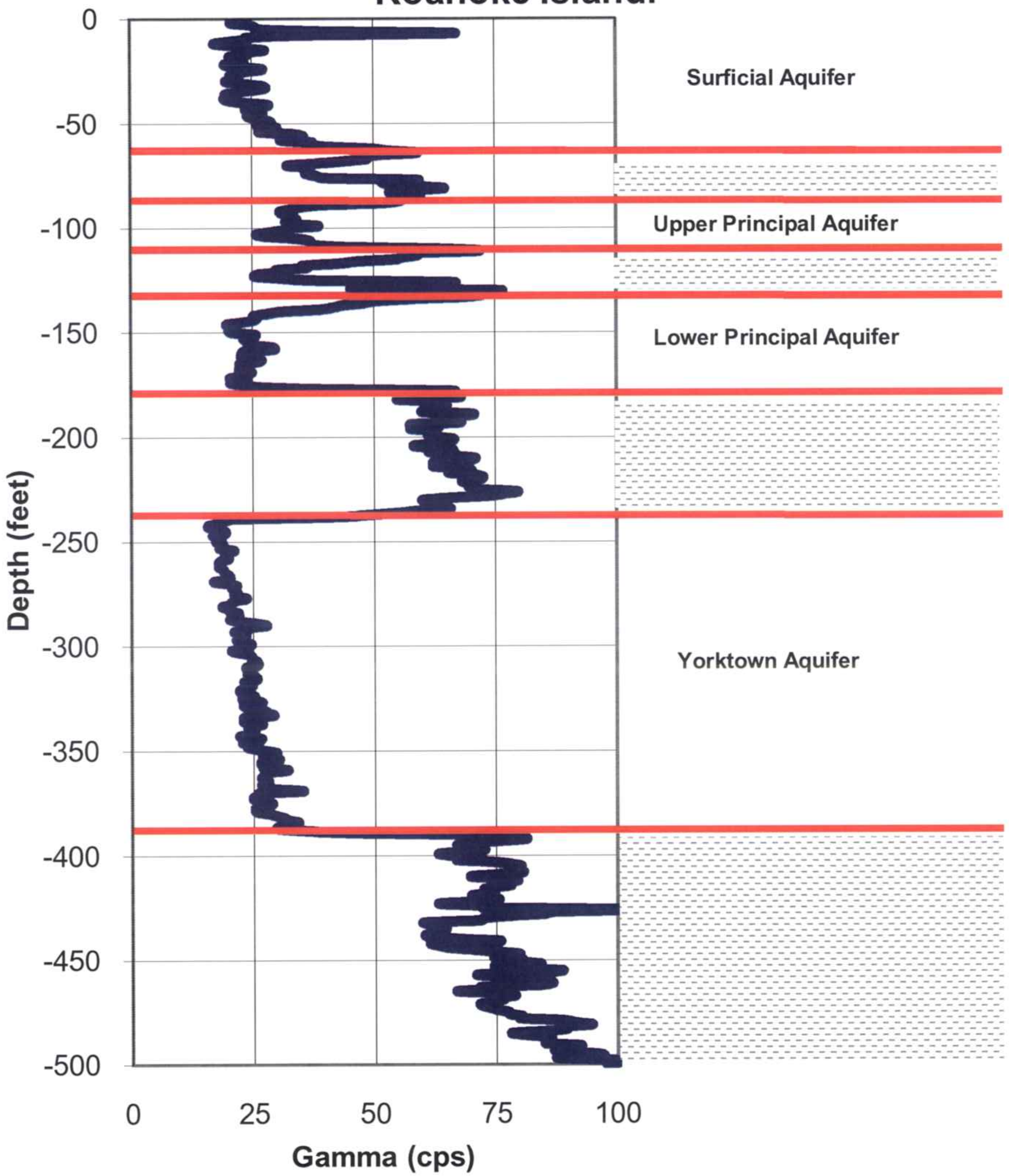
LEGEND

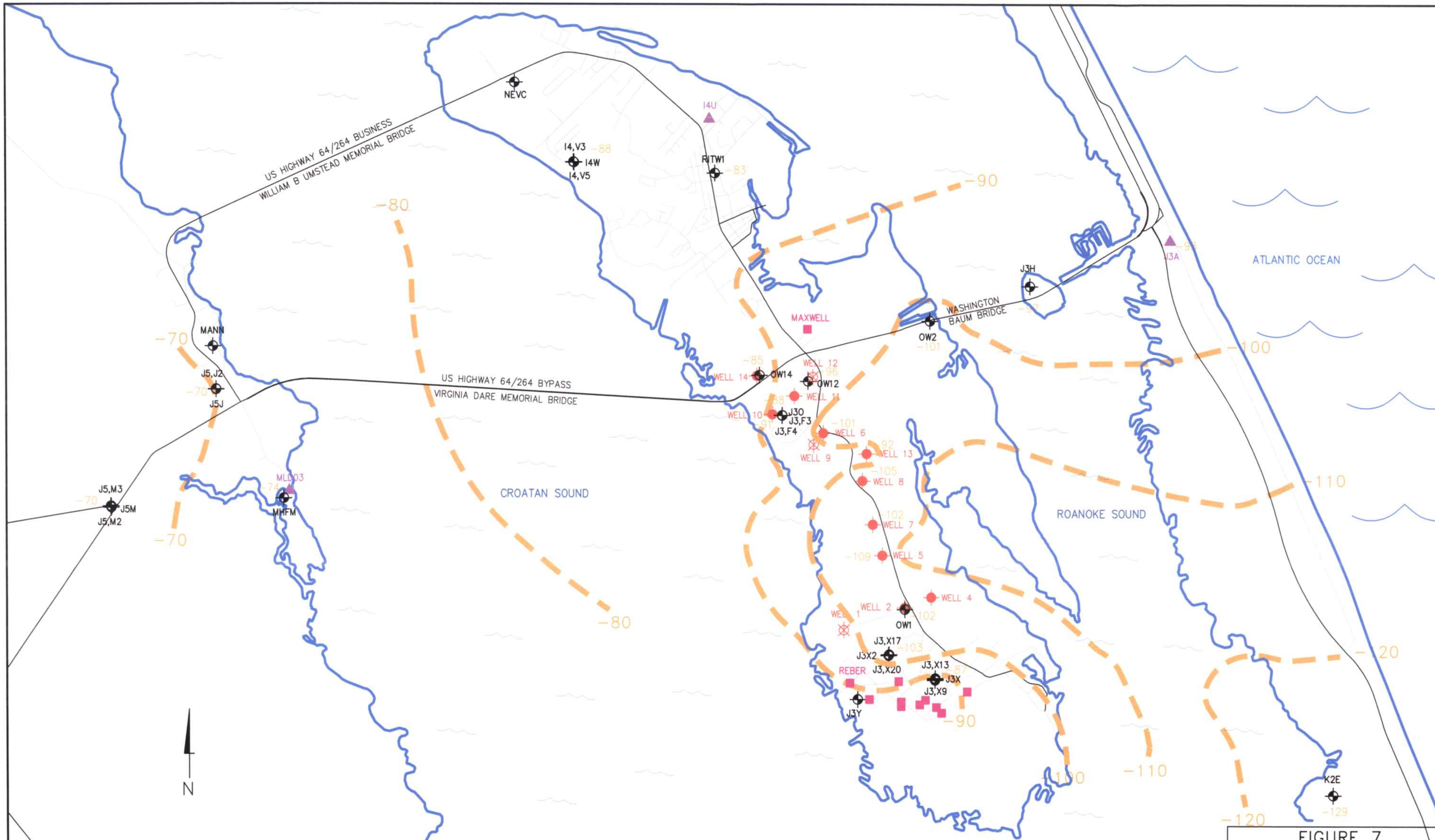
MODIFIED FROM MALLINSON, ETAL, 2005

GROUNDWATER MANAGEMENT ASSOCIATES, INC.

File: DRAWINGS\103501 SECTION	CROSS–SECTION VIEW OF THE ANCESTRAL ROANOKE–ALBEMARLE RIVER CHANNELS BENEATH KITTY HAWK AND NAGS HEAD	Date: 5/15/2008
Project No. 103501	ROANOKE ISLAND, DARE COUNTY, NC	Figure 5

Figure 6. Geophysical Log of Manns Harbor Showing Hydrostratigraphic Units Near Roanoke Island.





-LEGEND-

- DARE COUNTY WATER-SUPPLY WELL
- ABANDONED WATER-SUPPLY WELL
- MONITORING WELL
- BORING/COREHOLE
- RESIDENTIAL WELL
- OW=OBSERVATION WELL
- -102 ELEVATION IN FEET (MSL)

ELEVATION OF THE BASE OF THE SURFICIAL AQUIFER (MSL FEET)

ROANOKE ISLAND, DARE COUNTY, NC

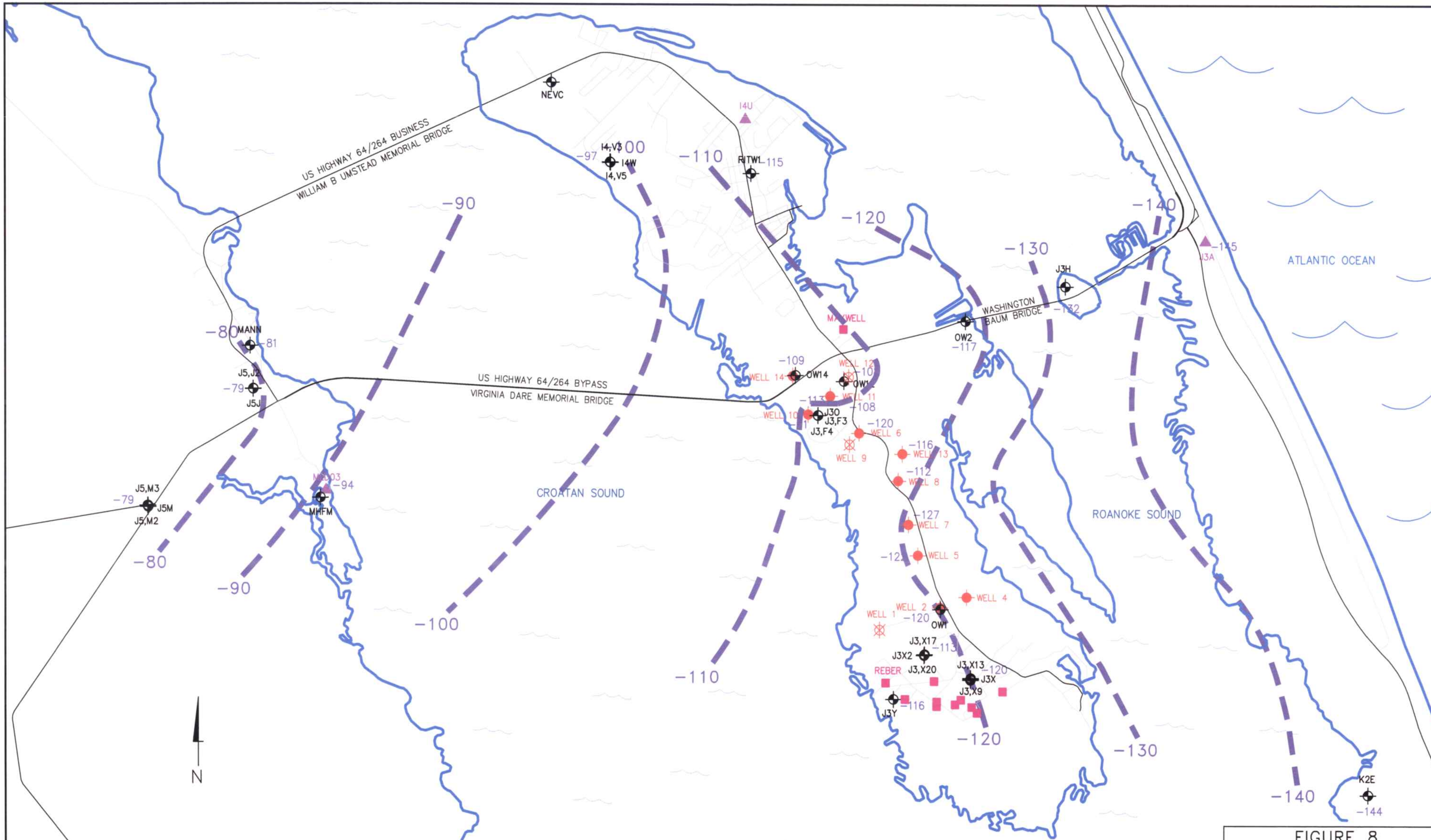
PROJECT 103501

DATE 6/11/2008

SCALE IN FEET
0 2500' 5000'
1"=5000'

FIGURE 7

GMA
Groundwater Management Associates, Inc.



-LEGEND-

- DARE COUNTY WATER-SUPPLY WELL
- ABANDONED WATER-SUPPLY WELL
- MONITORING WELL
- BORING/COREHOLE
- RESIDENTIAL WELL
- OW=OBSERVATION WELL
- -120 ELEVATION IN FEET (MSL)

ELEVATION OF THE TOP OF THE UPPER PRINCIPAL AQUIFER

ROANOKE ISLAND, DARE COUNTY, NC

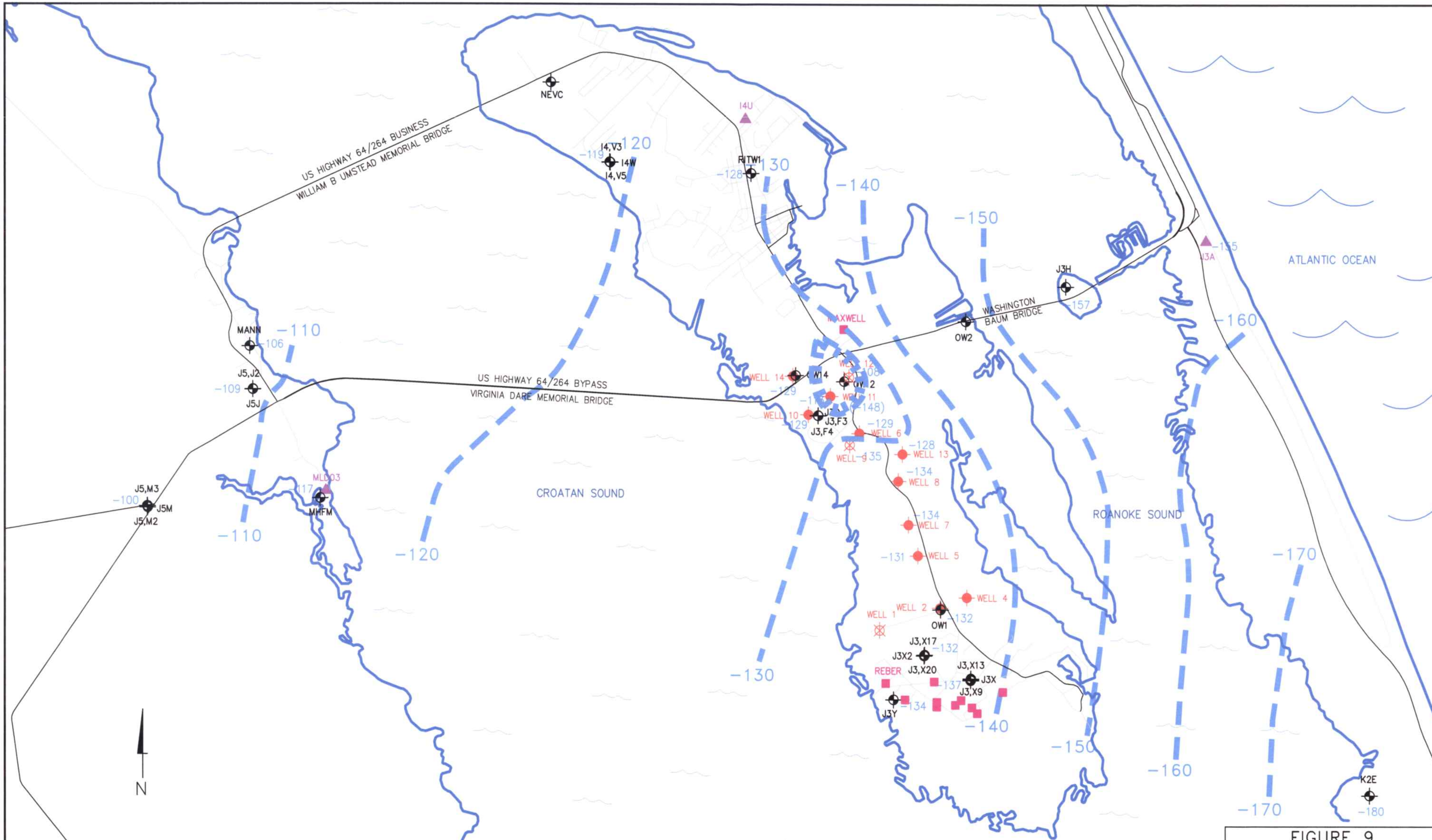
PROJECT 103501

DATE 6/11/2008

SCALE IN FEET
0 2500' 5000'
1"=5000'

FIGURE 8

GMA
Groundwater Management Associates, Inc.



-LEGEND-

- DARE COUNTY WATER-SUPPLY WELL
- ABANDONED WATER-SUPPLY WELL
- MONITORING WELL
- BORING/COREHOLE
- RESIDENTIAL WELL
- OW=OBSERVATION WELL
- -132 ELEVATION IN FEET (MSL)

ELEVATION OF THE BASE OF THE UPPER PRINCIPAL AQUIFER

ROANOKE ISLAND, DARE COUNTY, NC

PROJECT 103501

DATE 6/11/2008

SCALE IN FEET
0 2500' 5000'
1"=5000'

FIGURE 9

GMA
Groundwater Management Associates, Inc.

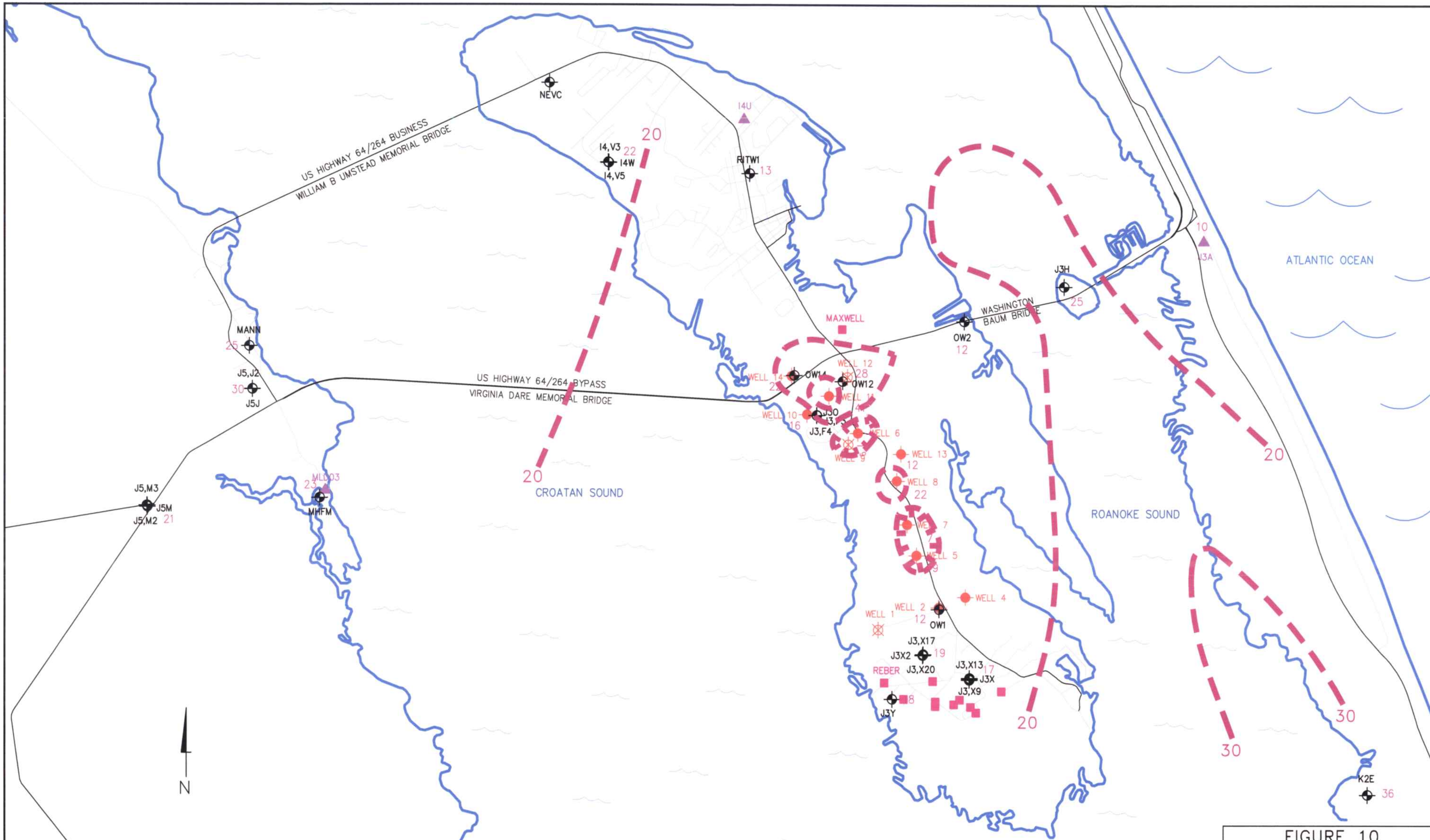


FIGURE 10

-LEGEND-

- DARE COUNTY WATER-SUPPLY WELL
- ABANDONED WATER-SUPPLY WELL
- MONITORING WELL
- BORING/COREHOLE
- RESIDENTIAL WELL
- OW=OBSERVATION WELL
- 12 THICKNESS IN FEET

THICKNESS OF THE UPPER PRINCIPAL AQUIFER

ROANOKE ISLAND, DARE COUNTY, NC

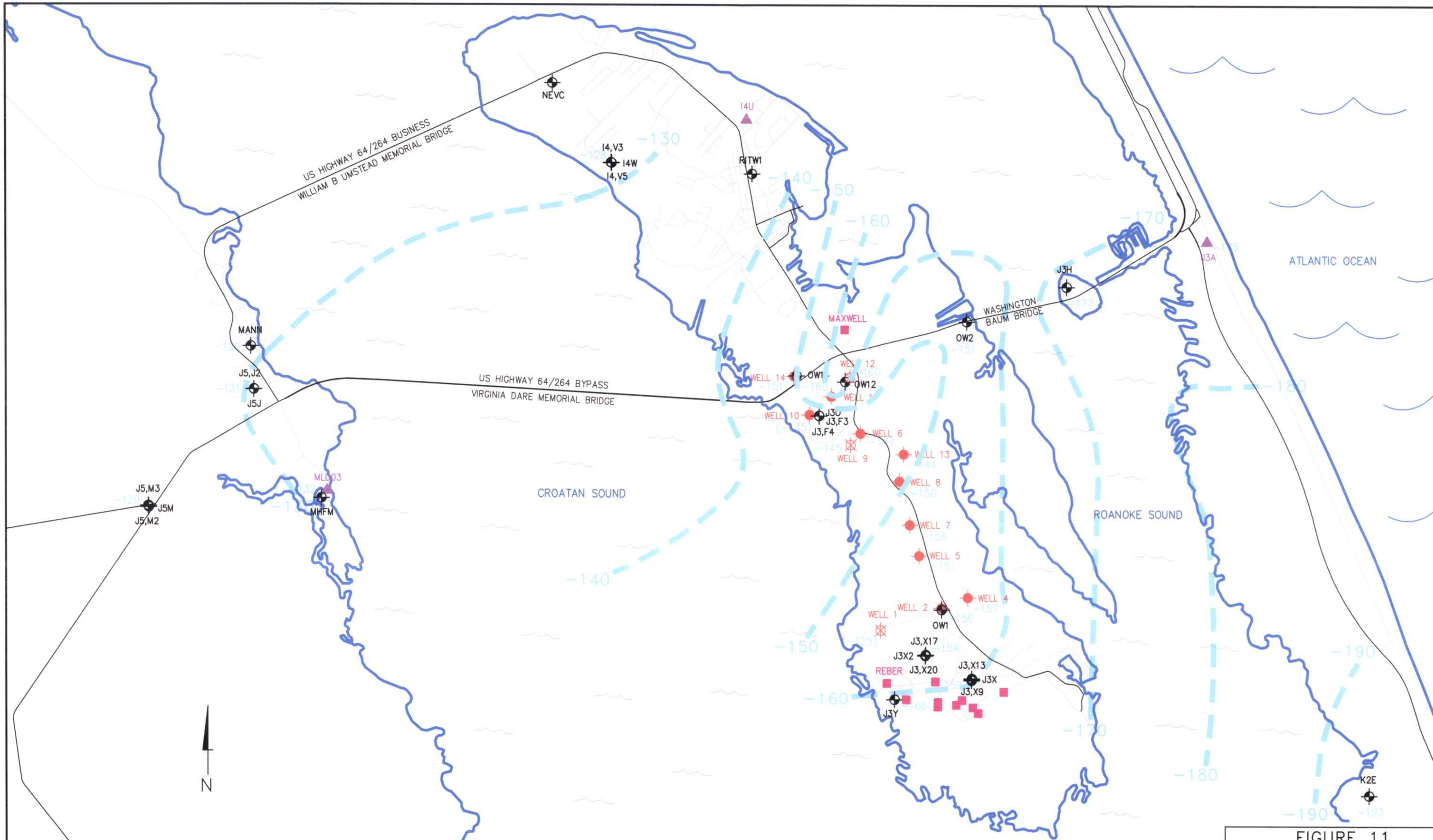
PROJECT 103501

DATE 6/11/2008

SCALE IN FEET
0 2500' 5000'
1"=5000'

GMA

Groundwater Management Associates, Inc.



-LEGEND-

DARE COUNTY WATER-SUPPLY WELL
ABANDONED WATER-SUPPLY WELL
MONITORING WELL
BORING/COREHOLE
RESIDENTIAL WELL
OW=OBSERVATION WELL
-156 ELEVATION IN FEET (MSL)

ELEVATION OF THE TOP OF THE LOWER PRINCIPAL AQUIFER

ROANOKE ISLAND, DARE COUNTY, NC

PROJECT 103501

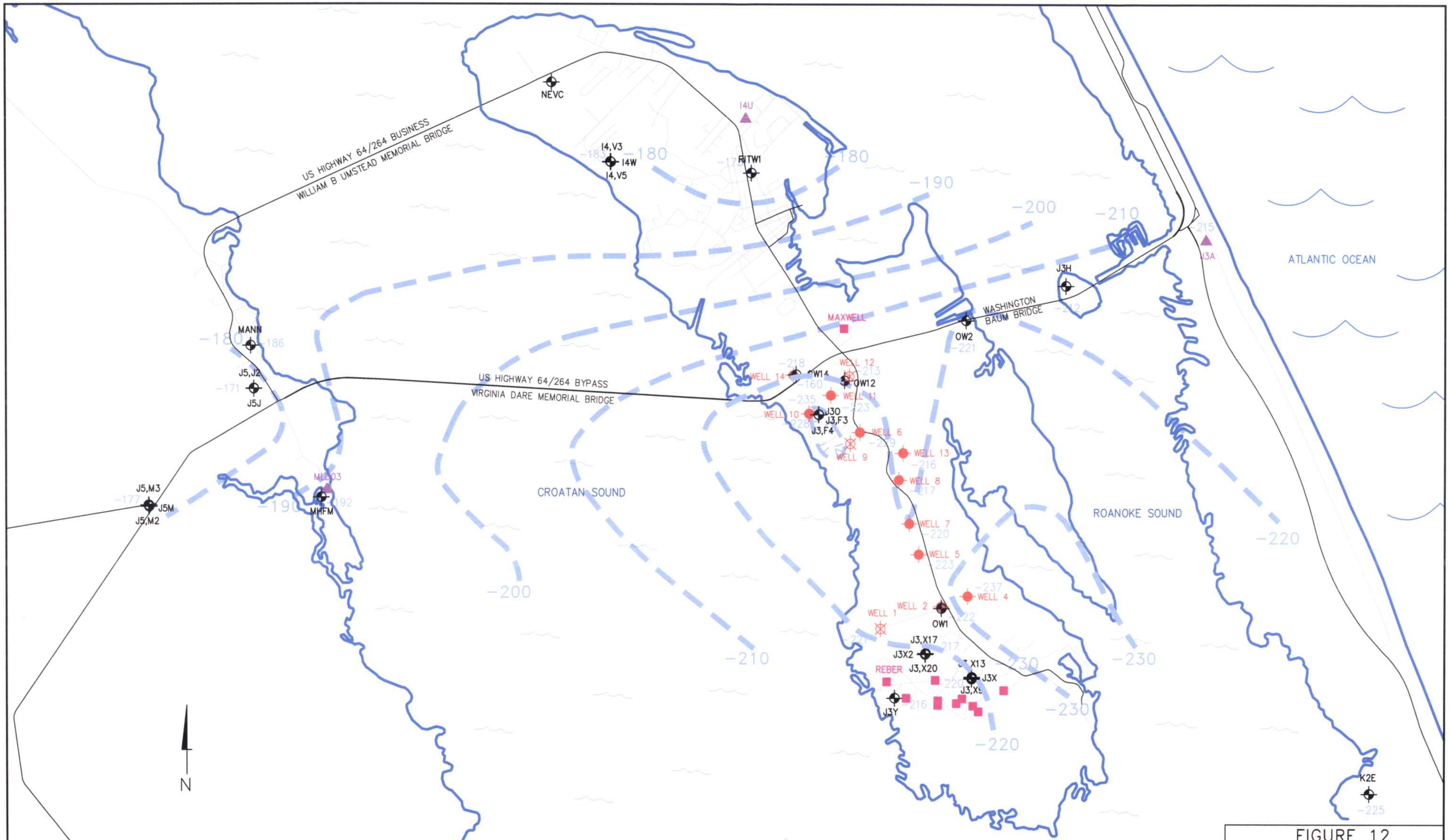
DATE 6/11/2008

SCALE IN FEET
0 2500' 5000'
1"=5000'

FIGURE 11

GMA

Groundwater Management Associates, Inc.



-LEGEND-

- DARE COUNTY WATER-SUPPLY WELL
- ABANDONED WATER-SUPPLY WELL
- MONITORING WELL
- BORING/COREHOLE
- RESIDENTIAL WELL
- OW=OBSERVATION WELL
- -222 ELEVATION IN FEET (MSL)

ELEVATION OF THE BASE OF THE LOWER PRINCIPAL AQUIFER

ROANOKE ISLAND, DARE COUNTY, NC

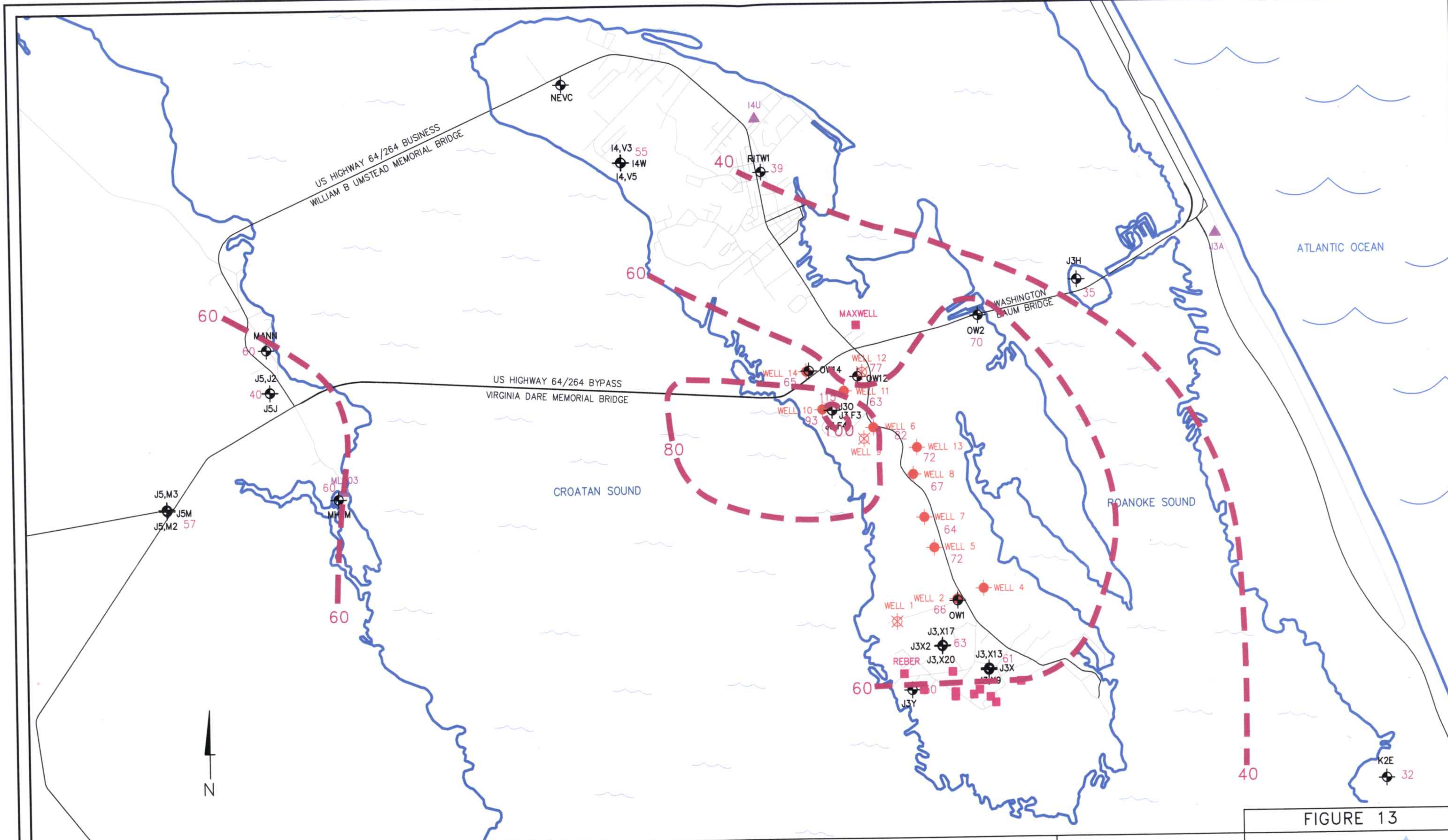
PROJECT 103501

DATE 6/11/2008

SCALE IN FEET: 0, 2500', 5000'; 1"=5000'

FIGURE 12

GMA Groundwater Management Associates, Inc.



-LEGEND-

- DARE COUNTY WATER-SUPPLY WELL
- ABANDONED WATER-SUPPLY WELL
- MONITORING WELL
- BORING/COREHOLE
- RESIDENTIAL WELL

OW=OBSERVATION WELL
66 THICKNESS IN FEET

THICKNESS OF THE LOWER PRINCIPAL AQUIFER

ROANOKE ISLAND, DARE COUNTY, NC

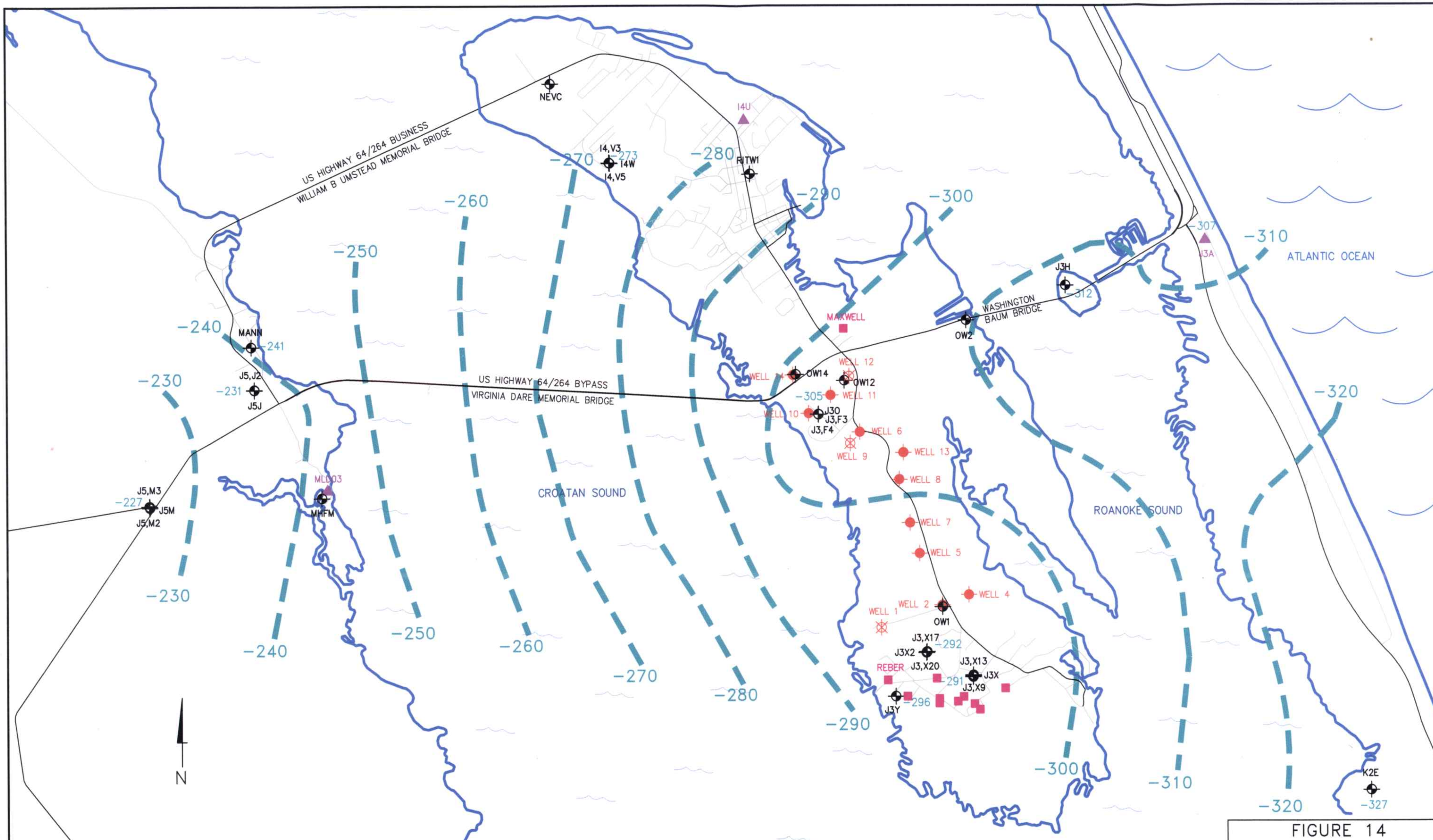
PROJECT 103501

DATE 6/11/2008

SCALE IN FEET
0 2500' 5000'
1"=5000'

FIGURE 13

GMA
Groundwater Management Associates, Inc.



-LEGEND-

- DARE COUNTY WATER-SUPPLY WELL
- ABANDONED WATER-SUPPLY WELL
- MONITORING WELL
- BORING/COREHOLE
- RESIDENTIAL WELL
- OW=OBSERVATION WELL
- -292 ELEVATION IN FEET (MSL)

ELEVATION OF THE TOP OF THE YORKTOWN AQUIFER

ROANOKE ISLAND, DARE COUNTY, NC

PROJECT 103501

DATE 6/11/2008

SCALE IN FEET
0 2500' 5000'
1"=5000'

FIGURE 14

GMA
Groundwater Management Associates, Inc.

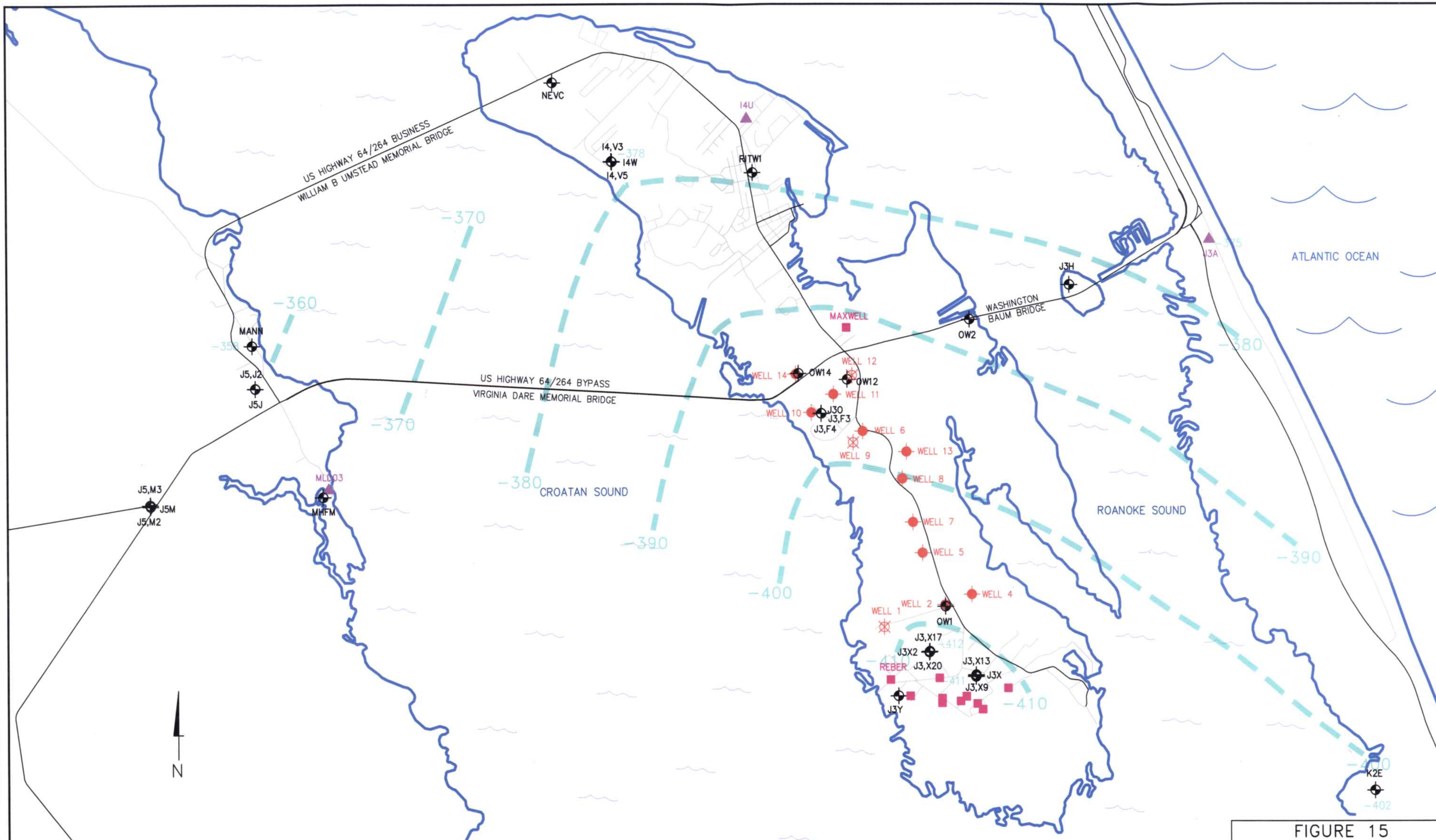


FIGURE 15

-LEGEND-
- DARE COUNTY WATER-SUPPLY WELL
- ABANDONED WATER-SUPPLY WELL
- MONITORING WELL
- BORING/COREHOLE
- RESIDENTIAL WELL
- OW=OBSERVATION WELL
- -412 ELEVATION IN FEET (MSL)

ELEVATION OF THE BASE OF THE YORKTOWN AQUIFER

ROANOKE ISLAND, DARE COUNTY, NC

PROJECT 103501

DATE 6/11/2008

SCALE IN FEET
0 2500' 5000'
1"=5000'

GMA
Groundwater Management Associates, Inc.

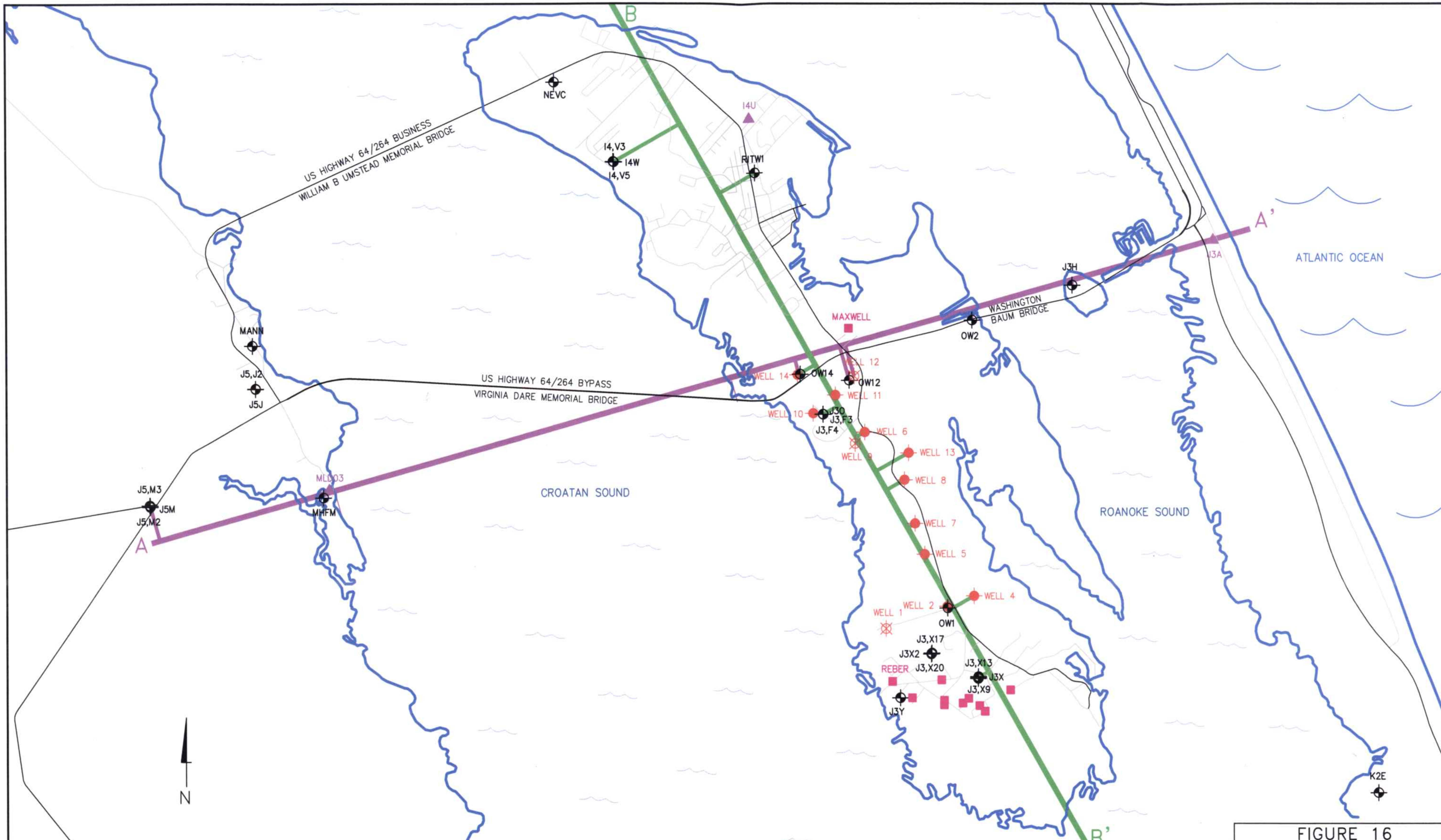


FIGURE 16

-LEGEND-

- DARE COUNTY WATER-SUPPLY WELL
- ABANDONED WATER-SUPPLY WELL
- MONITORING WELL
- BORING/COREHOLE
- RESIDENTIAL WELL
- OW=OBSERVATION WELL

MAP OF CROSS SECTION TRACES

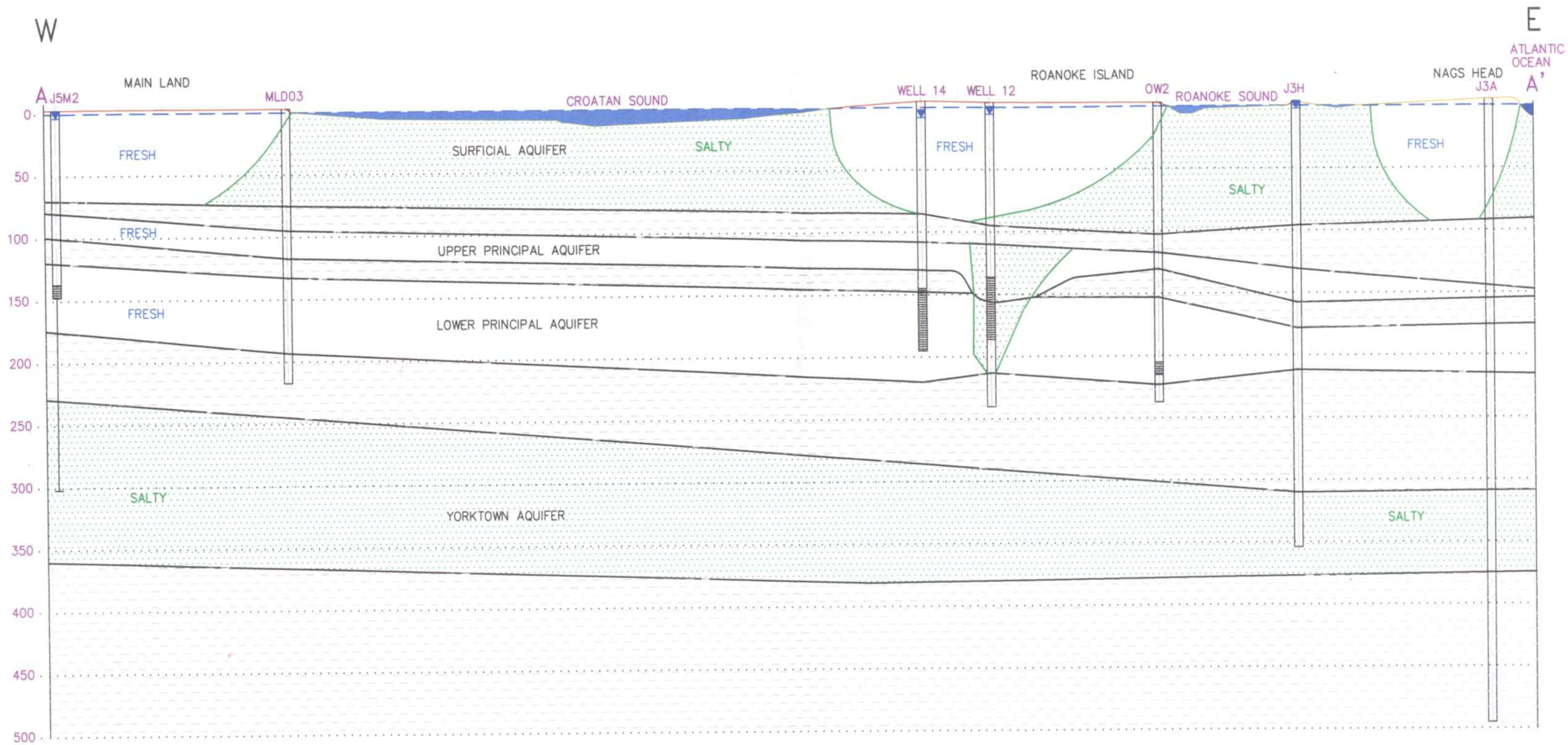
ROANOKE ISLAND, DARE COUNTY, NC

PROJECT 103501

DATE 6/11/2008

SCALE IN FEET
0 2500' 5000'
1"=5000'

GMA
Groundwater Management Associates, Inc.



-LEGEND-

HYDROGEOLOGICAL CROSS SECTION A–A'

ROANOKE ISLAND, DARE COUNTY, NC

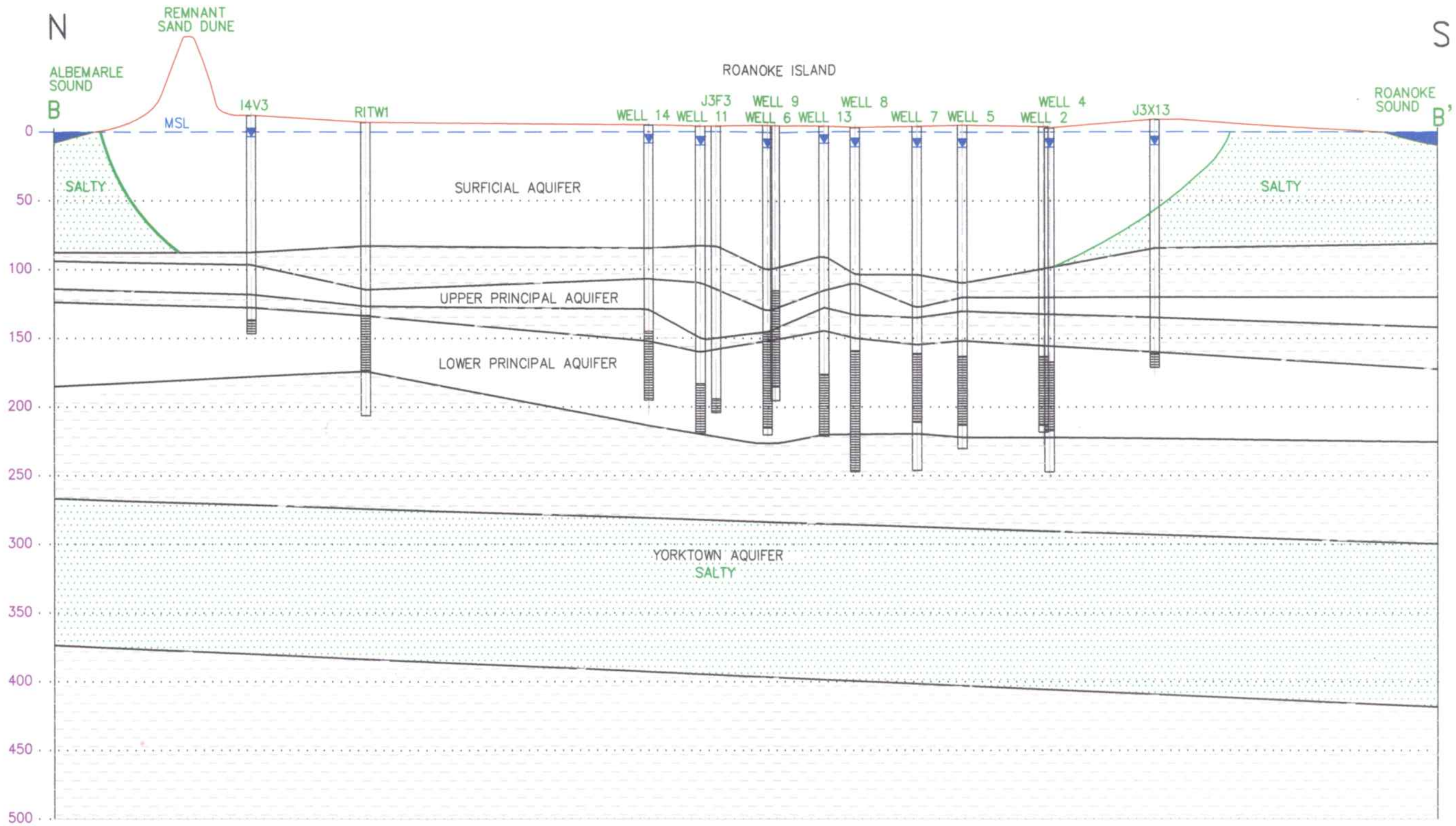
PROJECT 103501

DATE 3/13/2008

HORIZONTAL SCALE 1"=5000'
VERTICAL SCALE 1"=100'
(WELL WIDTH EXAGGERATED)

FIGURE 17

GMA
Groundwater Management Associates, Inc.



-LEGEND-

HYDROGEOLOGICAL CROSS SECTION B-B'

ROANOKE ISLAND, DARE COUNTY, NC

PROJECT 103501

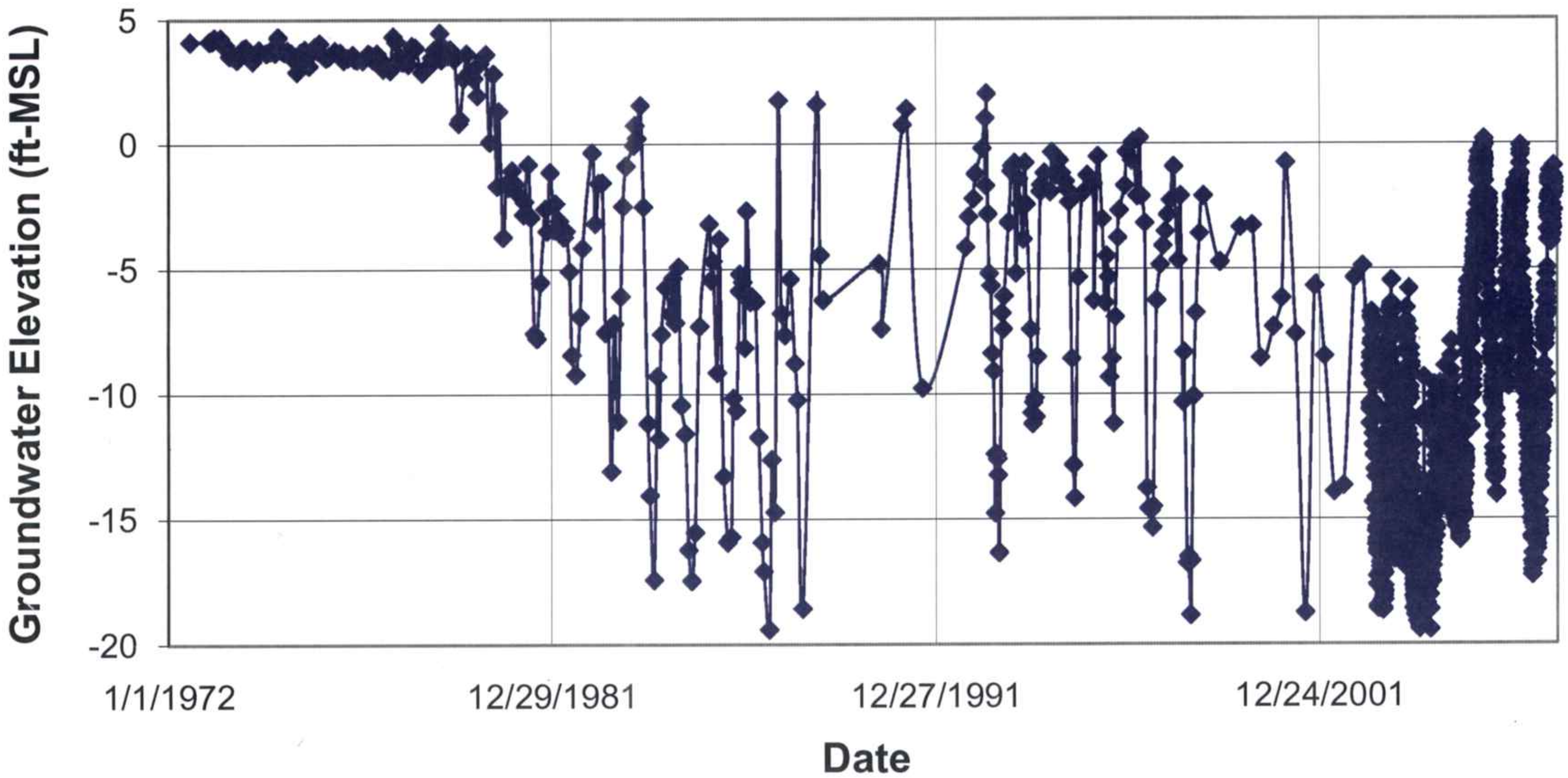
DATE 3/13/2008

HORIZONTAL SCALE 1"=5000'
VERTICAL SCALE 1"=100'
(WELL WIDTH EXAGGERATED)

FIGURE 18

GMA Groundwater Management Associates, Inc.

Figure 19. Water Level Record for the Lower Principal Aquifer - Skyco Road Monitoring Well



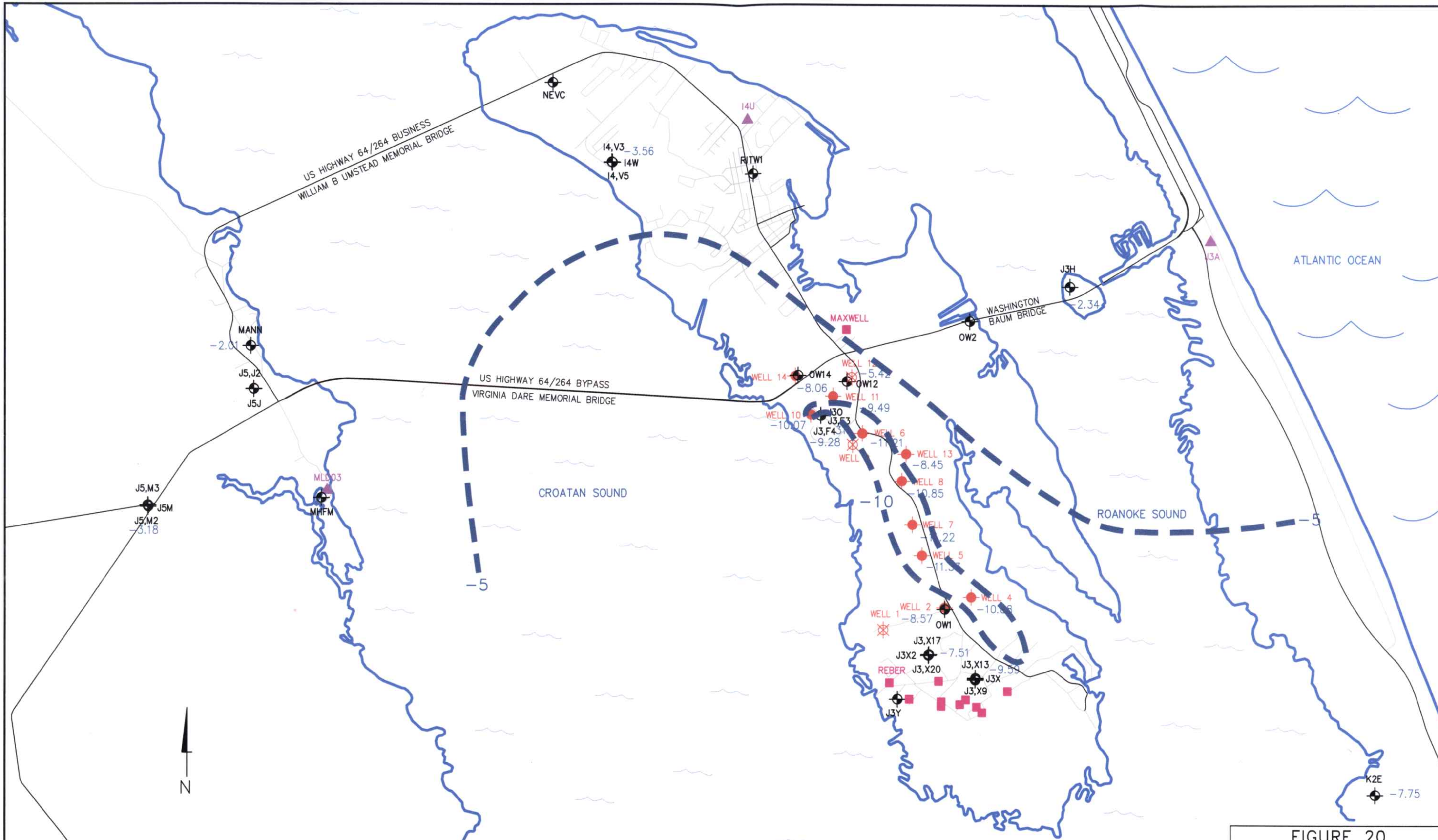


FIGURE 20

-LEGEND-

- DARE COUNTY WATER-SUPPLY WELL
- ABANDONED WATER-SUPPLY WELL
- MONITORING WELL
- BORING/COREHOLE
- RESIDENTIAL WELL
- OW=OBSERVATION WELL
- −8.57 THICKNESS IN FEET

NON-PUMPING WATER LEVELS IN THE LOWER PRINCIPAL AQUIFER
FALL/WINTER 2007

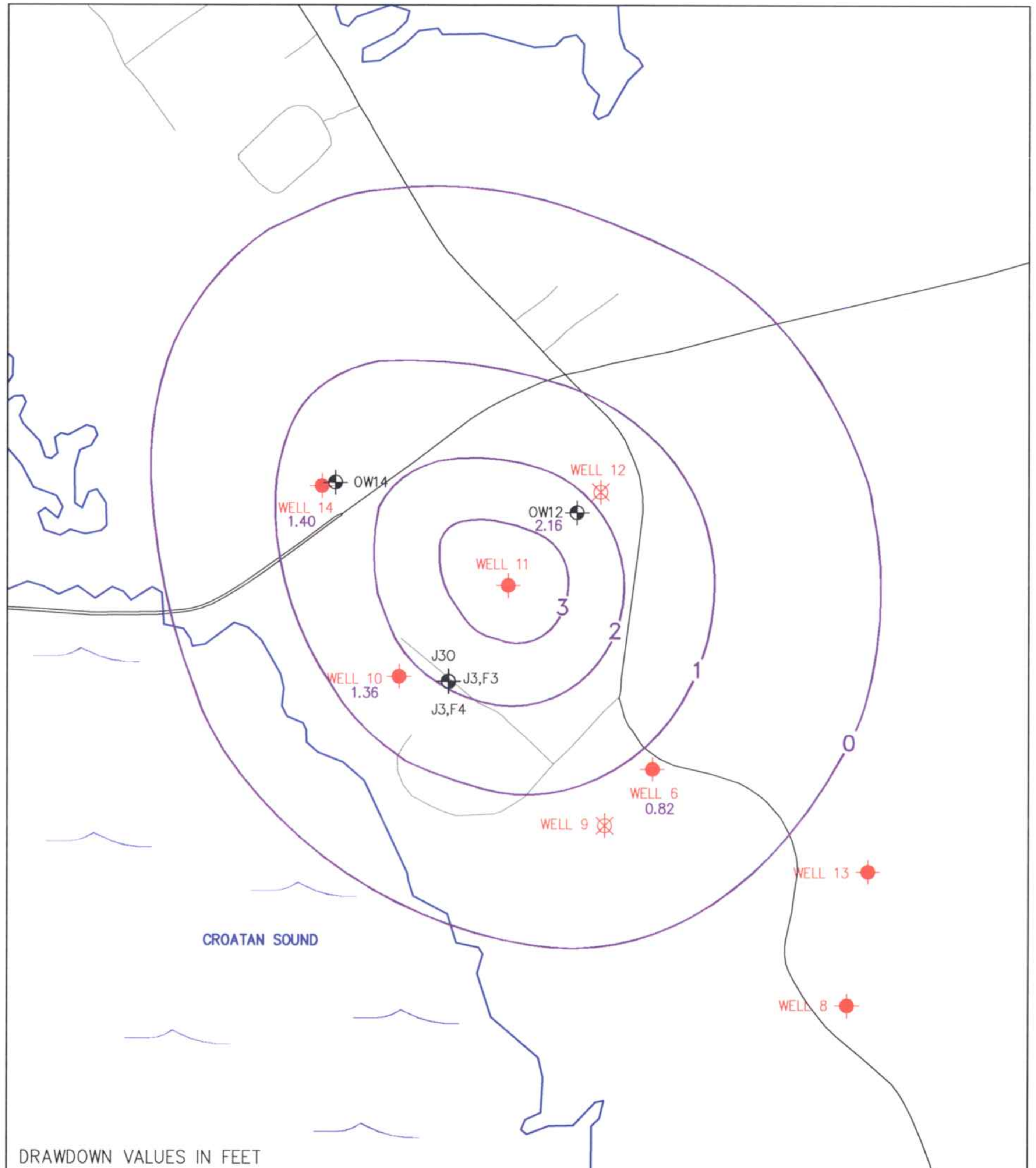
ROANOKE ISLAND, DARE COUNTY, NC

PROJECT 103501

DATE 6/11/2008

SCALE IN FEET
0 2500' 5000'
1"=5000'

GMA
Groundwater Management Associates, Inc.



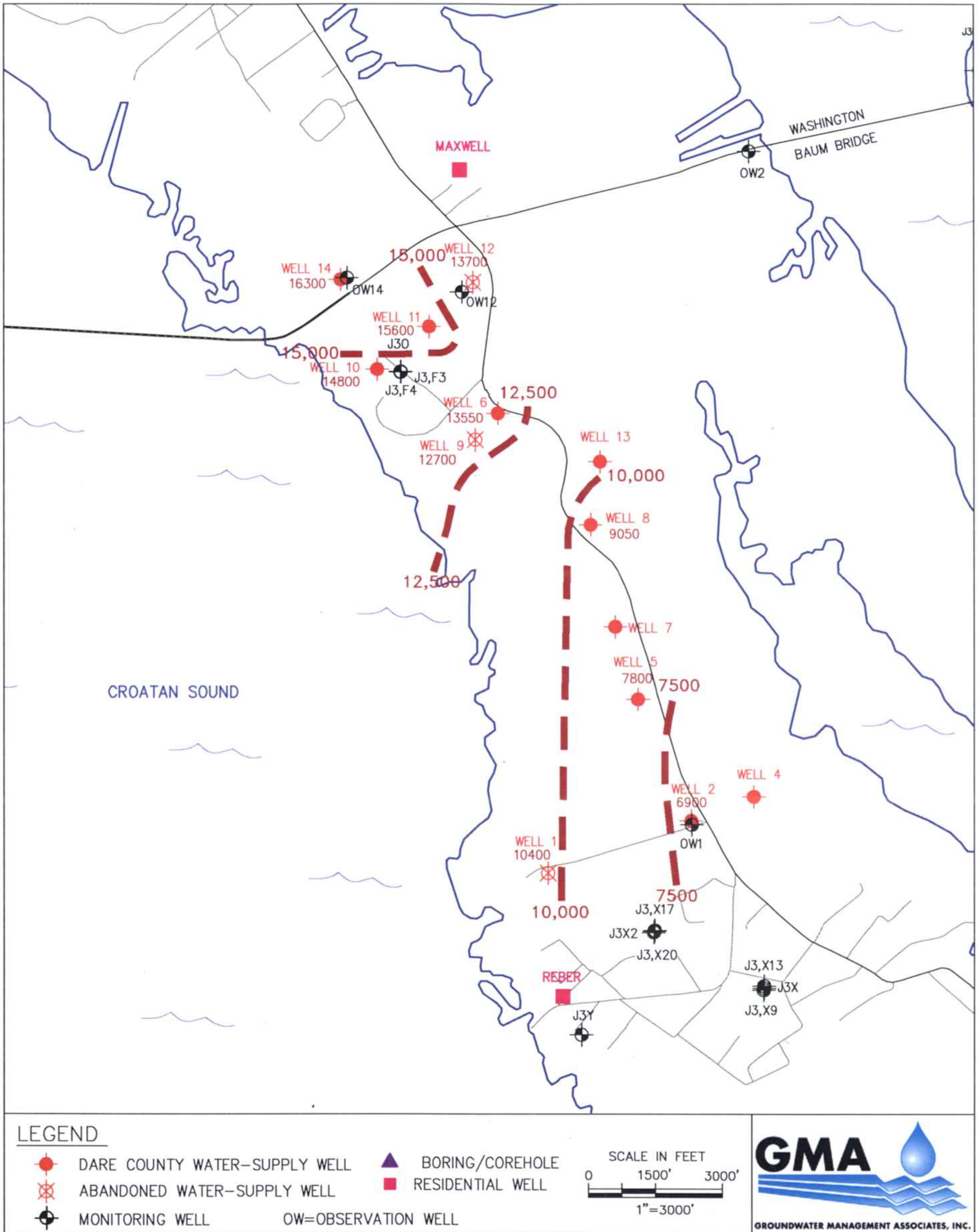
LEGEND

- DARE COUNTY WATER-SUPPLY WELL
- ABANDONED WATER-SUPPLY WELL
- MONITORING WELL OW=OBSERVATION WELL

SCALE IN FEET
0 750' 1500'
1"=1500'

GMA
GROUNDWATER MANAGEMENT ASSOCIATES, INC.

File: DRAWINGS\3-2008 DRAWDOWN1-08	DRAWDOWN IN THE LOWER PRINCIPAL AQUIFER AT 24-HOUR OF PUMPING FROM SKYCO #11	Date: 6/11/2008
Project No. 103501	ROANOKE ISLAND, DARE COUNTY, NC	Figure 21



GMA
GROUNDWATER MANAGEMENT ASSOCIATES, INC.

File: DRAWINGS/103501 TRANSM	TRANSMISSIVITY (FT^2/DAY) IN THE LOWER PRINCIPAL AQUIFER	Date: 6/11/2008
Project No. 103501	ROANOKE ISLAND, DARE COUNTY, NC	Figure 22

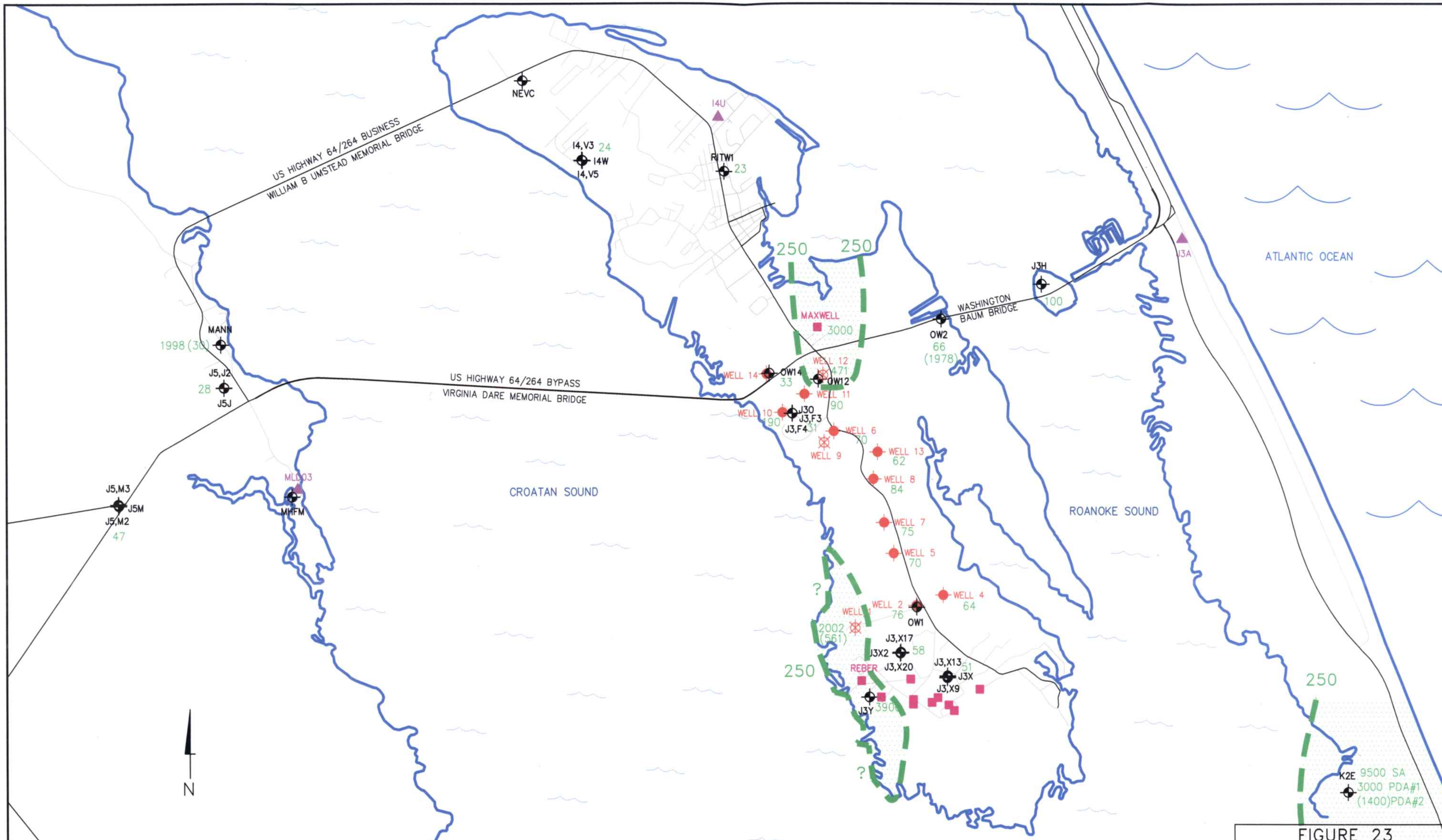


FIGURE 23

-LEGEND-

- DARE COUNTY WATER-SUPPLY WELL
- ABANDONED WATER-SUPPLY WELL
- MONITORING WELL
- BORING/COREHOLE
- RESIDENTIAL WELL
- OW=OBSERVATION WELL
- CHLORIDE <250mg/L

CHLORIDE CONCENTRATION IN THE LOWER PRINCIPAL AQUIFER

ROANOKE ISLAND, DARE COUNTY, NC

PROJECT 103501

DATE 6/11/2008

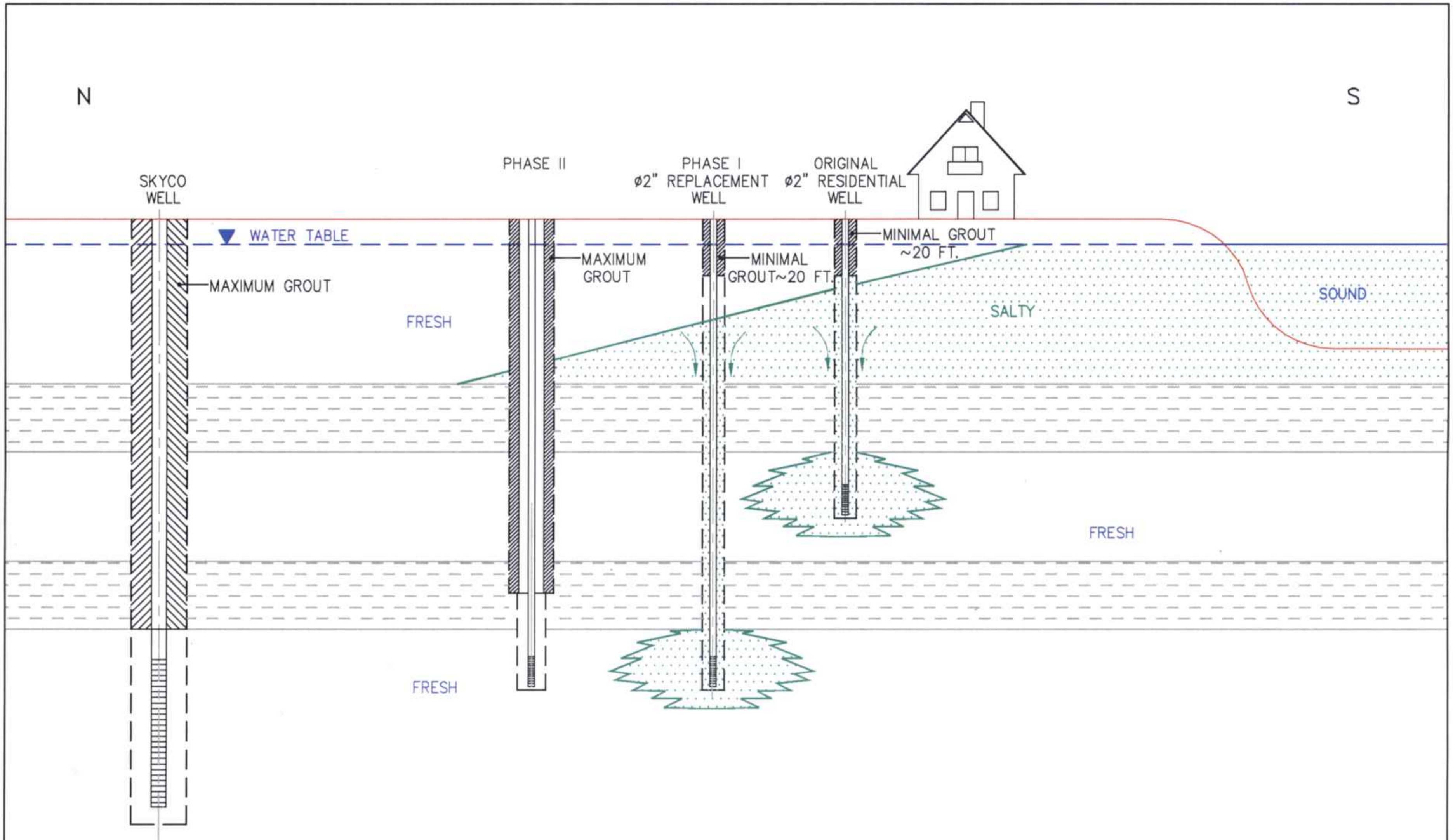
SCALE IN FEET

0 2500' 5000'

1"=5000'

GMA

Groundwater Management Associates, Inc.



— LEGEND —

File: DRAWINGS\103501 ILL5	HYDROGEOLOGIC CONDITIONS AND RESIDENTIAL WELL DEVELOPMENT IN WANCHESE	Date: 3/13/2008
Project No. 103501	ROANOKE ISLAND, DARE COUNTY, NC	Figure 24

GROUNDWATER MANAGEMENT ASSOCIATES, INC.

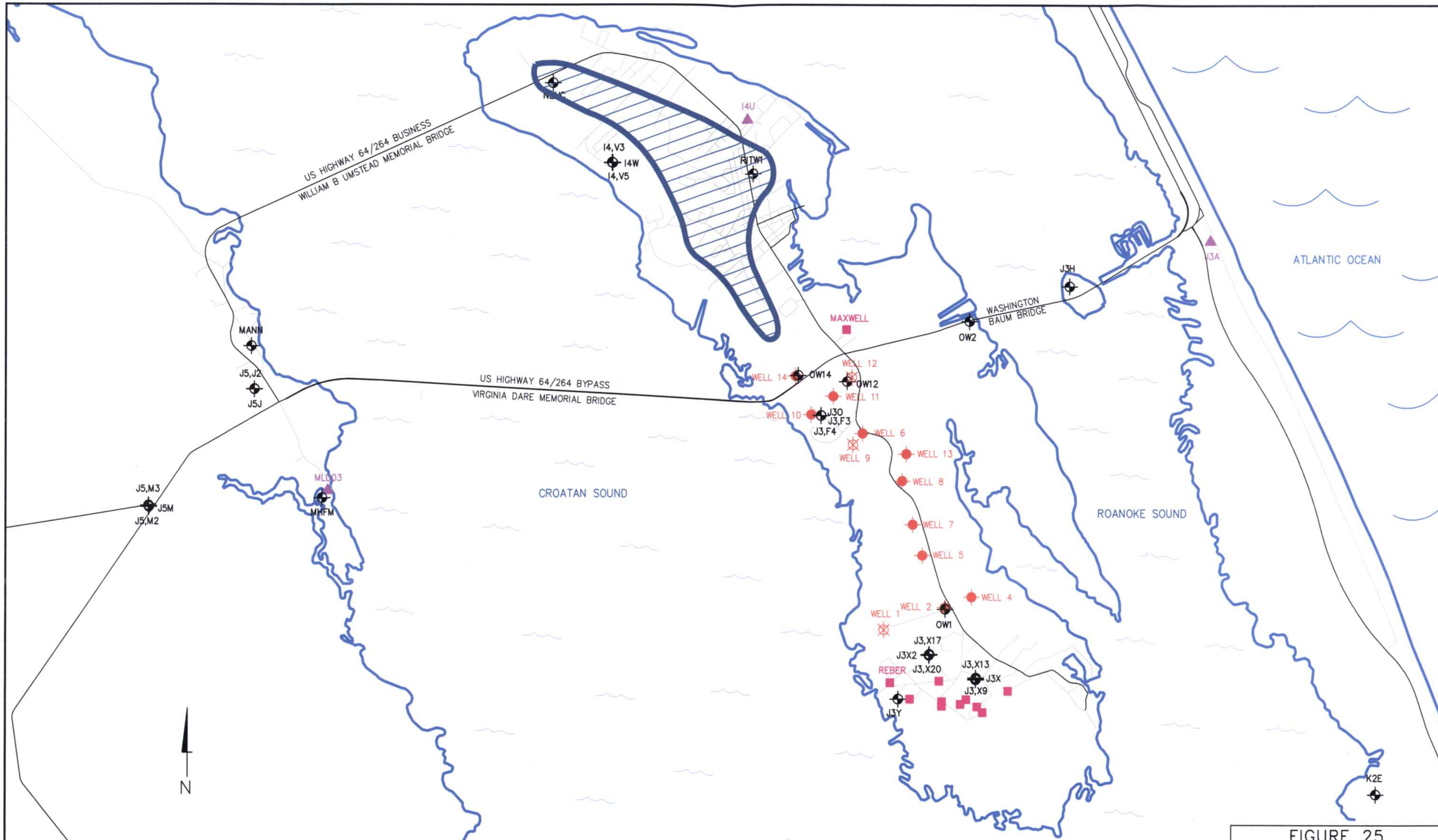


FIGURE 25

-LEGEND-
- DARE COUNTY WATER-SUPPLY WELL
- ABANDONED WATER-SUPPLY WELL
- MONITORING WELL
- BORING/COREHOLE
- RESIDENTIAL WELL REPLACED 2007-2008
- OW=OBSERVATION WELL
- AREA OF EXPLORATION

MAP OF RECOMMENDED EXPLORATION AND WELLFIELD EXPANSION

ROANOKE ISLAND, DARE COUNTY, NC

PROJECT 103501

DATE 6/11/2008

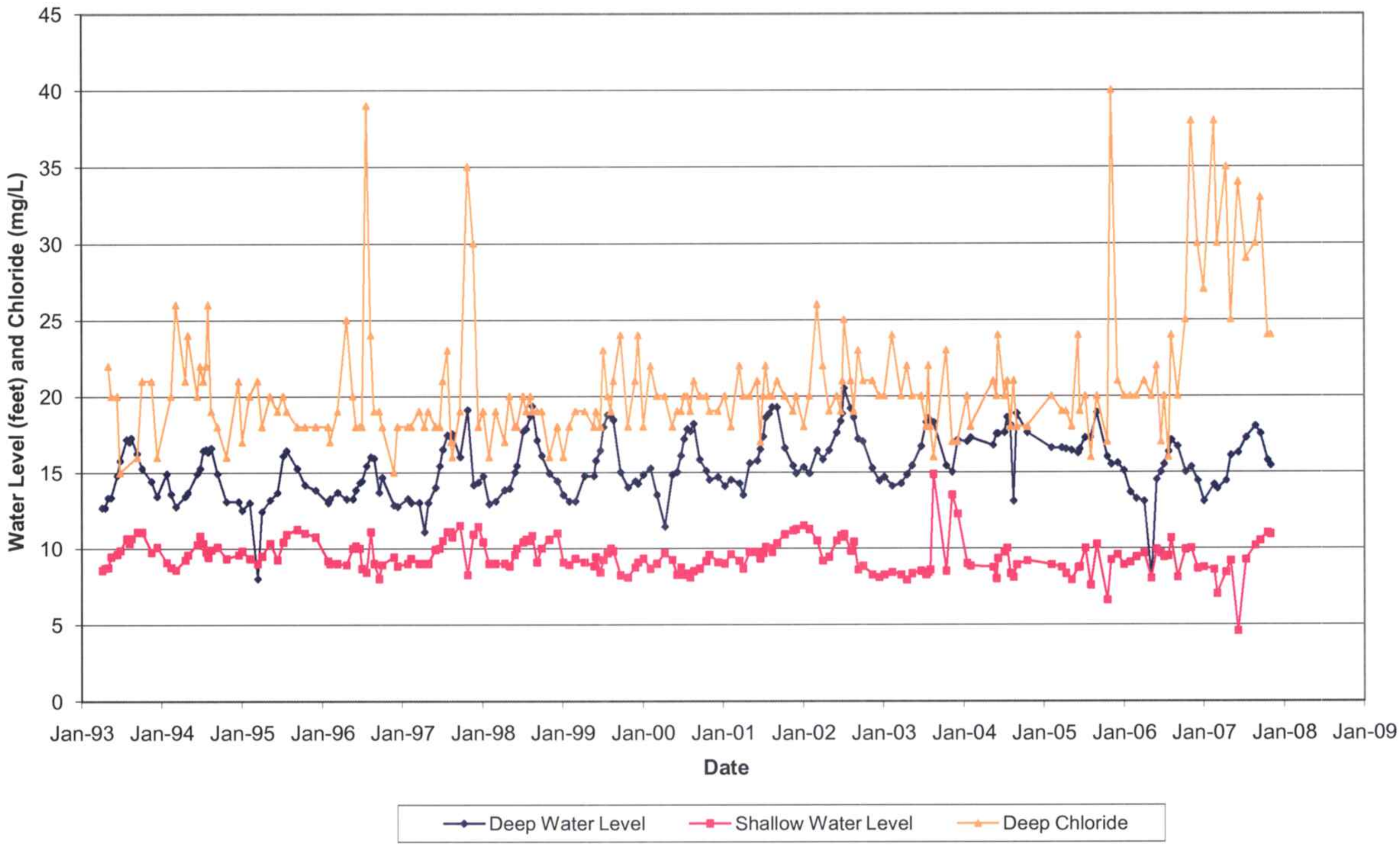
SCALE IN FEET
0 2500' 5000'
1"=5000'

GMA
Groundwater Management Associates, Inc.

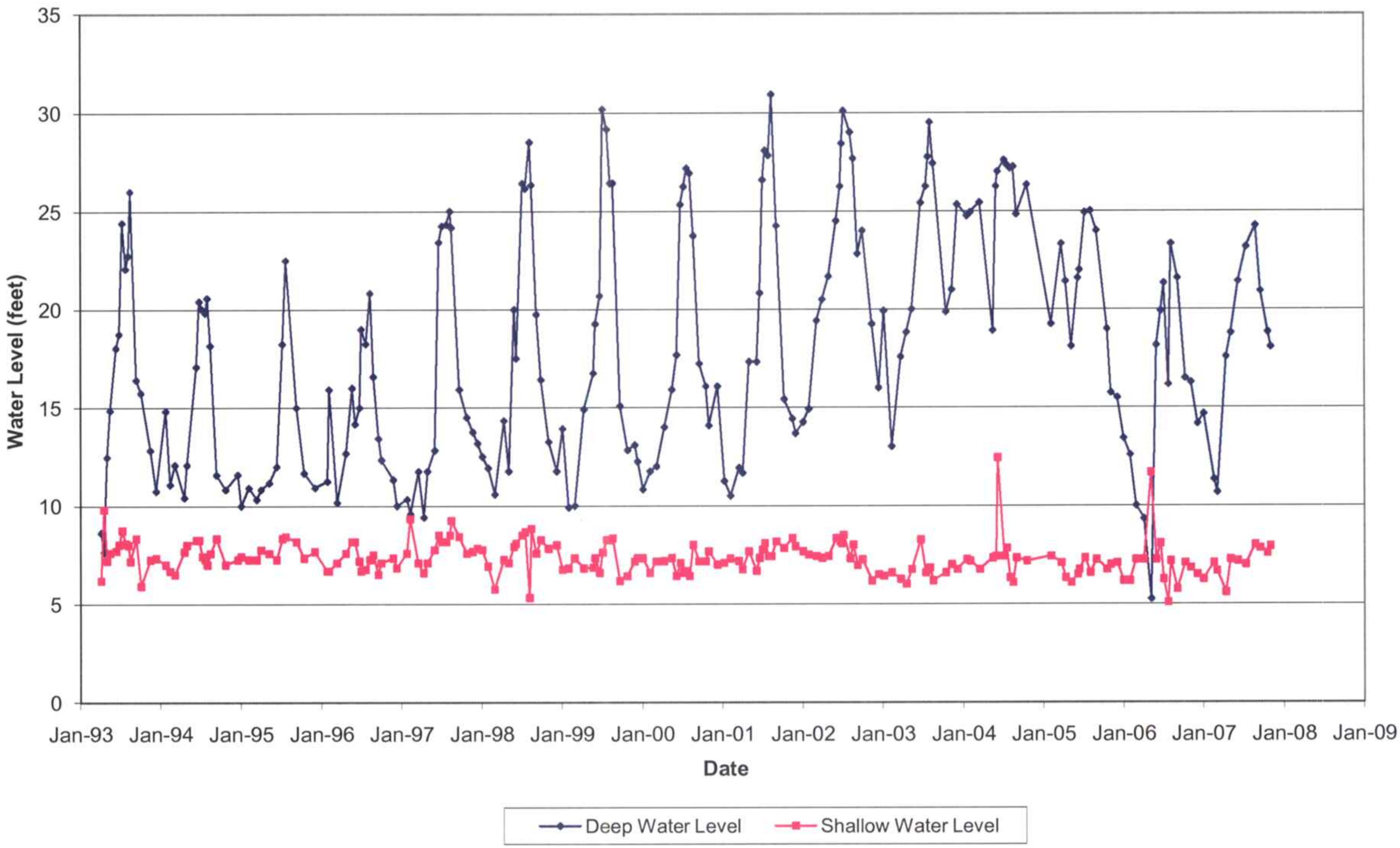
Appendix A

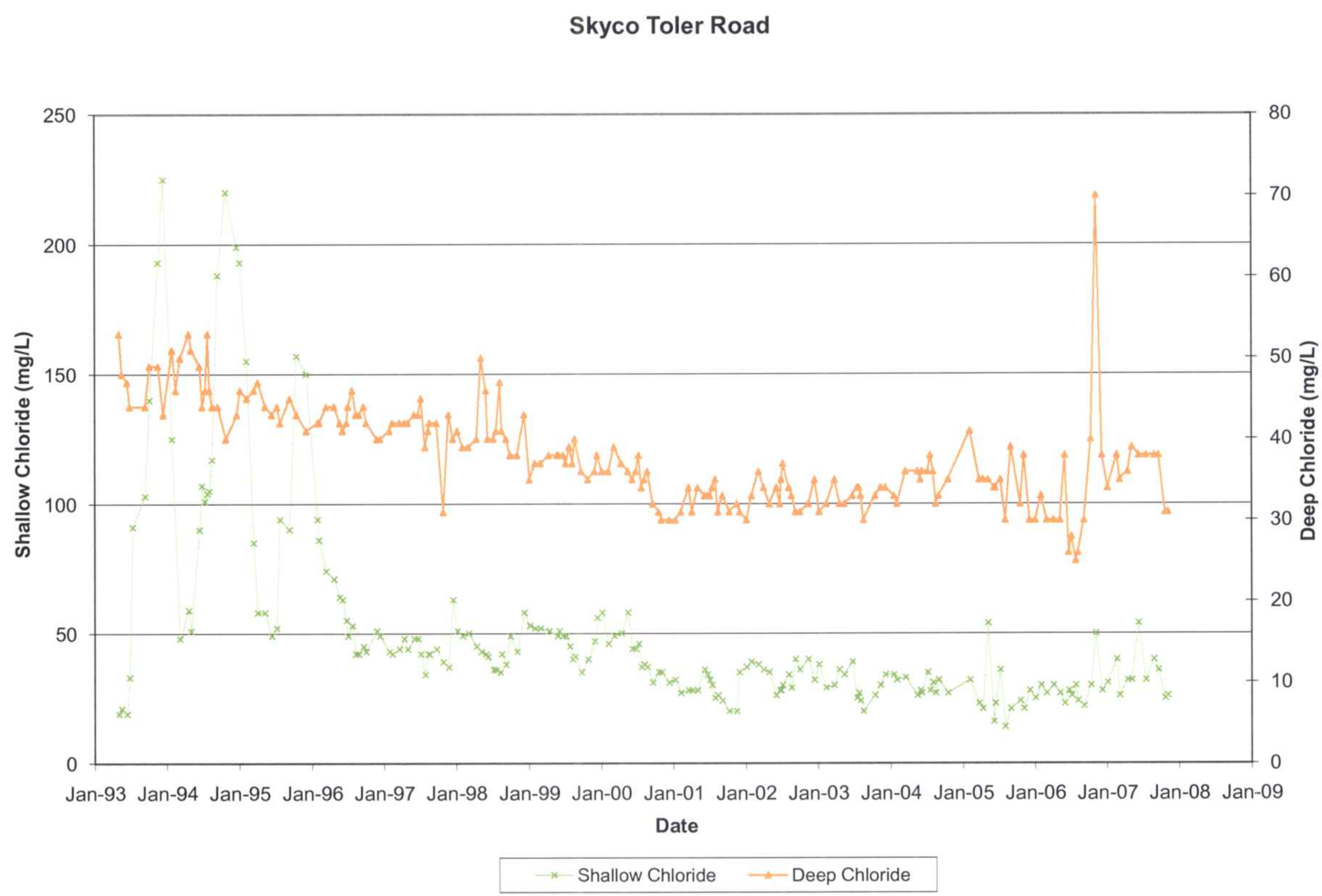
Water Level Records since 1993 for NCDENR Monitoring Wells

Manteo Airport

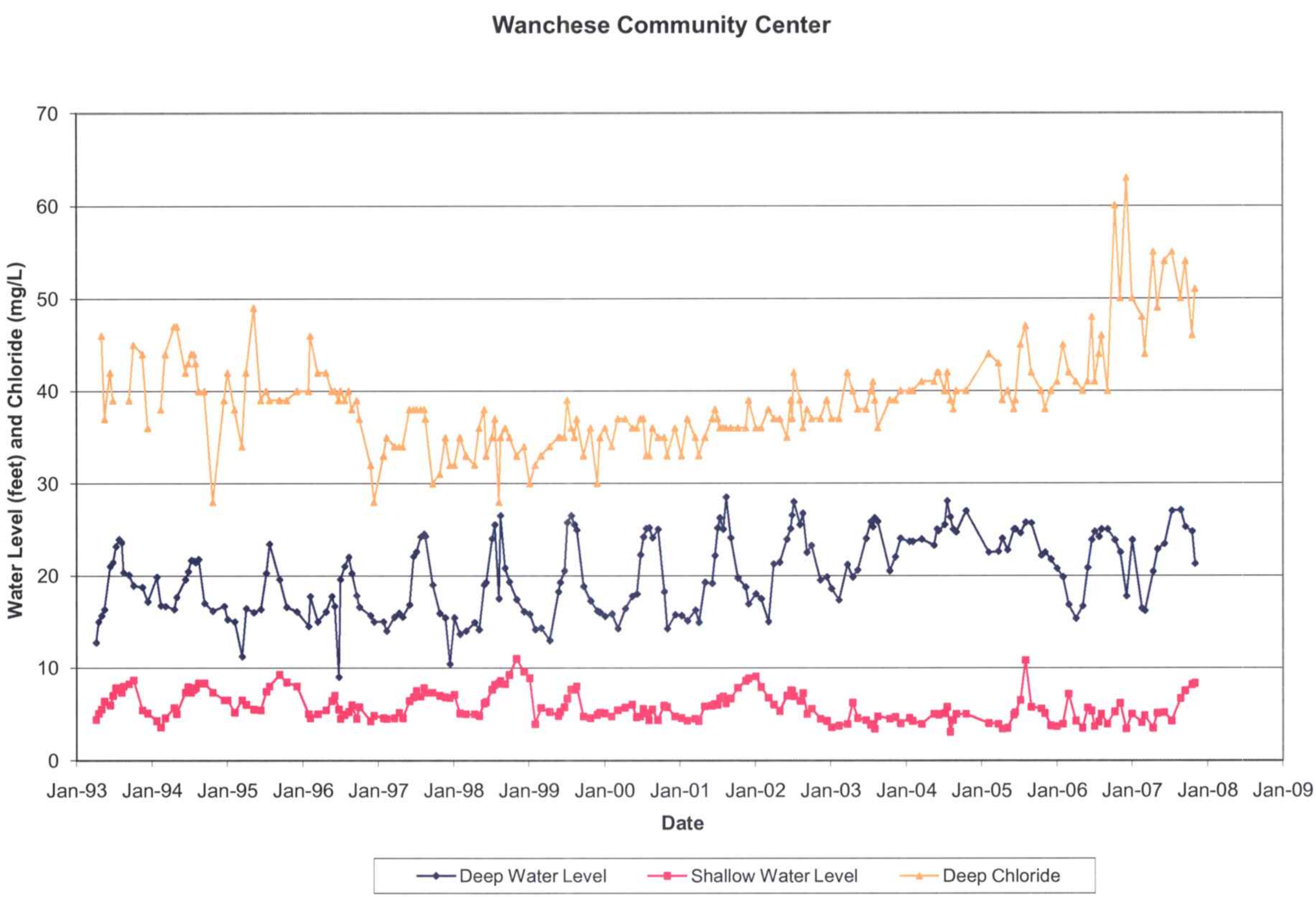


Skyco Toler Road

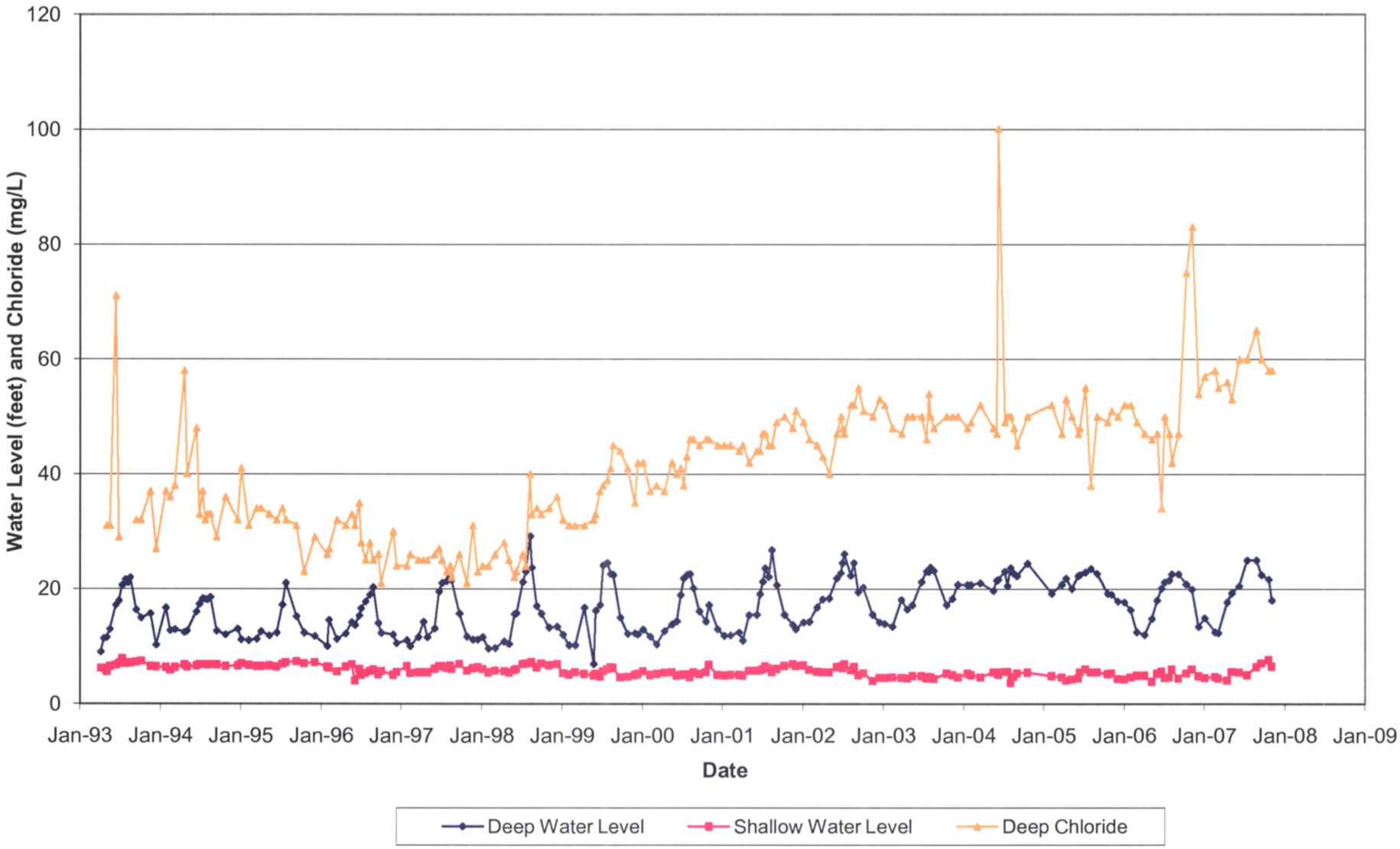




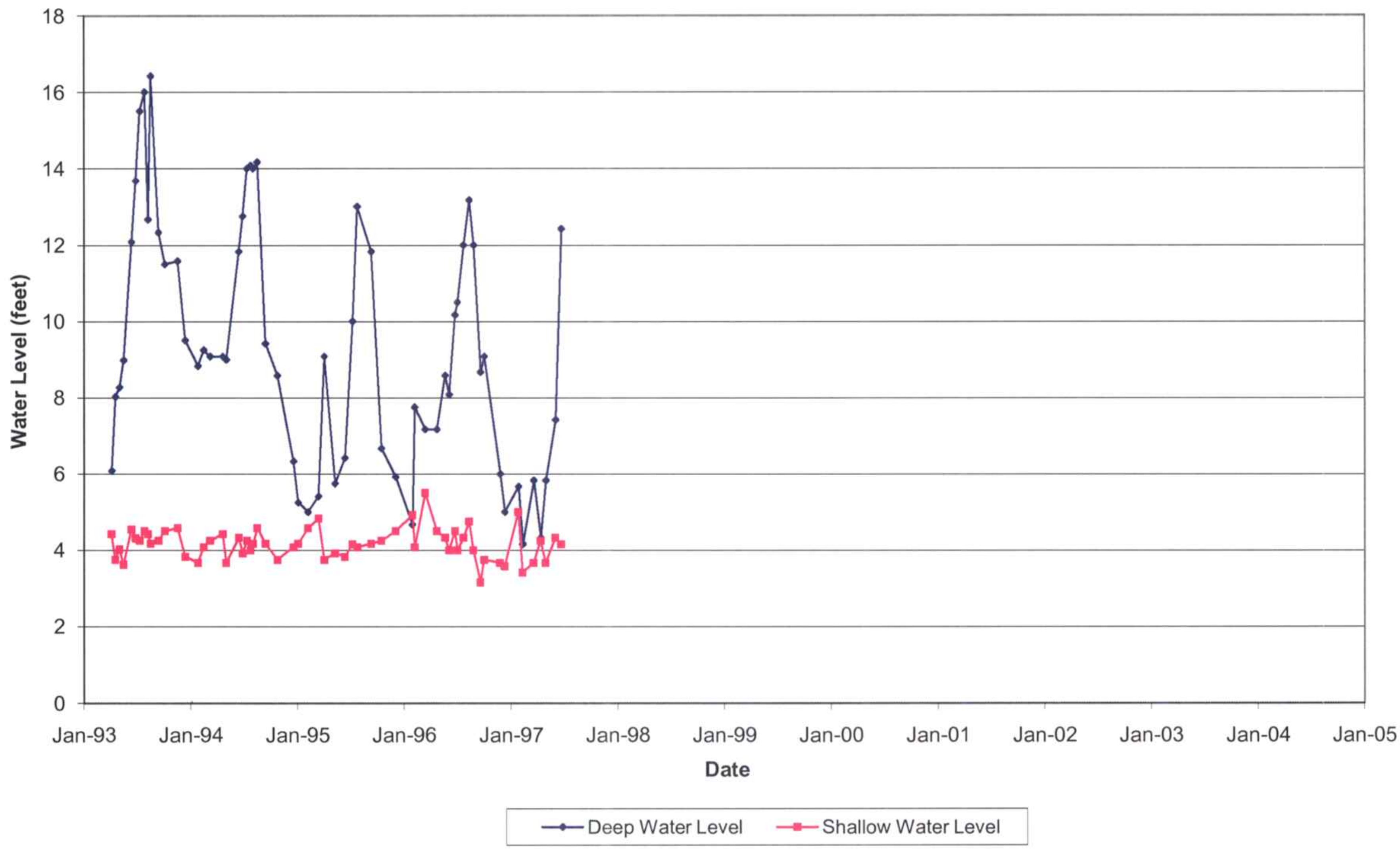
Skyco Toler Road
Shallow Chloride (mg/L)
250
200
150
100
50
0
Deep Chloride (mg/L)
80
70
60
50
40
30
20
10
0
Jan-93 Jan-94 Jan-95 Jan-96 Jan-97 Jan-98 Jan-99 Jan-00 Jan-01 Jan-02 Jan-03 Jan-04 Jan-05 Jan-06 Jan-07 Jan-08 Jan-09
Date
Shallow Chloride
Deep Chloride


Wanchese Community Center
Water Level (feet) and Chloride (mg/L)
70
60
50
40
30
20
10
0
Jan-93
Jan-94
Jan-95
Jan-96
Jan-97
Jan-98
Jan-99
Jan-00
Jan-01
Jan-02
Jan-03
Jan-04
Jan-05
Jan-06
Jan-07
Jan-08
Jan-09
Date
Deep Water Level
Shallow Water Level
Deep Chloride

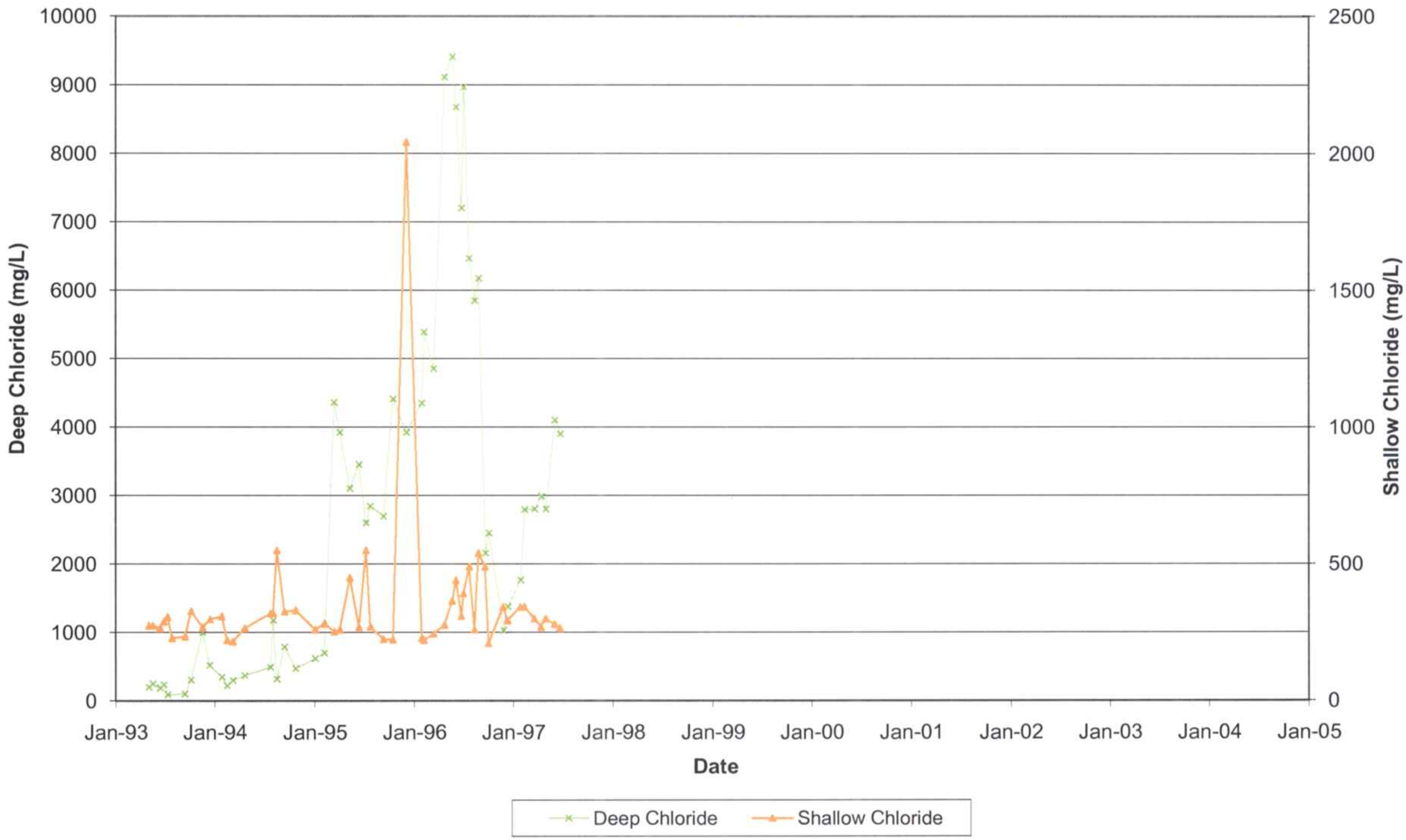
Wanchese Ball Park

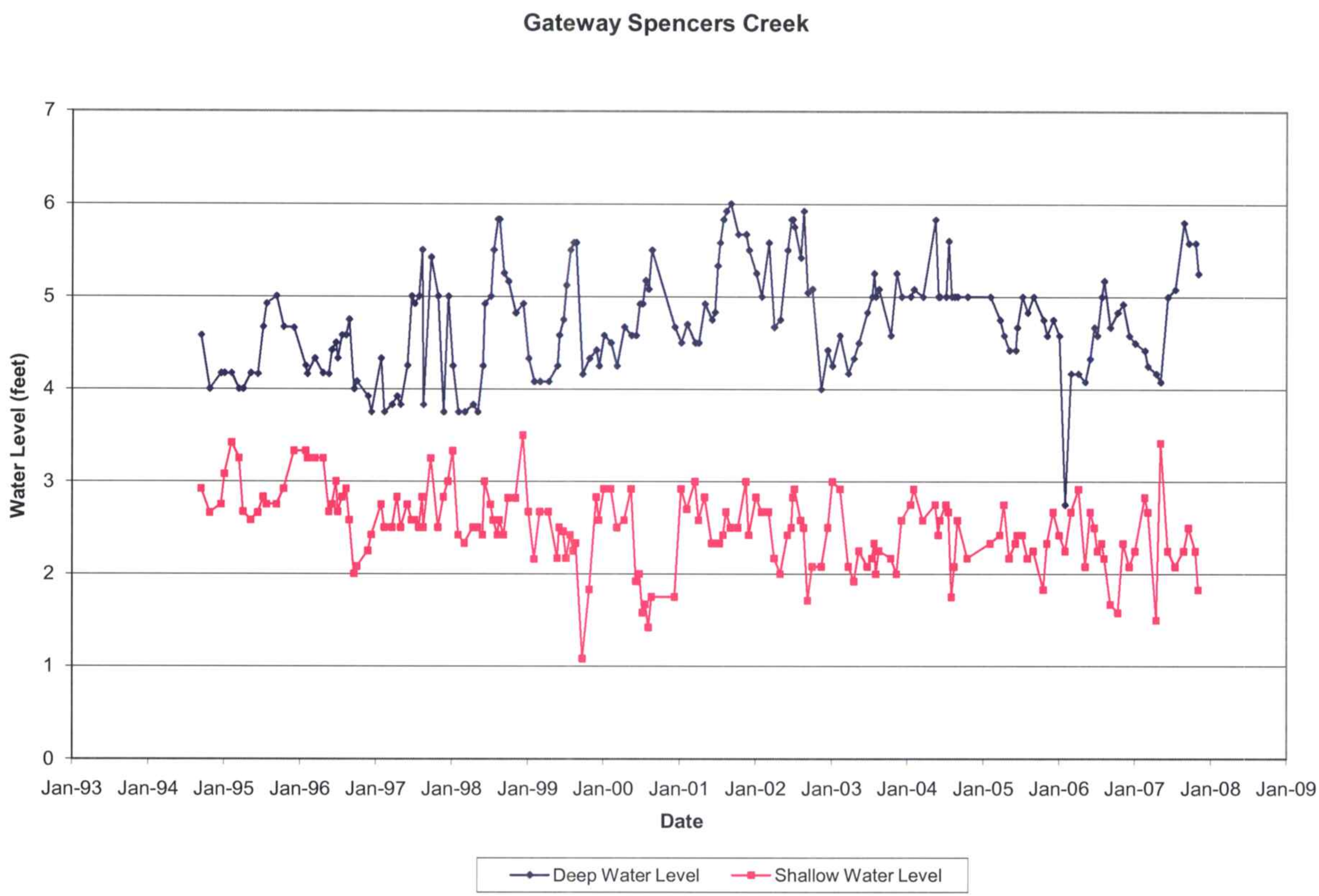


Eason Hickman Road

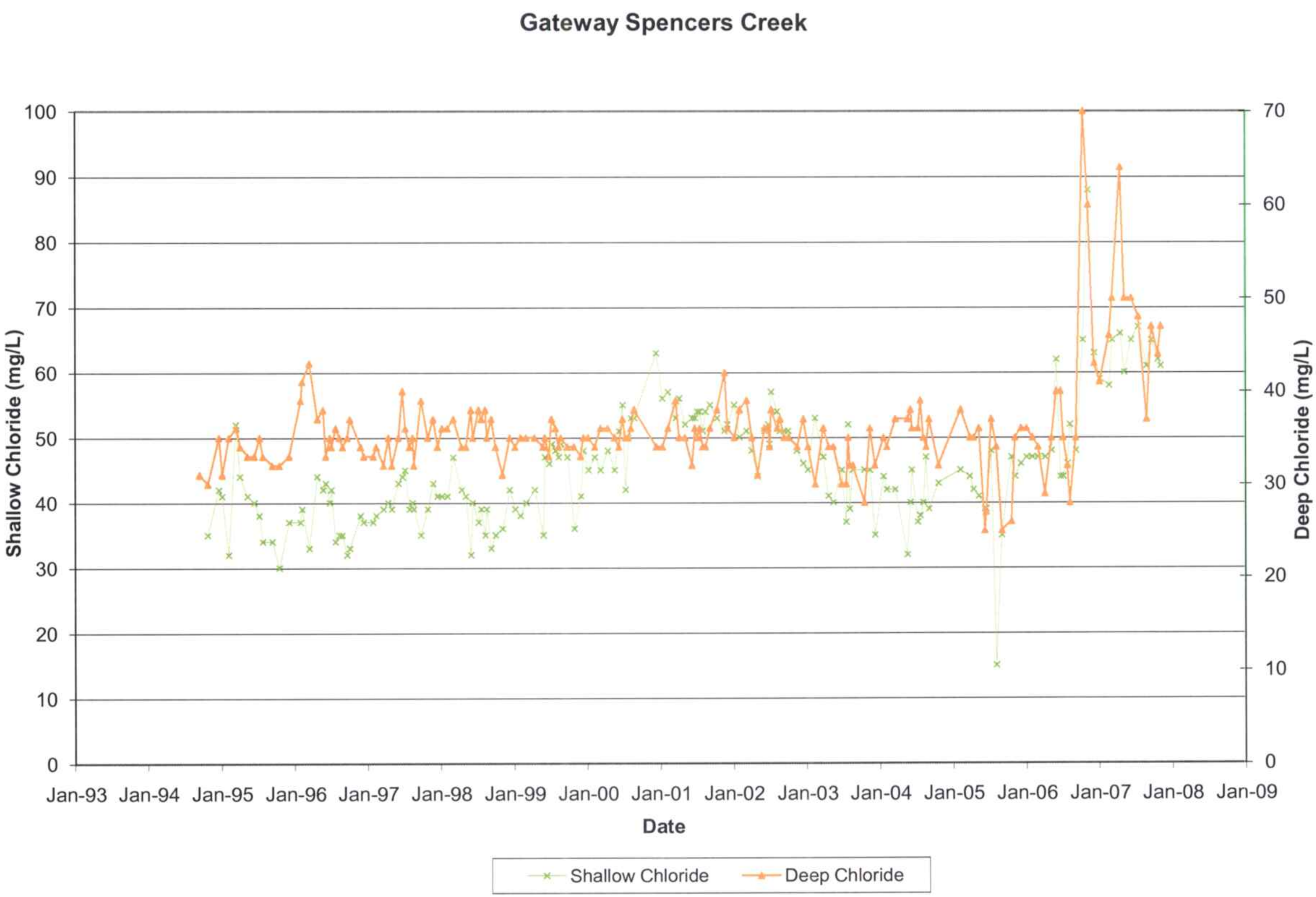


Eason Hickman Road

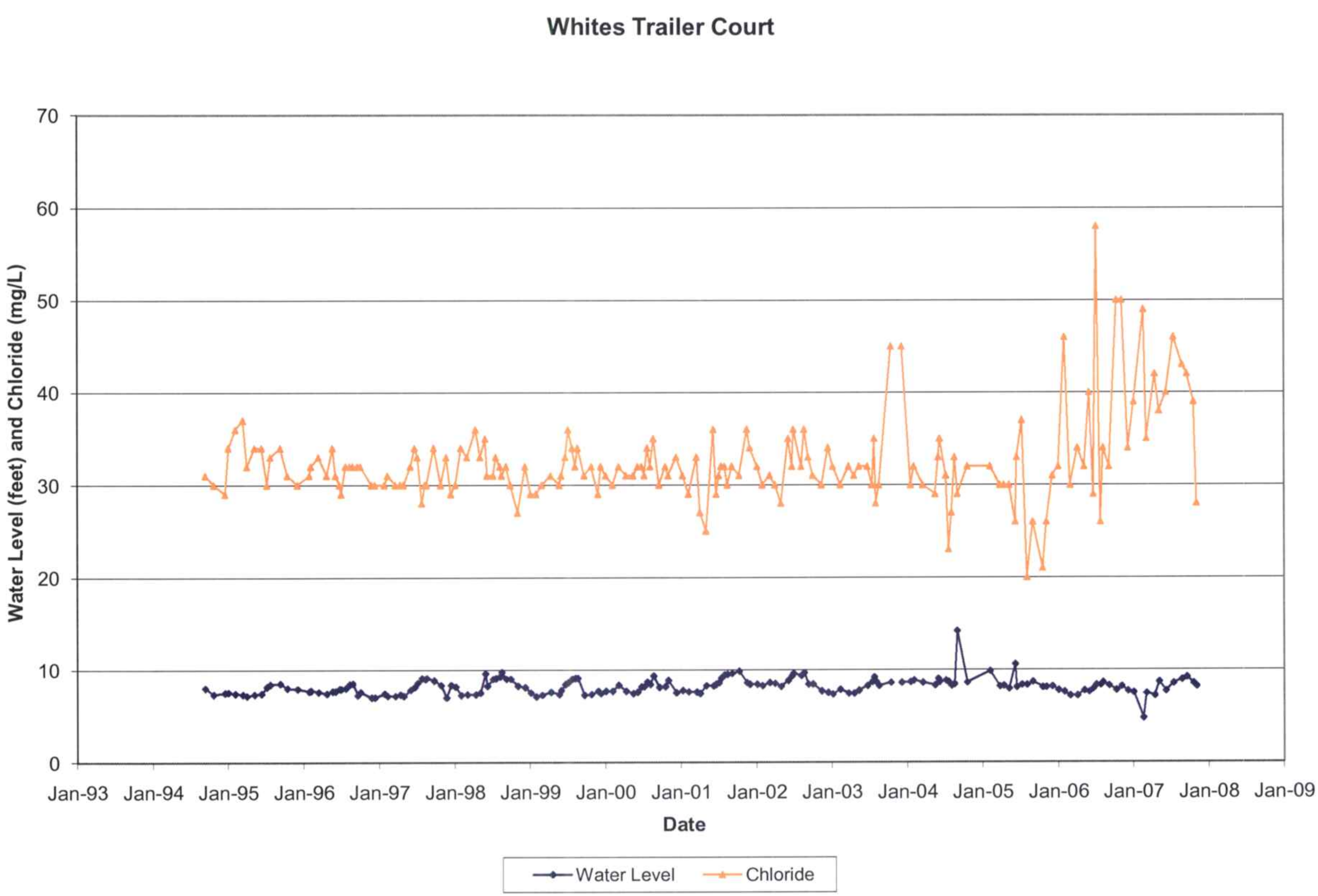




Gateway Spencers Creek
Water Level (feet)
0
1
2
3
4
5
6
7
Jan-93
Jan-94
Jan-95
Jan-96
Jan-97
Jan-98
Jan-99
Jan-00
Jan-01
Jan-02
Jan-03
Jan-04
Jan-05
Jan-06
Jan-07
Jan-08
Jan-09
Date
Deep Water Level
Shallow Water Level



Gateway Spencers Creek
Shallow Chloride (mg/L)
Deep Chloride (mg/L)
Date
Jan-93 Jan-94 Jan-95 Jan-96 Jan-97 Jan-98 Jan-99 Jan-00 Jan-01 Jan-02 Jan-03 Jan-04 Jan-05 Jan-06 Jan-07 Jan-08 Jan-09
0 10 20 30 40 50 60 70 80 90 100
0 10 20 30 40 50 60 70
Shallow Chloride
Deep Chloride


Whites Trailer Court
Water Level (feet) and Chloride (mg/L)
70
60
50
40
30
20
10
0
Jan-93
Jan-94
Jan-95
Jan-96
Jan-97
Jan-98
Jan-99
Jan-00
Jan-01
Jan-02
Jan-03
Jan-04
Jan-05
Jan-06
Jan-07
Jan-08
Jan-09
Date
Water Level
Chloride

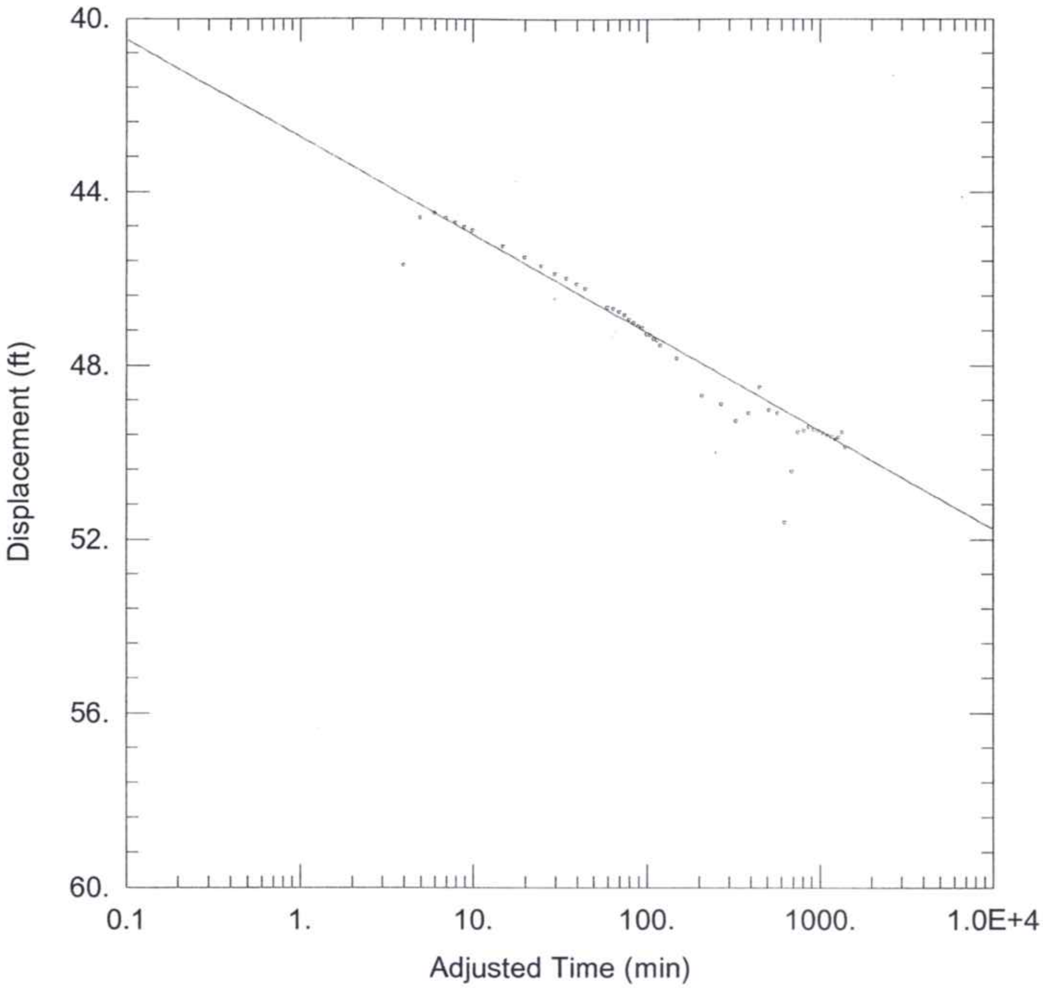
Appendix B

Well Test Analyses for Original 24-hour Well Tests

PW1 (2/20/74) Static= 2.1

Time (min.)	Drawdown	Rate	W.L.	Spec. Cap.
1	47.63	760	49.73	15.96
2	50.49	734	52.59	14.54
3	49.52	678	51.62	13.69
4	45.7	664	47.8	14.53
5	44.6	650	46.7	14.57
6	44.5	650	46.6	14.61
7	44.61	657	46.71	14.73
8	44.72	657	46.82	14.69
9	44.82	657	46.92	14.66
10	44.89	657	46.99	14.64
15	45.26	650	47.36	14.36
20	45.52	650	47.62	14.28
25	45.72	650	47.82	14.22
30	45.9	650	48	14.16
35	46.01	650	48.11	14.13
40	46.14	650	48.24	14.09
45	46.25	650	48.35	14.05
60	46.68	650	48.78	13.92
65	46.7	650	48.8	13.92
70	46.78	650	48.88	13.89
75	46.85	650	48.95	13.87
80	46.96	650	49.06	13.84
85	47.03	650	49.13	13.82
90	47.1	650	49.2	13.80
95	47.15	650	49.25	13.79
100	47.3	650	49.4	13.74
105	47.31	650	49.41	13.74
110	47.4	650	49.5	13.71
115	47.43	650	49.53	13.70
120	47.55	650	49.65	13.67
150	47.84	650	49.94	13.59
210	48.7	650	50.8	13.35
270	48.9	650	51	13.29
330	49.28	650	51.38	13.19
390	49.1	650	51.2	13.24
450	48.51	650	50.61	13.40
510	49.03	650	51.13	13.26
570	49.1	650	51.2	13.24
630	51.61	650	53.71	12.59
690	50.43	650	52.53	12.89
750	49.53	650	51.63	13.12
810	49.5	650	51.6	13.13
870	49.42	650	51.52	13.15
930	49.47	650	51.57	13.14
990	49.5	650	51.6	13.13
1050	49.56	650	51.66	13.12
1110	49.61	650	51.71	13.10
1170	49.63	650	51.73	13.10
1230	49.7	650	51.8	13.08

1290	49.65	650	51.75	13.09
1350	49.53	650	51.63	13.12
1410	49.868	650	51.968	13.03
1440				
1441	7.68		9.78	
1442	6.65		8.75	
1443	6.28		8.38	
1444	5.93		8.03	
1445	5.68		7.78	
1446	5.55		7.65	
1447	5.38		7.48	
1448	5.25		7.35	
1449	5.13		7.23	
1450	5.03		7.13	
1455	4.7		6.8	
1460	4.45		6.55	
1465	4.4		6.5	
1470	4.1		6.2	
1475	3.88		5.98	
1480	4.75		6.85	
1485	4.68		6.78	
1490	3.6		5.7	
1495				
1500	3.8		5.9	
1505	3.37		5.47	
1510	3.31		5.41	
1515	3.2		5.3	
1520	3.19		5.29	
1525	3.18		5.28	
1530	3.1		5.2	
1535	2.95		5.05	
1540	2.95		5.05	
1545	2.92		5.02	
1550	2.89		4.99	
1555	2.81		4.91	
1560	2.85		4.95	



ROANOKE IS. - SKYCO PW1 24HR. TEST (1974)

Data Set: Z:\...\PW1 - 1974CJ.aqt
Date: 07/02/08 Time: 08:53:38

PROJECT INFORMATION

Company: GMA
Client: Dare Co.
Project: 103501
Location: Roanoke Island
Test Well: PW1
Test Date: 2/20/74

AQUIFER DATA

Saturated Thickness: 96. ft Anisotropy Ratio (Kz/Kr): 1.

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
PW1	0	0

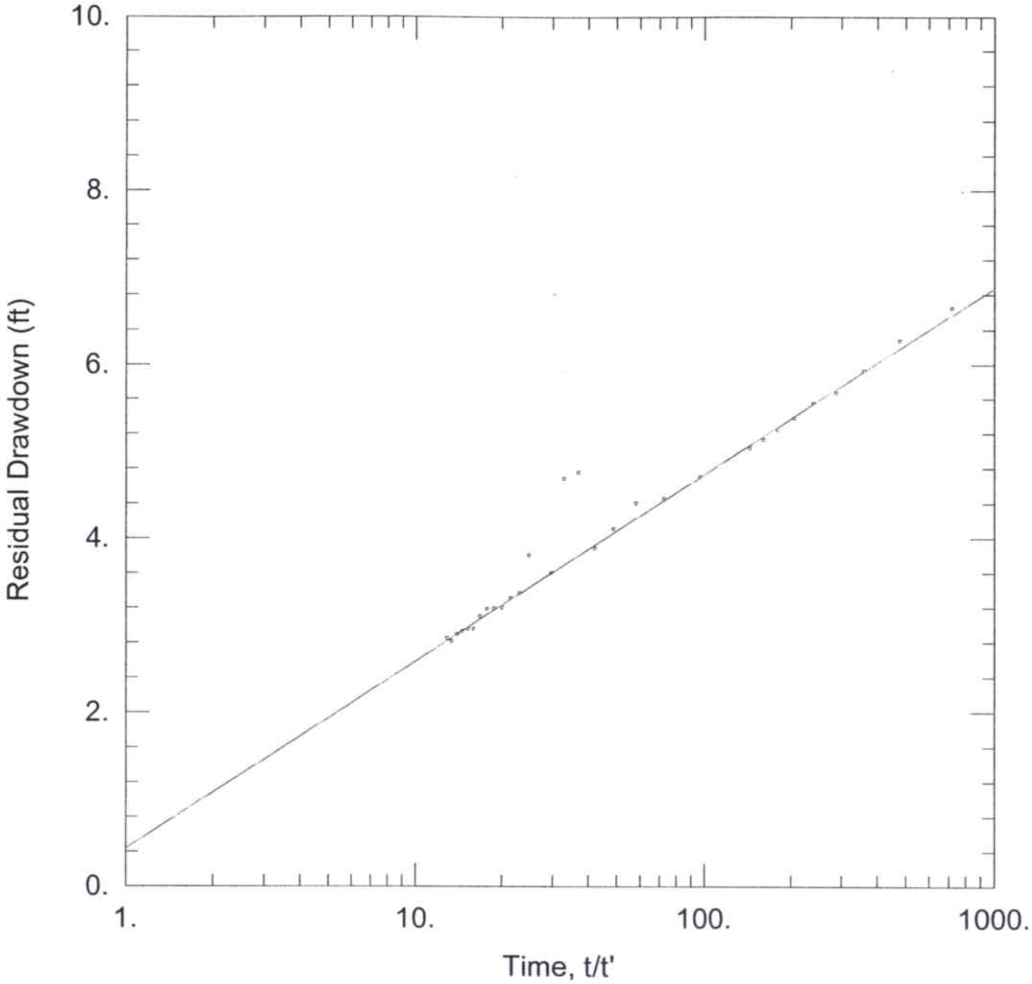
Observation Wells

Well Name	X (ft)	Y (ft)
PW1	0	0.33

SOLUTION

Aquifer Model: Confined Solution Method: Cooper-Jacob

T = 1.017E+4 ft^2/day S = 1.605E-17



ROANOKE IS. - SKYCO PW1 24HR. TEST (1974)

Data Set: Z:\...\PW1 - 1974REC.aqt
Date: 07/02/08 Time: 08:53:49

PROJECT INFORMATION

Company: GMA
Client: Dare Co.
Project: 103501
Location: Roanoke Island
Test Well: PW1
Test Date: 2/20/74

AQUIFER DATA

Saturated Thickness: 96. ft Anisotropy Ratio (Kz/Kr): 1.

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
PW1	0	0

Observation Wells

Well Name	X (ft)	Y (ft)
PW1	0	0.33

SOLUTION

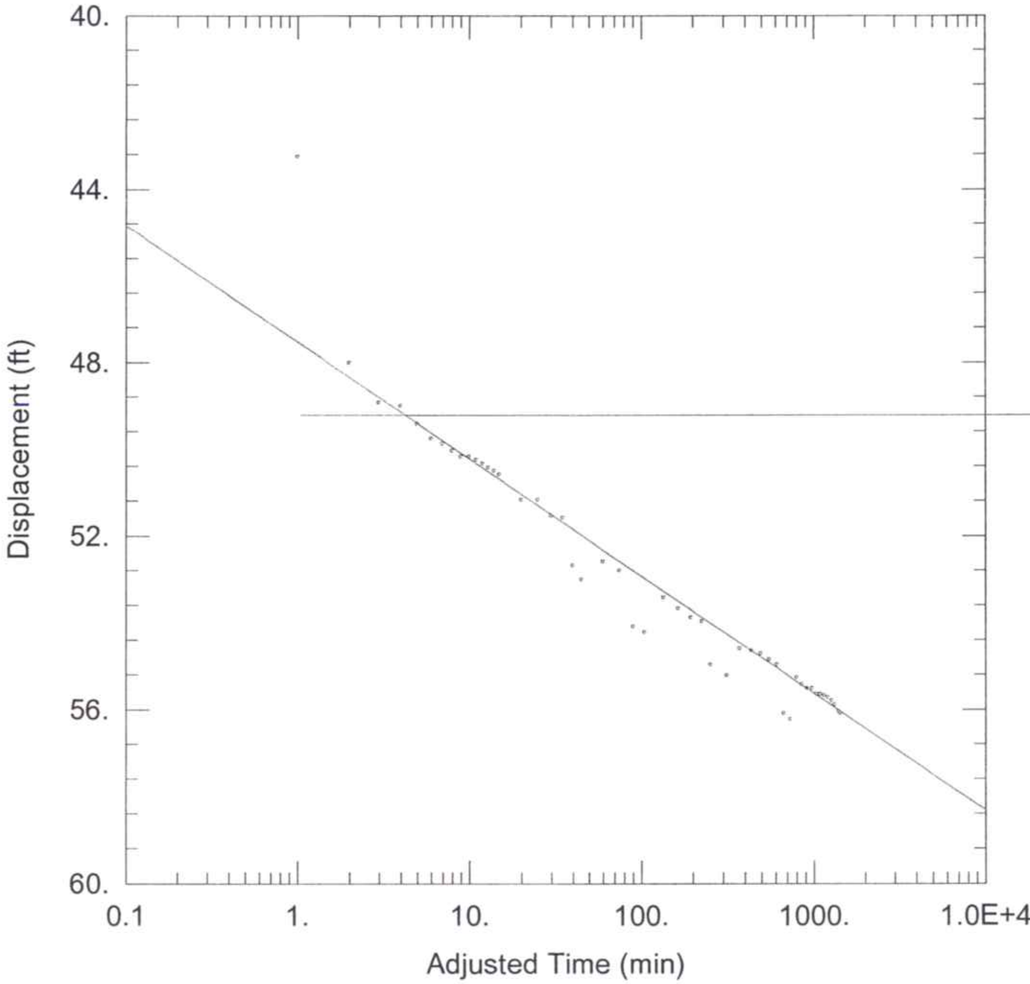
Aquifer Model: Confined Solution Method: Theis (Recovery)

T = 1.068E+4 ft^2/day S/S' = 0.6308

PW2 (6/21/78) Static= 6.75

Time (min.	Drawdown	Rate	W.L. (ft.)	(in.)	W.L. (dec.)	Spec. Cap.
1	43.25	503	50		50.00	11.63
2	48.00	503	54	9	54.75	10.48
3	48.92	503	55	8	55.67	10.28
4	49.00	503	55	9	55.75	10.27
5	49.42	503	56	2	56.17	10.18
6	49.75	503	56	6	56.50	10.11
7	49.88	503	56	7.5	56.63	10.09
8	50.04	503	56	9.5	56.79	10.05
9	50.17	503	56	11	56.92	10.03
10	50.17	503	56	11	56.92	10.03
11	50.25	503	57		57.00	10.01
12	50.33	503	57	1	57.08	9.99
13	50.42	503	57	2	57.17	9.98
14	50.50	503	57	3	57.25	9.96
15	50.58	503	57	4	57.33	9.94
20	51.17	503	57	11	57.92	9.83
25	51.17	503	57	11	57.92	9.83
30	51.54	503	58	3.5	58.29	9.76
35	51.58	503	58	4	58.33	9.75
40	52.67	503	59	5	59.42	9.55
45	53.00	503	59	9	59.75	9.49
60	52.58	503	59	4	59.33	9.57
75	52.79	503	59	6.5	59.54	9.53
90	54.08	503	60	10	60.83	9.30
105	54.21	503	60	11.5	60.96	9.28
135	53.42	503	60	2	60.17	9.42
165	53.67	503	60	5	60.42	9.37
195	53.88	503	60	7.5	60.63	9.34
225	53.96	503	60	8.5	60.71	9.32
255	54.96	503	61	8.5	61.71	9.15
315	55.21	503	61	11.5	61.96	9.11
375	54.58	503	61	4	61.33	9.22
435	54.63	503	61	4.5	61.38	9.21
495	54.71	503	61	5.5	61.46	9.19
555	54.83	503	61	7	61.58	9.17
615	54.96	503	61	8.5	61.71	9.15
675	56.08	503	62	10	62.83	8.97
735	56.21	503	62	11.5	62.96	8.95
795	55.25	503	62		62.00	9.10
855	55.42	503	62	2	62.17	9.08
915	55.50	503	62	3	62.25	9.06
975	55.50	503	62	3	62.25	9.06
1035	55.63	503	62	4.5	62.38	9.04
1095	55.63	503	62	4.5	62.38	9.04
1155	55.67	503	62	5	62.42	9.04
1215	55.71	503	62	5.5	62.46	9.03
1275	55.79	503	62	6.5	62.54	9.02
1335	55.88	503	62	7.5	62.63	9.00
1395	56.04	503	62	9.5	62.79	8.98

1440	56.08	503	62	10	62.83	8.97
1441	5.71		12	5.5	12.46	
1442	6.58		13	4	13.33	
1443	6.13		12	10.5	12.88	
1444	5.83		12	7	12.58	
1445	5.71		12	5.5	12.46	
1446	5.54		12	3.5	12.29	
1447	5.33		12	1	12.08	
1448	5.13		11	10.5	11.88	
1449	4.75		11	6	11.50	
1450	4.58		11	4	11.33	
1451	4.54		11	3.5	11.29	
1452	4.46		11	2.5	11.21	
1453	4.46		11	2.5	11.21	
1454	4.38		11	1.5	11.13	
1455	4.33		11	1	11.08	
1460	4.00		10	9	10.75	
1465	3.75		10	6	10.50	
1470	3.42		10	2	10.17	
1480	3.25		10		10.00	
1490	3.21		9	11.5	9.96	
1500	3.08		9	10	9.83	
1510	2.75		9	6	9.50	
1520	2.58		9	4	9.33	
1525	2.50		9	3	9.25	
1535	2.46		9	2.5	9.21	
1545	2.42		9	2	9.17	
1560	2.38		9	1.5	9.13	



ROANOKE IS. - SKYCO PW 24HR. TEST (1978)

Data Set: Z:\...\PW2 - 1978CJ.aqt
Date: 07/02/08 Time: 08:54:08

PROJECT INFORMATION

Company: GMA
Client: Dare Co.
Project: 103501
Location: Roanoke Island
Test Well: PW2
Test Date: 6/21/78

AQUIFER DATA

Saturated Thickness: 66. ft Anisotropy Ratio (Kz/Kr): 1.

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
PW2	0	0

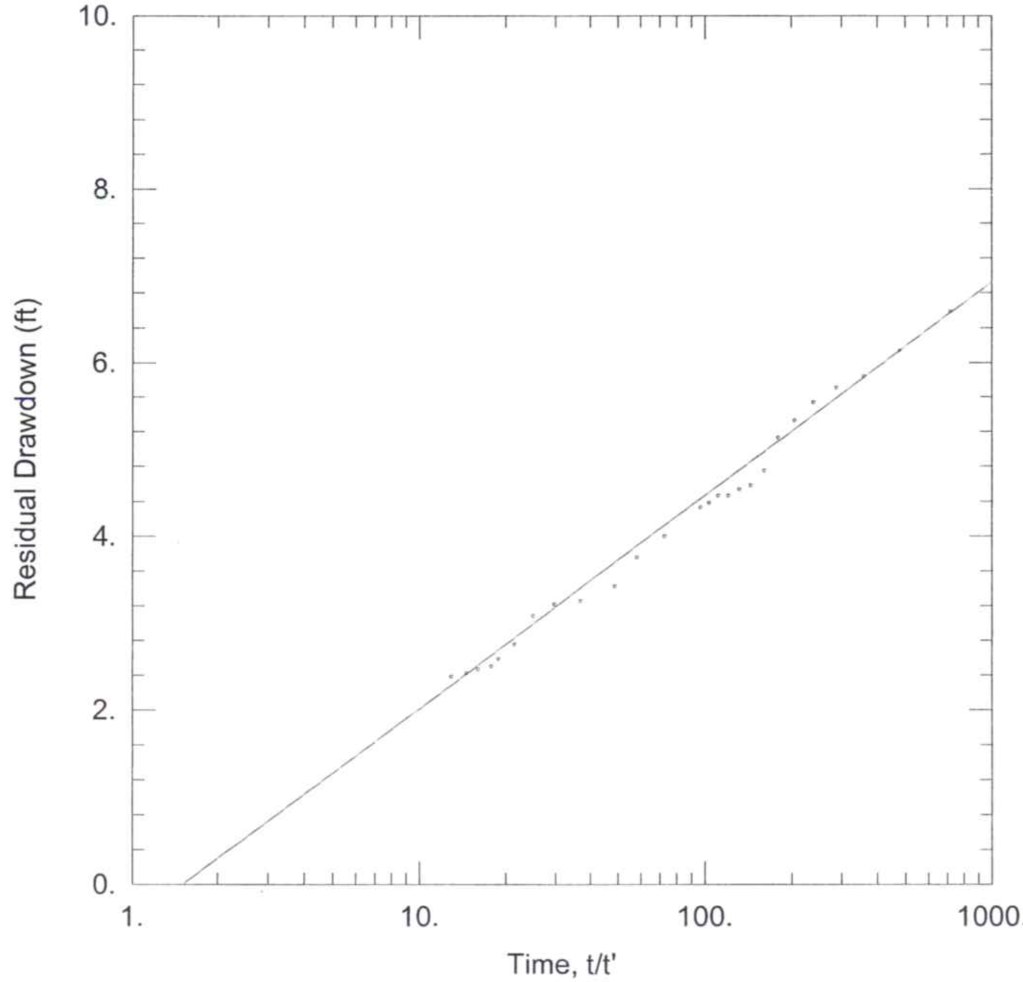
Observation Wells

Well Name	X (ft)	Y (ft)
PW2	0	0.33

SOLUTION

Aquifer Model: Confined Solution Method: Cooper-Jacob

$T = 6585.1\ ft^2/day$ $S = 2.161E-16$



ROANOKE IS. - SKYCO PW 24HR. TEST (1978)

Data Set: Z:\...\PW2 - 1978REC.aqt
Date: 07/02/08 Time: 08:54:20

PROJECT INFORMATION

Company: GMA
Client: Dare Co.
Project: 103501
Location: Roanoke Island
Test Well: PW2
Test Date: 6/21/78

AQUIFER DATA

Saturated Thickness: 66. ft Anisotropy Ratio (Kz/Kr): 1.

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
PW2	0	0

Observation Wells

Well Name	X (ft)	Y (ft)
PW2	0	0.33

SOLUTION

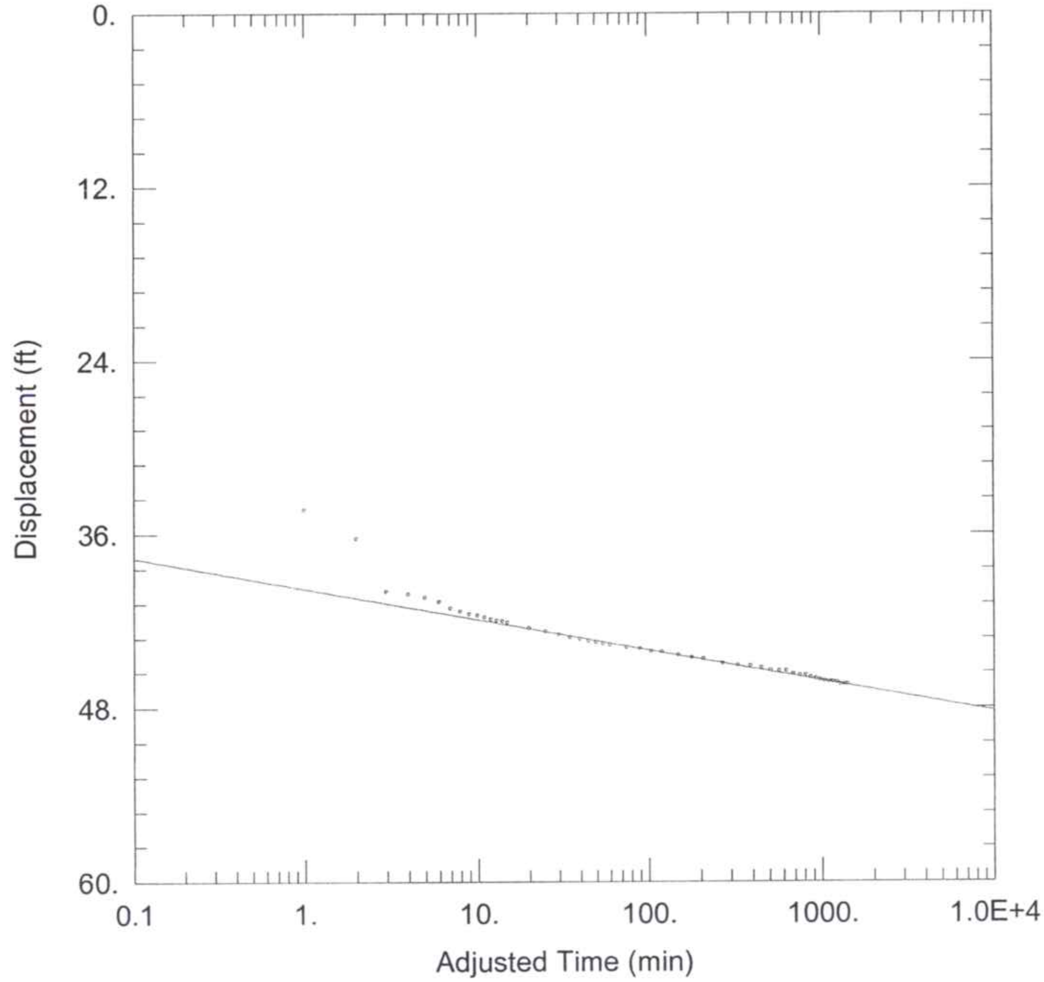
Aquifer Model: Confined Solution Method: Theis (Recovery)

T = 7221.1 ft^2/day S/S' = 1.524

PW5 (7/27/77) Static= 5.667

Time (min.	Drawdown	Rate	W.L. (ft.)	(in.)	W.L. (dec.	Spec. Cap.
1	34.33	503	40		40.00	14.65
2	36.33	503	42		42.00	13.84
3	39.96	503	45	7.5	45.63	12.59
4	40.17	503	45	10	45.83	12.52
5	40.37	503	46	0.5	46.04	12.46
6	40.71	503	46	4.5	46.38	12.36
7	41.12	503	46	9.5	46.79	12.23
8	41.37	503	47	0.5	47.04	12.16
9	41.54	503	47	2.5	47.21	12.11
10	41.62	503	47	3.5	47.29	12.08
11	41.77	503	47	5.25	47.44	12.04
12	41.87	503	47	6.5	47.54	12.01
13	41.96	503	47	7.5	47.63	11.99
14	42.04	503	47	8.5	47.71	11.96
15	42.10	503	47	9.25	47.77	11.95
20	42.52	503	48	2.25	48.19	11.83
25	42.75	503	48	5	48.42	11.77
30	42.96	503	48	7.5	48.63	11.71
35	43.15	503	48	9.75	48.81	11.66
40	43.27	503	48	11.25	48.94	11.62
45	43.42	503	49	1	49.08	11.59
50	43.50	503	49	2	49.17	11.56
55	43.58	503	49	3	49.25	11.54
60	43.67	503	49	4	49.33	11.52
75	43.83	503	49	6	49.50	11.48
90	43.92	503	49	7	49.58	11.45
105	44.12	503	49	9.5	49.79	11.40
120	44.17	503	49	10	49.83	11.39
150	44.37	503	50	0.5	50.04	11.34
180	44.54	503	50	2.5	50.21	11.29
210	44.65	503	50	3.75	50.31	11.27
270	44.96	503	50	7.5	50.63	11.19
330	45.08	503	50	9	50.75	11.16
390	45.15	503	50	9.75	50.81	11.14
450	45.27	503	50	11.25	50.94	11.11
510	45.46	503	51	1.5	51.13	11.07
570	45.50	503	51	2	51.17	11.06
630	45.50	503	51	2	51.17	11.06
690	45.69	503	51	4.25	51.35	11.01
750	45.79	503	51	5.5	51.46	10.98
810	45.81	503	51	5.75	51.48	10.98
870	45.92	503	51	7	51.58	10.95
930	46.00	503	51	8	51.67	10.93
990	46.10	503	51	9.25	51.77	10.91
1050	46.21	503	51	10.5	51.88	10.89
1110	46.23	503	51	10.75	51.90	10.88
1170	46.25	503	51	11	51.92	10.88
1230	46.27	503	51	11.25	51.94	10.87
1290	46.42	503	52	1	52.08	10.84

1350	46.42	503	52	1	52.08	10.84
1410	46.42	503	52	1	52.08	10.84
1441	6.92		12	7	12.58	
1442	5.75		11	5	11.42	
1443	5.33		11		11.00	
1444	5.02		10	8.25	10.69	
1445	4.73		10	4.75	10.40	
1446	4.50		10	2	10.17	
1447	4.33		10		10.00	
1448	4.17		9	10	9.83	
1449	4.02		9	8.25	9.69	
1450	3.92		9	7	9.58	
1451	3.79		9	5.5	9.46	
1452	3.69		9	4.25	9.35	
1453	3.62		9	3.5	9.29	
1454	3.52		9	2.25	9.19	
1455	3.44		9	1.25	9.10	
1460	3.12		8	9.5	8.79	
1465	2.92		8	7	8.58	
1470	2.73		8	4.75	8.40	
1475	2.54		8	2.5	8.21	
1480	2.40		8	0.75	8.06	
1485	2.29		7	11.5	7.96	
1490	2.21		7	10.5	7.88	
1495	2.12		7	9.5	7.79	
1500	2.04		7	8.5	7.71	
1515	1.85		7	6.25	7.52	
1530	1.67		7	4	7.33	
1560	1.54		7	2.5	7.21	



ROANOKE IS. - SKYCO PW5 4HR. TEST (1977)

Data Set: Z:\...\PW5 - 1977.aqt
Date: 07/02/08 Time: 08:54:32

PROJECT INFORMATION

Company: GMA
Client: Dare Co.
Project: 103501
Location: Roanoke Island
Test Well: PW5
Test Date: 7/27/77

AQUIFER DATA

Saturated Thickness: 50. ft Anisotropy Ratio (Kz/Kr): 1.

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
PW5	0	0

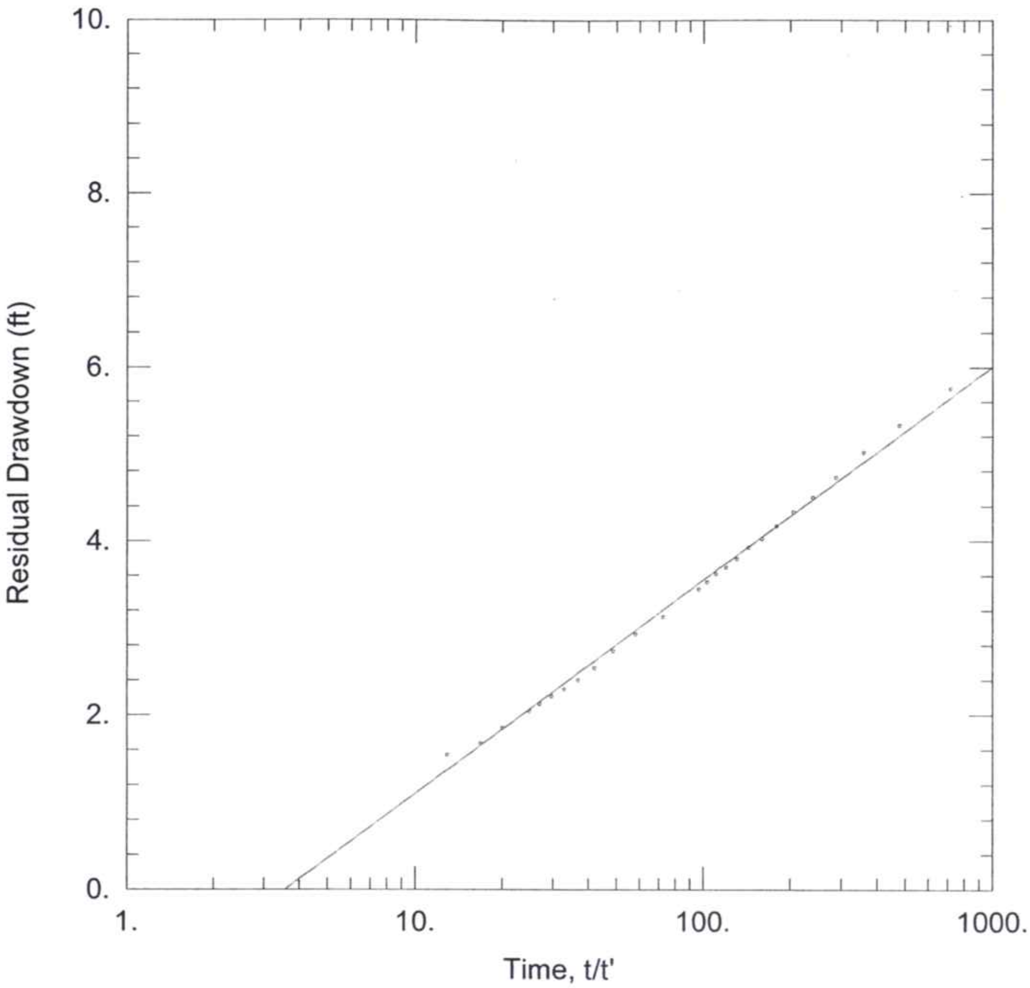
Observation Wells

Well Name	X (ft)	Y (ft)
PW5	0	0.33

SOLUTION

Aquifer Model: Confined Solution Method: Cooper-Jacob

T = 8404.3 ft^2/day S = 1.697E-17



ROANOKE IS. - SKYCO PW5, 24HR. TEST (1977)

Data Set: Z:\...\PW5 - 1977rec.aqt
Date: 07/02/08 Time: 08:54:59

PROJECT INFORMATION

Company: GMA
Client: Dare Co.
Project: 103501
Location: Roanoke Island
Test Well: PW5
Test Date: 7/27/77

AQUIFER DATA

Saturated Thickness: 50. ft Anisotropy Ratio (Kz/Kr): 1.

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
PW5	0	0

Observation Wells

Well Name	X (ft)	Y (ft)
PW5	0	0.33

SOLUTION

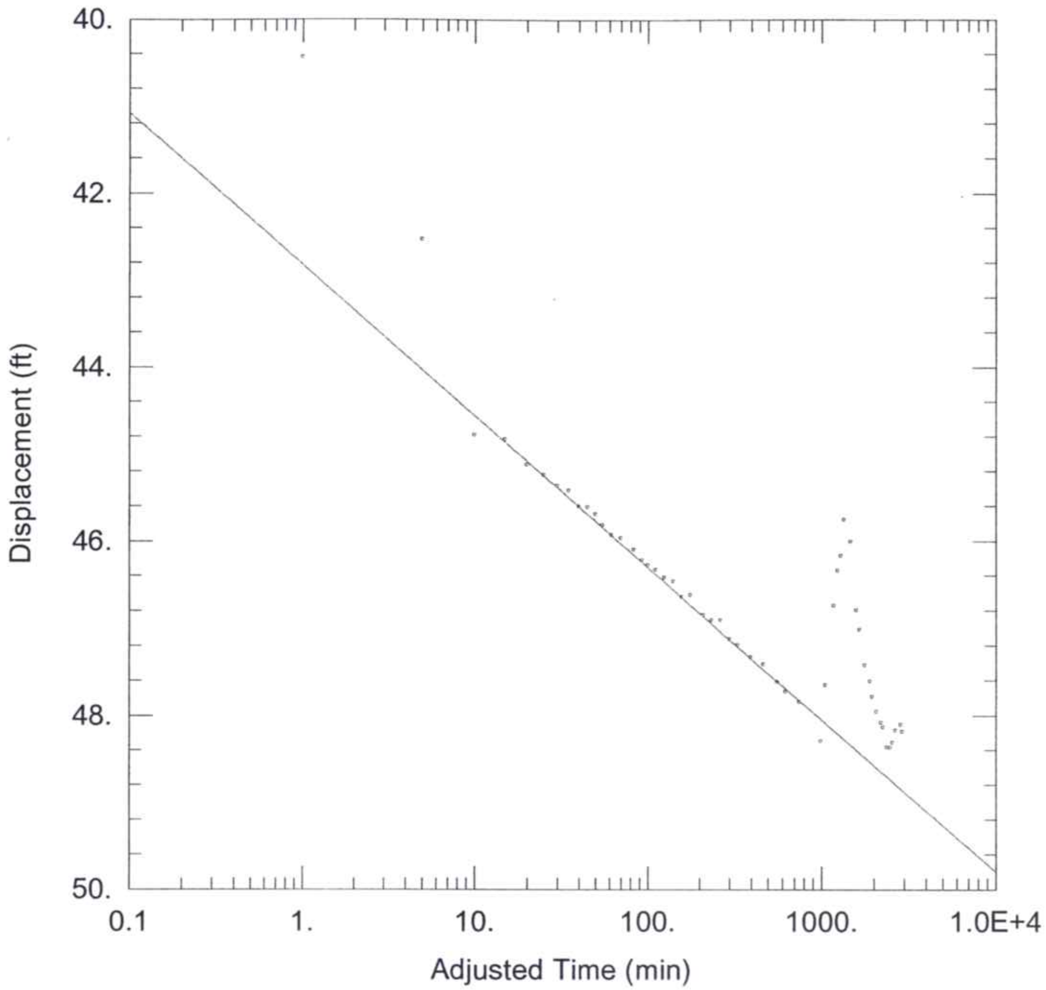
Aquifer Model: Confined Solution Method: Theis (Recovery)

T = 7231.4 ft^2/day S/S' = 3.593

PW6 (11/9/04) Static= 32.96

Time (min.	Drawdown	Rate	W.L. (dec.	Spec. Cap.
0.5	35.80	600	68.76	16.76
1	40.43	600	73.39	14.84
5	42.53	600	75.49	14.11
10	44.78	600	77.74	13.40
15	44.83	600	77.79	13.38
20	45.12	600	78.08	13.30
25	45.24	600	78.20	13.26
30	45.37	600	78.33	13.22
35	45.42	600	78.38	13.21
40	45.60	600	78.56	13.16
45	45.61	600	78.57	13.16
50	45.69	600	78.65	13.13
55	45.82	600	78.78	13.09
62	45.93	600	78.89	13.06
70	45.97	600	78.93	13.05
83	46.10	600	79.06	13.02
93	46.22	600	79.18	12.98
100	46.28	600	79.24	12.96
111	46.33	600	79.29	12.95
125	46.42	600	79.38	12.93
141	46.46	600	79.42	12.91
158	46.64	600	79.60	12.86
178	46.62	600	79.58	12.87
211	46.85	600	79.81	12.81
236	46.91	600	79.87	12.79
265	46.91	600	79.87	12.79
298	47.12	600	80.08	12.73
334	47.19	600	80.15	12.71
398	47.33	600	80.29	12.68
472	47.41	600	80.37	12.66
561	47.61	600	80.57	12.60
630	47.72	600	80.68	12.57
750	47.84	600	80.80	12.54
999	48.29	600	81.25	12.42
1058	47.65	600	80.61	12.59
1178	46.74	600	79.70	12.84
1238	46.34	600	79.30	12.95
1298	46.17	600	79.13	13.00
1358	45.75	600	78.71	13.11
1478	46.00	600	78.96	13.04
1598	46.79	600	79.75	12.82
1658	47.01	600	79.97	12.76
1778	47.42	600	80.38	12.65
1898	47.60	600	80.56	12.61
1958	47.78	600	80.74	12.56
2078	47.95	600	80.91	12.51
2198	48.08	600	81.04	12.48
2258	48.13	600	81.09	12.47
2378	48.36	600	81.32	12.41

2498	48.37	600	81.33	12.40
2558	48.31	600	81.27	12.42
2678	48.17	600	81.13	12.46
2858	48.10	600	81.06	12.47
2910	48.18	600	81.14	12.45
2911	4.99		37.95	
2919	3.23		36.19	
2929	2.63		35.59	
2939	2.28		35.24	
2949	2.09		35.05	
2959	1.94		34.90	
2969	1.80		34.76	
2979	1.71		34.67	
2989	1.62		34.58	
3029	1.40		34.36	
3147	1.06		34.02	
3271	0.91		33.87	
3397	0.82		33.78	
3527	0.77		33.73	
3645	0.66		33.62	
3787	0.56		33.52	
3897	0.47		33.43	
3957	0.42		33.38	
4157	0.27		33.23	
4231	0.22		33.18	
4395	0.14		33.10	
4483	0.12		33.08	
4579	0.10		33.06	
4677	0.06		33.02	
4783	0.02		32.98	
4895	-0.05		32.91	
5013	-1.05		31.91	
5373	-2.80		30.16	
5973	-1.92		31.04	
14853	-2.65		30.31	



ROANOKE IS. - SKYCO PW6, 24HR. TEST 2004

Data Set: Z:\...\PW6 - 2004.aqt
Date: 07/02/08 Time: 08:55:14

PROJECT INFORMATION

Company: GMA
Client: Dare Co.
Project: 103501
Location: Roanoke Island
Test Well: PW6
Test Date: 11/9/04

AQUIFER DATA

Saturated Thickness: 70. ft Anisotropy Ratio (Kz/Kr): 1.

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
PW6	0	0

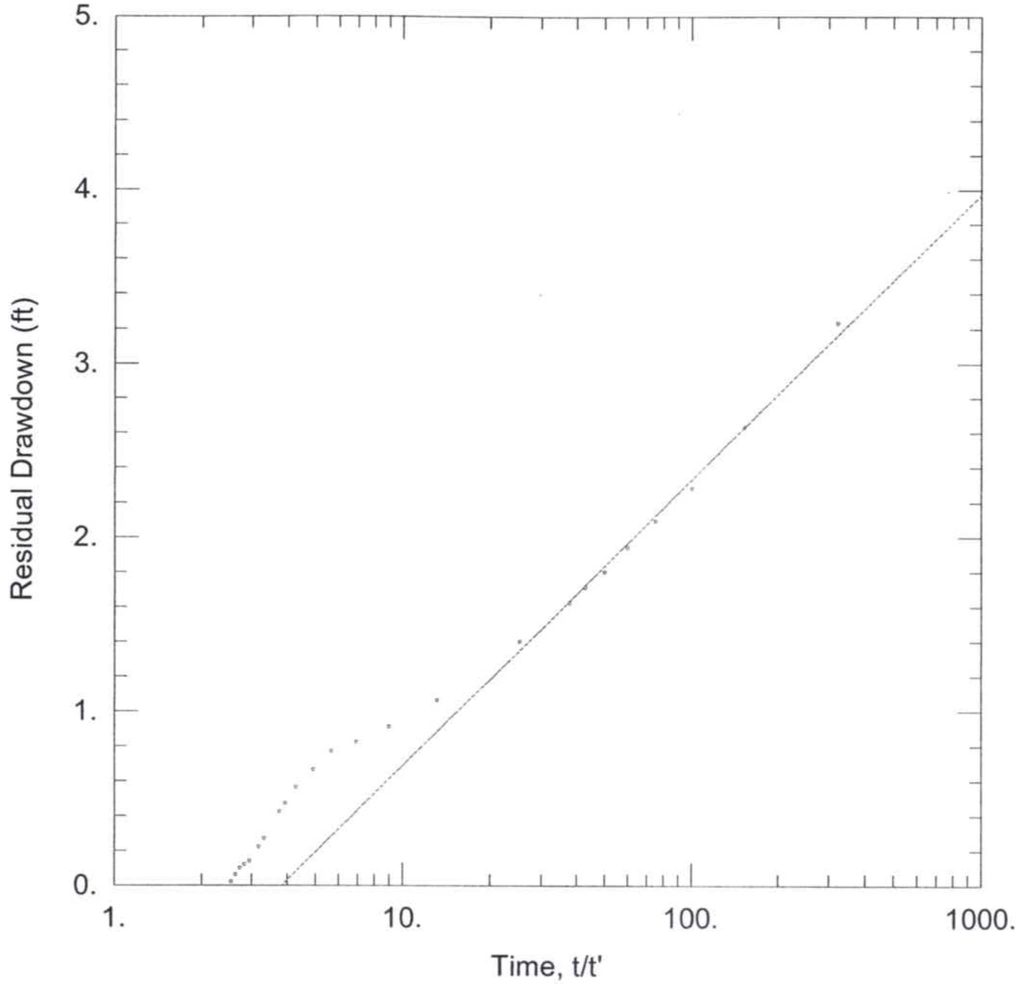
Observation Wells

Well Name	X (ft)	Y (ft)
PW6	0	0.33

SOLUTION

Aquifer Model: Confined Solution Method: Cooper-Jacob

T = 1.215E+4 ft^2/day S = 4.664E-23



ROANOKE IS. - SKYCO PW6, 24HR. TEST 2004

Data Set: Z:\...\PW6 - 2004REC.aqt
Date: 07/02/08 Time: 08:55:28

PROJECT INFORMATION

Company: GMA
Client: Dare Co.
Project: 103501
Location: Roanoke Island
Test Well: PW6
Test Date: 11/9/04

AQUIFER DATA

Saturated Thickness: 70. ft Anisotropy Ratio (Kz/Kr): 1.

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
PW6	0	0

Observation Wells

Well Name	X (ft)	Y (ft)
PW6	0	0.33

SOLUTION

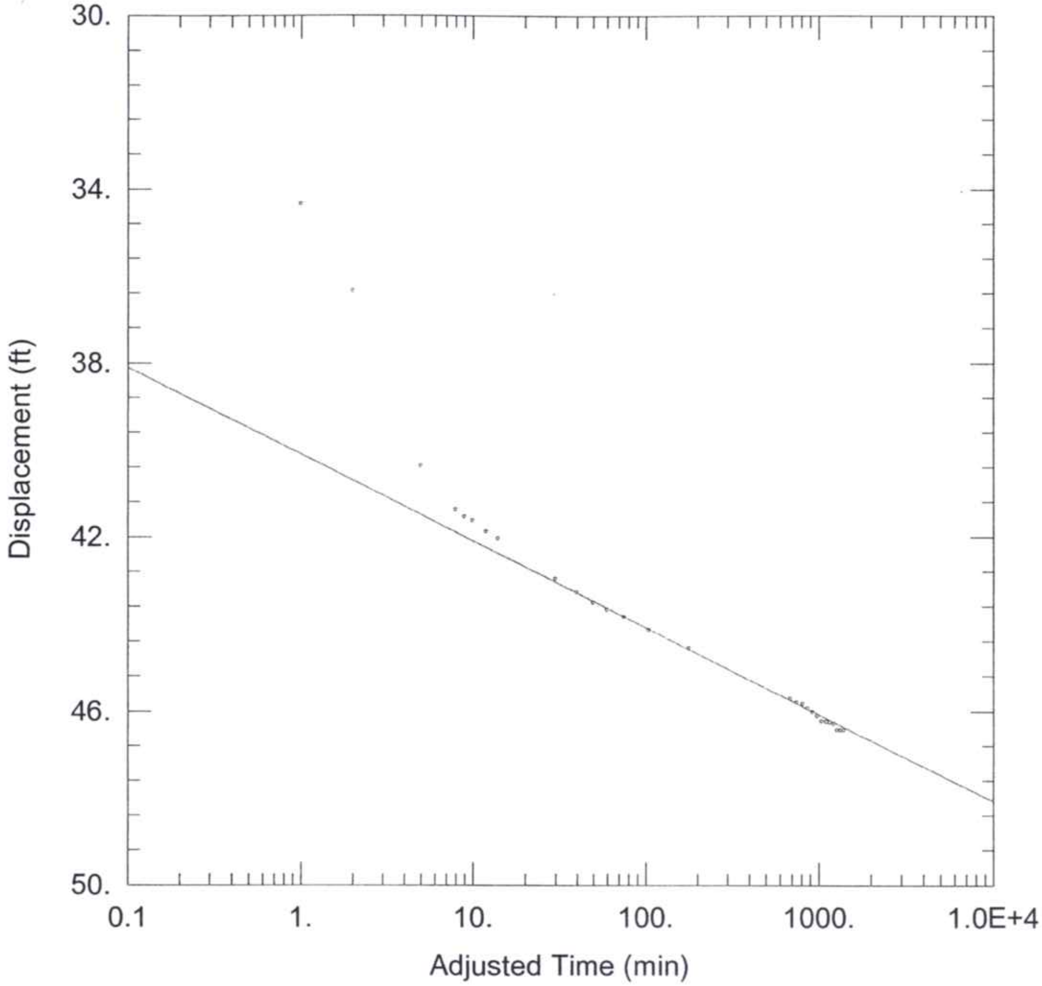
Aquifer Model: Confined Solution Method: Theis (Recovery)

T = 1.289E+4 ft^2/day S/S' = 3.831

PW8 (5/2/78) Static= 3.75

Time (min.	Drawdown	Rate	W.L. (ft.)	(in.)	W.L. (dec.	Spec. Cap.
1	65.00	503	68	9	68.75	7.74
2	68.96	503	72	8.5	72.71	7.29
3	69.67	503	73	5	73.42	7.22
4	70.25	503	74		74.00	7.16
5	71.54	503	75	3.5	75.29	7.03
6	71.83	503	75	7	75.58	7.00
7	72.08	503	75	10	75.83	6.98
8	72.42	503	76	2	76.17	6.95
9	72.71	503	76	5.5	76.46	6.92
10	73.00	503	76	9	76.75	6.89
11	73.25	503	77		77.00	6.87
12	73.42	503	77	2	77.17	6.85
13	73.58	503	77	4	77.33	6.84
14	73.83	503	77	7	77.58	6.81
15	73.92	503	77	8	77.67	6.80
20	74.42	503	78	2	78.17	6.76
25	74.75	503	78	6	78.50	6.73
30	74.92	503	78	8	78.67	6.71
35	74.92	503	78	8	78.67	6.71
40	75.42	503	79	2	79.17	6.67
45	75.50	503	79	3	79.25	6.66
50	75.63	503	79	4.5	79.38	6.65
55	75.79	503	79	6.5	79.54	6.64
60	75.92	503	79	8	79.67	6.63
75	76.04	503	79	9.5	79.79	6.61
90	76.42	503	80	2	80.17	6.58
105	76.79	503	80	6.5	80.54	6.55
120	76.92	503	80	8	80.67	6.54
150	77.04	503	80	9.5	80.79	6.53
180	77.33	503	81	1	81.08	6.50
210	77.54	503	81	3.5	81.29	6.49
240	77.79	503	81	6.5	81.54	6.47
270	78.08	503	81	10	81.83	6.44
300	78.58	503	82	4	82.33	6.40
330	79.63	503	83	4.5	83.38	6.32
360	80.04	503	83	9.5	83.79	6.28
390	80.38	503	84	1.5	84.13	6.26
420	80.50	503	84	3	84.25	6.25
450	81.00	503	84	9	84.75	6.21
480	81.04	503	84	9.5	84.79	6.21
510	81.08	503	84	10	84.83	6.20
540	81.17	503	84	11	84.92	6.20
570	81.17	503	84	11	84.92	6.20
600	81.42	503	85	2	85.17	6.18
630	81.50	503	85	3	85.25	6.17
660	81.63	503	85	4.5	85.38	6.16
720	81.75	503	85	6	85.50	6.15
780	82.00	503	85	9	85.75	6.13
840	82.25	503	86		86.00	6.12

900	82.42	503	86	2	86.17	6.10
960	82.58	503	86	4	86.33	6.09
1020	82.58	503	86	4	86.33	6.09
1080	82.67	503	86	5	86.42	6.08
1140	82.88	503	86	7.5	86.63	6.07
1200	83.04	503	86	9.5	86.79	6.06
1260	83.13	503	86	10.5	86.88	6.05
1320	83.21	503	86	11.5	86.96	6.05
1380	83.21	503	86	11.5	86.96	6.05
1440	83.25	503	87		87.00	6.04
1455	83.25	503	87		87.00	6.04
1456	21.25		25		25.00	
1457	6.25		10		10.00	
1458	5.17		8	11	8.92	
1459	4.33		8	1	8.08	
1460	3.92		7	8	7.67	
1465	3.67		7	5	7.42	
1470	3.13		6	10.5	6.88	
1480	2.75		6	6	6.50	
1490	2.42		6	2	6.17	
1500	2.25		6		6.00	
1515	2.08		5	10	5.83	
1530	1.92		5	8	5.67	
1560	1.67		5	5	5.42	
1590	1.50		5	3	5.25	



ROANOKE IS. - SKYCO PW8, 24HR. TEST (1978)

Data Set: Z:\...\PW8 - 1978.aqt
Date: 07/02/08 Time: 08:55:39

PROJECT INFORMATION

Company: GMA
Client: Dare Co.
Project: 103501
Location: Roanoke Island
Test Well: PW8
Test Date: 5/2/78

AQUIFER DATA

Saturated Thickness: 88. ft Anisotropy Ratio (Kz/Kr): 1.

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
PW8	0	0

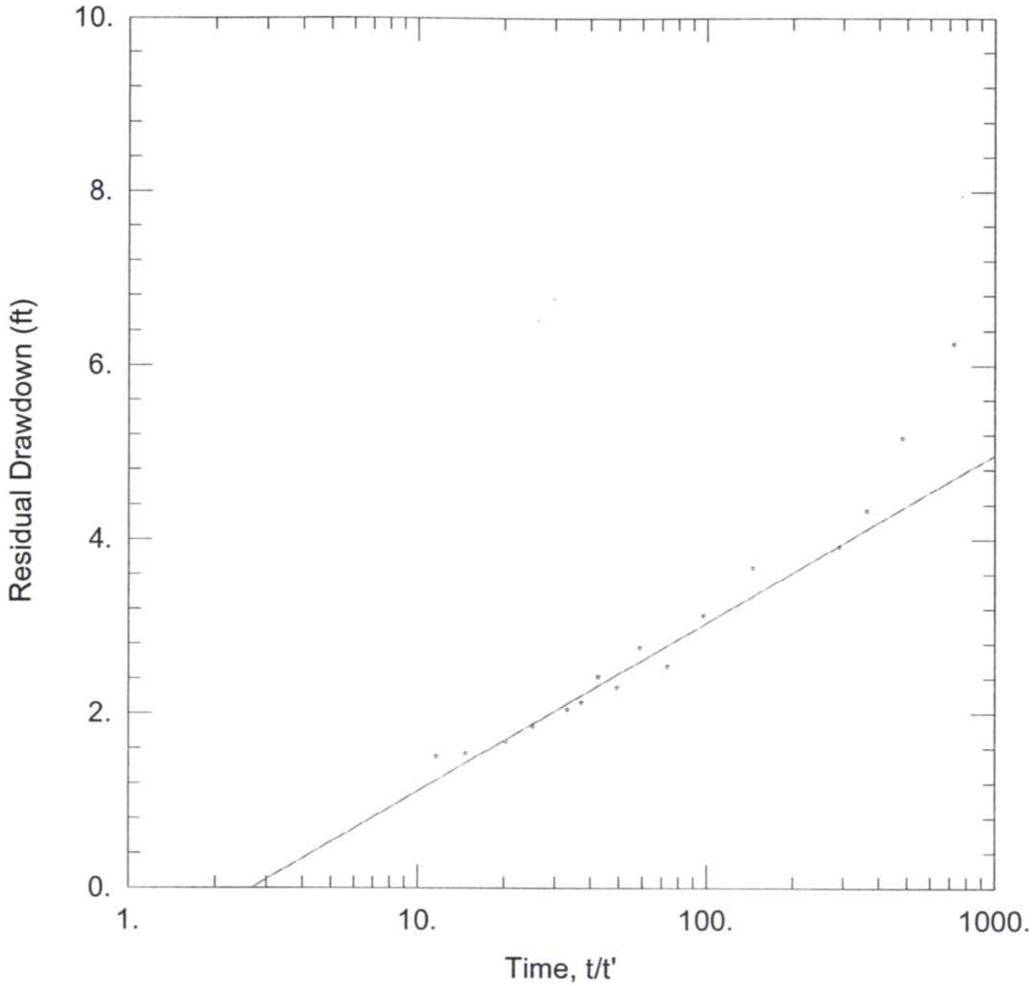
Observation Wells

Well Name	X (ft)	Y (ft)
PW8	0	0.33

SOLUTION

Aquifer Model: Confined
Solution Method: Cooper-Jacob

T = 8914.9 ft^2/day
S = 9.125E-19



ROANOKE IS. - SKYCO PW8, 24HR. TEST (1978)

Data Set: Z:\...\PW8 - 1978rec.aqt
Date: 07/02/08 Time: 08:55:51

PROJECT INFORMATION

Company: GMA
Client: Dare Co.
Project: 103501
Location: Roanoke Island
Test Well: PW8
Test Date: 5/2/78

AQUIFER DATA

Saturated Thickness: 88. ft Anisotropy Ratio (Kz/Kr): 1.

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
PW8	0	0

Observation Wells

Well Name	X (ft)	Y (ft)
PW8	0	0.33

SOLUTION

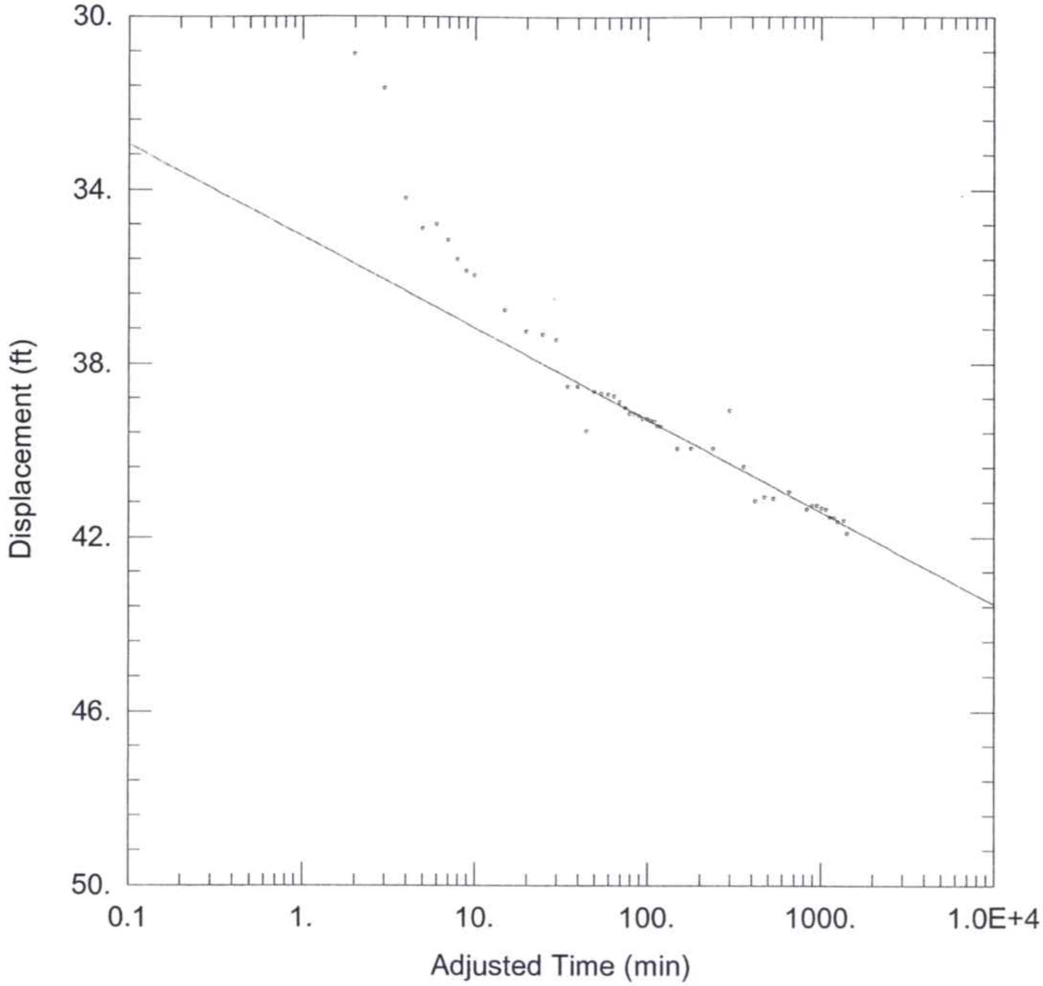
Aquifer Model: Confined Solution Method: Theis (Recovery)

T = 9183.1 ft^2/day S/S' = 2.685

PW9 (1/3/74) Static= 3.74

Time (min.	Drawdown	Rate	W.L. (dec.	Spec. Cap.
1	29.36	852	33.10	29.02
2	30.88	847	34.62	27.43
3	31.66	852	35.40	26.91
4	34.20	847	37.94	24.77
5	34.89	836	38.63	23.96
6	34.79	842	38.53	24.20
7	35.16	842	38.90	23.95
8	35.61	842	39.35	23.65
9	35.87	842	39.61	23.47
10	35.98	842	39.72	23.40
15	36.78	842	40.52	22.89
20	37.27	842	41.01	22.59
25	37.34	836	41.08	22.39
30	37.46	836	41.20	22.32
35	38.54	852	42.28	22.11
40	38.54	852	42.28	22.11
45	39.57	852	43.31	21.53
50	38.66	847	42.40	21.91
55	38.70	847	42.44	21.89
60	38.72	847	42.46	21.88
65	38.77	847	42.51	21.85
70	38.89	847	42.63	21.78
75	39.03	847	42.77	21.70
80	39.17	847	42.91	21.62
85	39.16	842	42.90	21.50
90	39.20	842	42.94	21.48
95	39.28	842	43.02	21.44
100	39.28	842	43.02	21.43
105	39.32	842	43.06	21.41
110	39.34	842	43.08	21.40
115	39.44	842	43.18	21.35
120	39.46	842	43.20	21.34
150	39.96	842	43.70	21.07
180	39.96	842	43.70	21.07
240	39.96	842	43.70	21.07
300	39.09	836	42.83	21.39
360	40.38	836	44.12	20.70
420	41.16	836	44.90	20.31
480	41.08	836	44.82	20.35
540	41.10	836	44.84	20.34
600	-3.74	836		
660	40.96	836	44.70	20.41
840	41.36	836	45.10	20.21
900	41.27	836	45.01	20.26
960	41.27	836	45.01	20.26
1020	41.33	836	45.07	20.23
1080	41.36	836	45.10	20.21
1140	41.53	836	45.27	20.13
1200	41.55	836	45.29	20.12

1260	41.63	836	45.37	20.08
1320	-3.74	836		
1380	41.61	836	45.35	20.09
1440	41.91	836	45.65	19.95
1441	8.86		12.60	
1442	7.62		11.36	
1443	7.12		10.86	
1444	7.21		10.95	
1445	6.23		9.97	
1446	6.02		9.76	
1447	5.82		9.56	
1448	5.70		9.44	
1449	5.53		9.27	
1450	5.36		9.10	
1451	5.22		8.96	
1452	5.20		8.94	
1453	5.13		8.87	
1454	5.00		8.74	
1455	4.93		8.67	
1460	4.55		8.29	
1465	4.23		7.97	
1470	4.09		7.83	
1475	4.00		7.74	
1480	3.84		7.58	
1485	3.70		7.44	
1490	3.72		7.46	
1495	3.76		7.50	
1500	3.43		7.17	
1505	3.38		7.12	
1510	3.22		6.96	
1515	3.26		7.00	
1520	3.21		6.95	
1525	3.15		6.89	
1530	3.09		6.83	
1535	3.06		6.80	
1540	2.96		6.70	
1545	2.90		6.64	
1550	2.89		6.63	
1555	2.91		6.65	
1560	2.86		6.60	
1620	2.23		5.97	
1680	2.00		5.74	
1800	1.60		5.34	



ROANOKE IS. - SKYCO PW9, 24HR. TEST (1974)

Data Set: Z:\...\PW9 - 1974.aqt
Date: 07/02/08 Time: 08:56:05

PROJECT INFORMATION

Company: GMA
Client: Dare Co.
Project: 103501
Location: Roanoke Island
Test Well: PW9
Test Date: 1/3/74

AQUIFER DATA

Saturated Thickness: 70. ft Anisotropy Ratio (Kz/Kr): 1.

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
PW9	0	0

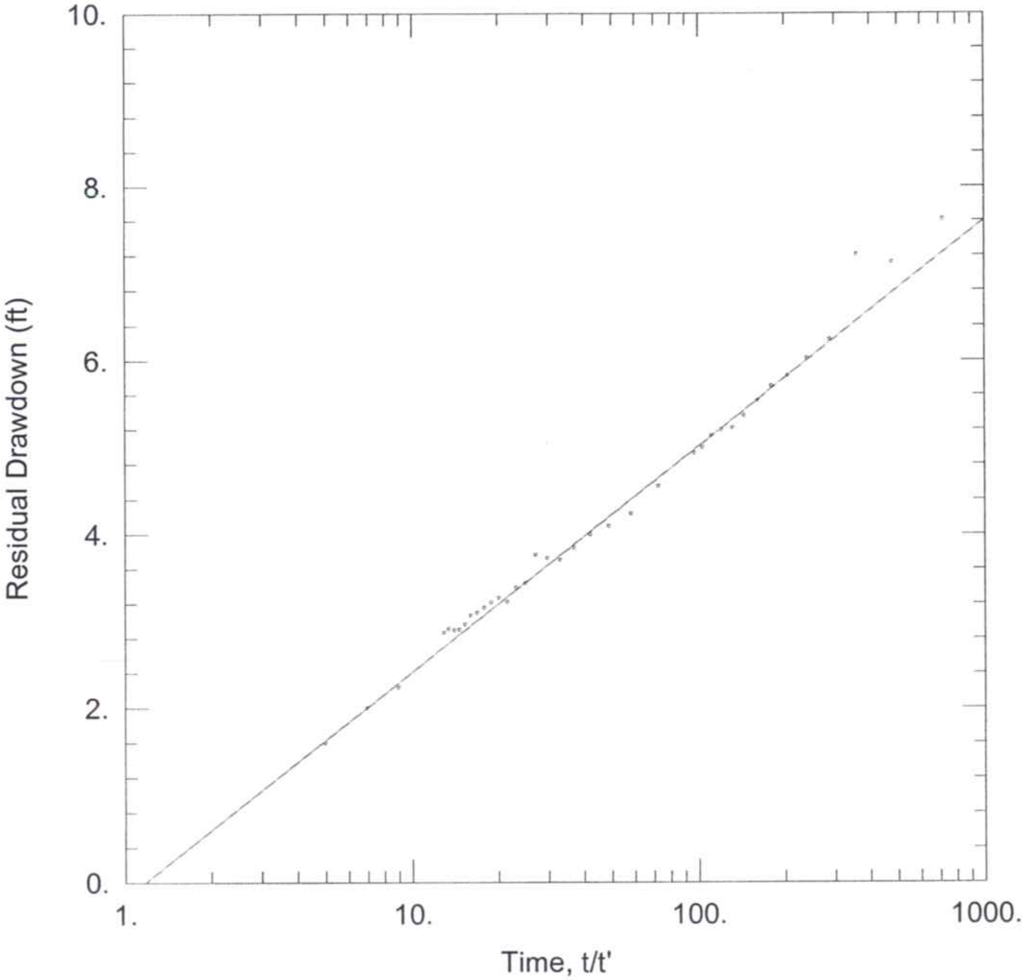
Observation Wells

Well Name	X (ft)	Y (ft)
PW9	0	0.33

SOLUTION

Aquifer Model: Confined Solution Method: Cooper-Jacob

T = 1.401E+4 ft^2/day S = 5.336E-15



ROANOKE IS. - SKYCO PW9, 24HR. TEST (1974)

Data Set: Z:\...\PW9 - 1974rec.aqt
Date: 07/02/08 Time: 08:56:16

PROJECT INFORMATION

Company: GMA
Client: Dare Co.
Project: 103501
Location: Roanoke Island
Test Well: PW9
Test Date: 1/3/74

AQUIFER DATA

Saturated Thickness: 70. ft Anisotropy Ratio (Kz/Kr): 1.

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
PW9	0	0

Observation Wells

Well Name	X (ft)	Y (ft)
PW9	0	0.33

SOLUTION

Aquifer Model: Confined Solution Method: Theis (Recovery)

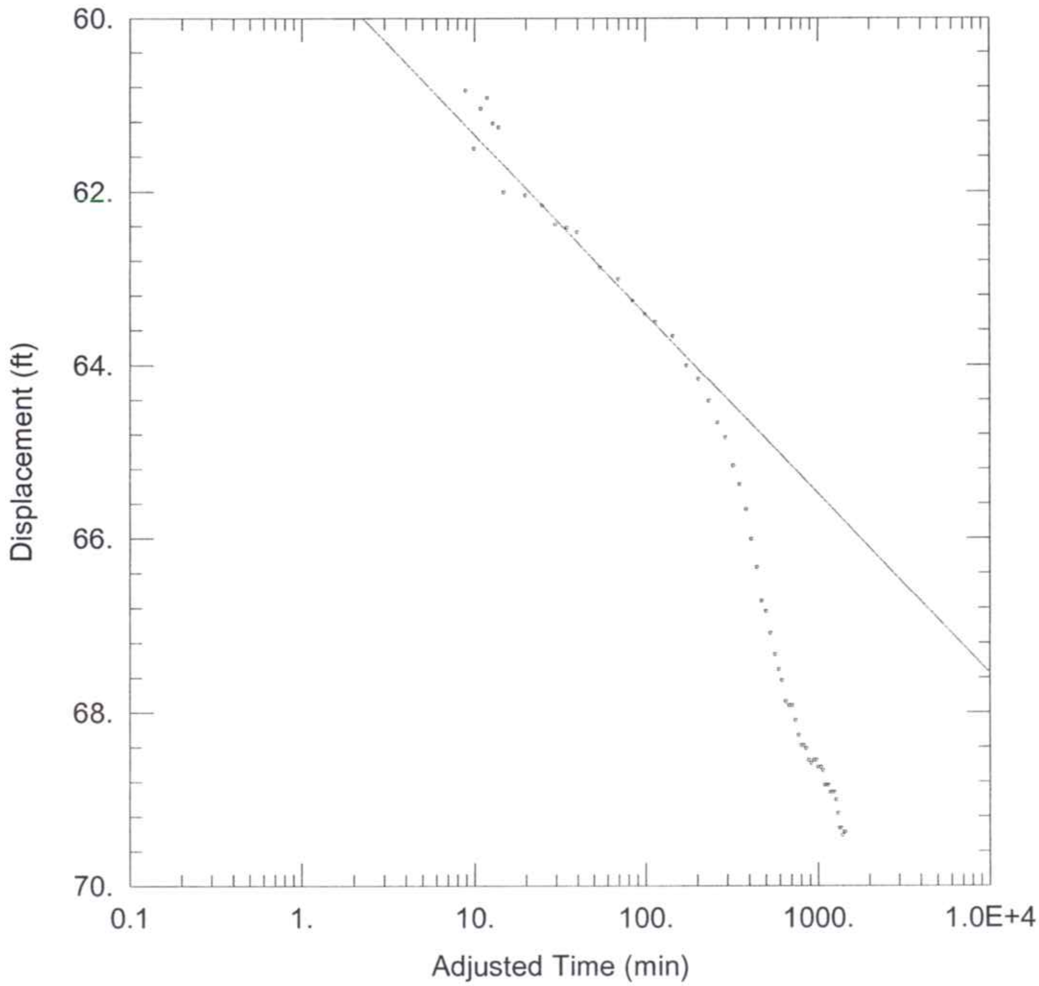
T = 1.142E+4 ft^2/day S/S' = 1.179

PW10 (3/30/78) Static= 7.16

Time (min.	Drawdown	Rate	W.L. (ft.)	(in.)	W.L. (dec.	Spec. Cap.
1	47.92	554	55	1	55.08	11.56
9	60.84	554	68		68.00	9.11
10	61.51	554	68	8	68.67	9.01
11	61.05	554	68	2.5	68.21	9.07
12	60.92	554	68	1	68.08	9.09
13	61.22	554	68	4.5	68.38	9.05
14	61.26	554	68	5	68.42	9.04
15	62.01	554	69	2	69.17	8.93
20	62.05	554	69	2.5	69.21	8.93
25	62.17	554	69	4	69.33	8.91
30	62.38	554	69	6.5	69.54	8.88
35	62.42	554	69	7	69.58	8.87
40	62.47	554	69	7.5	69.63	8.87
55	62.88	554	70	0.5	70.04	8.81
70	63.01	554	70	2	70.17	8.79
85	63.26	554	70	5	70.42	8.76
100	63.42	554	70	7	70.58	8.73
115	63.51	554	70	8	70.67	8.72
145	63.67	554	70	10	70.83	8.70
175	64.01	554	71	2	71.17	8.66
205	64.17	554	71	4	71.33	8.63
235	64.42	554	71	7	71.58	8.60
265	64.67	554	71	10	71.83	8.57
295	64.84	554	72		72.00	8.54
325	65.17	554	72	4	72.33	8.50
355	65.38	554	72	6.5	72.54	8.47
385	65.67	554	72	10	72.83	8.44
415	66.01	554	73	2	73.17	8.39
445	66.34	554	73	6	73.50	8.35
475	66.72	554	73	10.5	73.88	8.30
505	66.84	554	74		74.00	8.29
535	67.09	554	74	3	74.25	8.26
565	67.34	554	74	6	74.50	8.23
595	67.51	554	74	8	74.67	8.21
625	67.63	554	74	9.5	74.79	8.19
655	67.88	554	75	0.5	75.04	8.16
685	67.92	554	75	1	75.08	8.16
715	67.92	554	75	1	75.08	8.16
745	68.09	554	75	3	75.25	8.14
775	68.26	554	75	5	75.42	8.12
805	68.38	554	75	6.5	75.54	8.10
835	68.38	554	75	6.5	75.54	8.10
865	68.42	554	75	7	75.58	8.10
895	68.55	554	75	8.5	75.71	8.08
925	68.59	554	75	9	75.75	8.08
955	68.55	554	75	8.5	75.71	8.08
985	68.55	554	75	8.5	75.71	8.08
1015	68.63	554	75	9.5	75.79	8.07
1045	68.63	554	75	9.5	75.79	8.07

1075	68.67	554	75	10	75.83	8.07
1105	68.84	554	76		76.00	8.05
1135	68.84	554	76		76.00	8.05
1165	68.84	554	76		76.00	8.05
1195	68.92	554	76	1	76.08	8.04
1225	68.92	554	76	1	76.08	8.04
1255	68.92	554	76	1	76.08	8.04
1285	69.01	554	76	2	76.17	8.03
1315	69.17	554	76	4	76.33	8.01
1345	69.34	554	76	6	76.50	7.99
1375	69.34	554	76	6	76.50	7.99
1405	69.42	554	76	7	76.58	7.98
1435	69.38	554	76	6.5	76.54	7.98
1445	69.38	554	76	6.5	76.54	7.98

*No usable recovery data.



ROANOKE IS. - SKYCO PW10, 24HR. TEST (1978)

Data Set: Z:\...\PW10 - 1978.aqt
Date: 07/02/08 Time: 08:56:33

PROJECT INFORMATION

Company: GMA
Client: Dare Co.
Project: 103501
Location: Roanoke Island
Test Well: PW10
Test Date: 3/30/78

AQUIFER DATA

Saturated Thickness: 70. ft Anisotropy Ratio (Kz/Kr): 1.

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
PW10	0	0

Observation Wells

Well Name	X (ft)	Y (ft)
PW10	0	0.33

SOLUTION

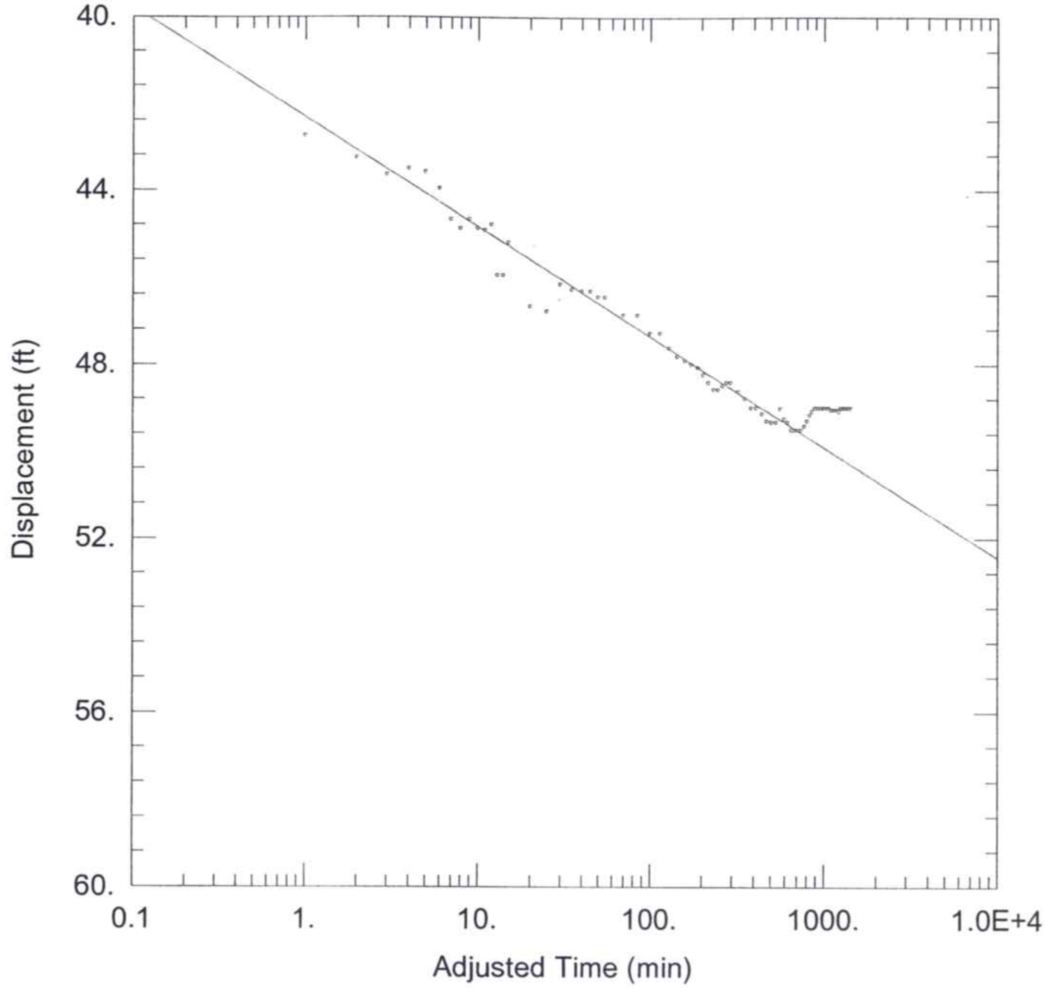
Aquifer Model: Confined Solution Method: Cooper-Jacob

$T = 9448.6\ ft^2/day$ $S = 2.953E-27$

PW12 (2/6/78) Static= 1

Time (min.	Drawdown	Rate	W.L. (ft.)	(in.)	W.L. (dec.	Spec. Cap.
1	42.75	900	43	9	43.75	21.05
2	43.25	900	44	3	44.25	20.81
3	43.63	900	44	7.5	44.63	20.63
4	43.50	900	44	6	44.50	20.69
5	43.58	900	44	7	44.58	20.65
6	43.96	900	44	11.5	44.96	20.47
7	44.67	900	45	8	45.67	20.15
8	44.88	900	45	10.5	45.88	20.06
9	44.67	900	45	8	45.67	20.15
10	44.88	900	45	10.5	45.88	20.06
11	44.92	900	45	11	45.92	20.04
12	44.79	900	45	9.5	45.79	20.09
13	45.96	900	46	11.5	46.96	19.58
14	45.96	900	46	11.5	46.96	19.58
15	45.21	900	46	2.5	46.21	19.91
20	46.67	900	47	8	47.67	19.29
25	46.79	900	47	9.5	47.79	19.23
30	46.17	900	47	2	47.17	19.49
35	46.29	900	47	3.5	47.29	19.44
40	46.33	900	47	4	47.33	19.42
45	46.33	900	47	4	47.33	19.42
50	46.46	900	47	5.5	47.46	19.37
55	46.46	900	47	5.5	47.46	19.37
70	46.88	900	47	10.5	47.88	19.20
85	46.88	900	47	10.5	47.88	19.20
100	47.29	900	48	3.5	48.29	19.03
115	47.29	900	48	3.5	48.29	19.03
130	47.63	900	48	7.5	48.63	18.90
145	47.83	900	48	10	48.83	18.82
160	47.92	900	48	11	48.92	18.78
175	48.00	900	49		49.00	18.75
190	48.08	900	49	1	49.08	18.72
205	48.25	900	49	3	49.25	18.65
220	48.42	900	49	5	49.42	18.59
235	48.58	900	49	7	49.58	18.52
250	48.58	900	49	7	49.58	18.52
265	48.50	900	49	6	49.50	18.56
280	48.42	900	49	5	49.42	18.59
295	48.42	900	49	5	49.42	18.59
325	48.63	900	49	7.5	49.63	18.51
355	48.79	900	49	9.5	49.79	18.45
385	49.00	900	50		50.00	18.37
415	49.00	900	50		50.00	18.37
445	49.13	900	50	1.5	50.13	18.32
475	49.29	900	50	3.5	50.29	18.26
505	49.33	900	50	4	50.33	18.24
535	49.33	900	50	4	50.33	18.24
565	49.02	900	50	0.25	50.02	18.36
595	49.25	900	50	3	50.25	18.27

625	49.33	900	50	4	50.33	18.24
655	49.50	900	50	6	50.50	18.18
685	49.50	900	50	6	50.50	18.18
715	49.50	900	50	6	50.50	18.18
745	49.50	900	50	6	50.50	18.18
775	49.42	900	50	5	50.42	18.21
805	49.29	900	50	3.5	50.29	18.26
835	49.17	900	50	2	50.17	18.31
865	49.08	900	50	1	50.08	18.34
895	49.00	900	50		50.00	18.37
925	49.00	900	50		50.00	18.37
955	49.00	900	50		50.00	18.37
985	49.00	900	50		50.00	18.37
1015	49.00	900	50		50.00	18.37
1045	49.00	900	50		50.00	18.37
1075	49.00	900	50		50.00	18.37
1105	49.04	900	50	0.5	50.04	18.35
1135	49.04	900	50	0.5	50.04	18.35
1165	49.04	900	50	0.5	50.04	18.35
1195	49.04	900	50	0.5	50.04	18.35
1225	49.08	900	50	1	50.08	18.34
1255	49.00	900	50		50.00	18.37
1285	49.00	900	50		50.00	18.37
1315	49.00	900	50		50.00	18.37
1345	49.00	900	50		50.00	18.37
1375	49.00	900	50		50.00	18.37
1405	49.00	900	50		50.00	18.37
1440	49.00	900	50		50.00	18.37
1442	49.00	900	50		50.00	18.37
1443	7.33		8	4	8.33	
1444	7.17		8	2	8.17	
1445	6.92		7	11	7.92	
1446	6.50		7	6	7.50	
1447	6.17		7	2	7.17	
1448	5.92		6	11	6.92	
1449	5.67		6	8	6.67	
1450	5.21		6	2.5	6.21	
1451	4.92		5	11	5.92	
1452	4.75		5	9	5.75	
1453	4.58		5	7	5.58	
1454	4.54		5	6.5	5.54	
1455	4.50		5	6	5.50	
1456	4.46		5	5.5	5.46	
1457	4.42		5	5	5.42	
1462	4.21		5	2.5	5.21	
1465	3.92		4	11	4.92	
1470	3.67		4	8	4.67	
1475	3.50		4	6	4.50	
1479	3.33		4	4	4.33	
1484	3.17		4	2	4.17	
1489	3.00		4		4.00	
1494	2.92		3	11	3.92	
1499	2.75		3	9	3.75	
1504	2.63		3	7.5	3.63	
1514	2.42		3	5	3.42	
1524	2.33		3	4	3.33	
1534	2.25		3	3	3.25	
1544	2.17		3	2	3.17	
1554	2.13		3	1.5	3.13	



ROANOKE IS. - SKYCO PW12, 24HR. TEST (1978)

Data Set: Z:\...\PW12 - 1978.aqt
Date: 07/02/08
Time: 08:56:46

PROJECT INFORMATION

Company: GMA
Client: Dare Co.
Project: 103501
Location: Roanoke Island
Test Well: PW12
Test Date: 2/9/78

AQUIFER DATA

Saturated Thickness: 50. ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
PW12	0	0

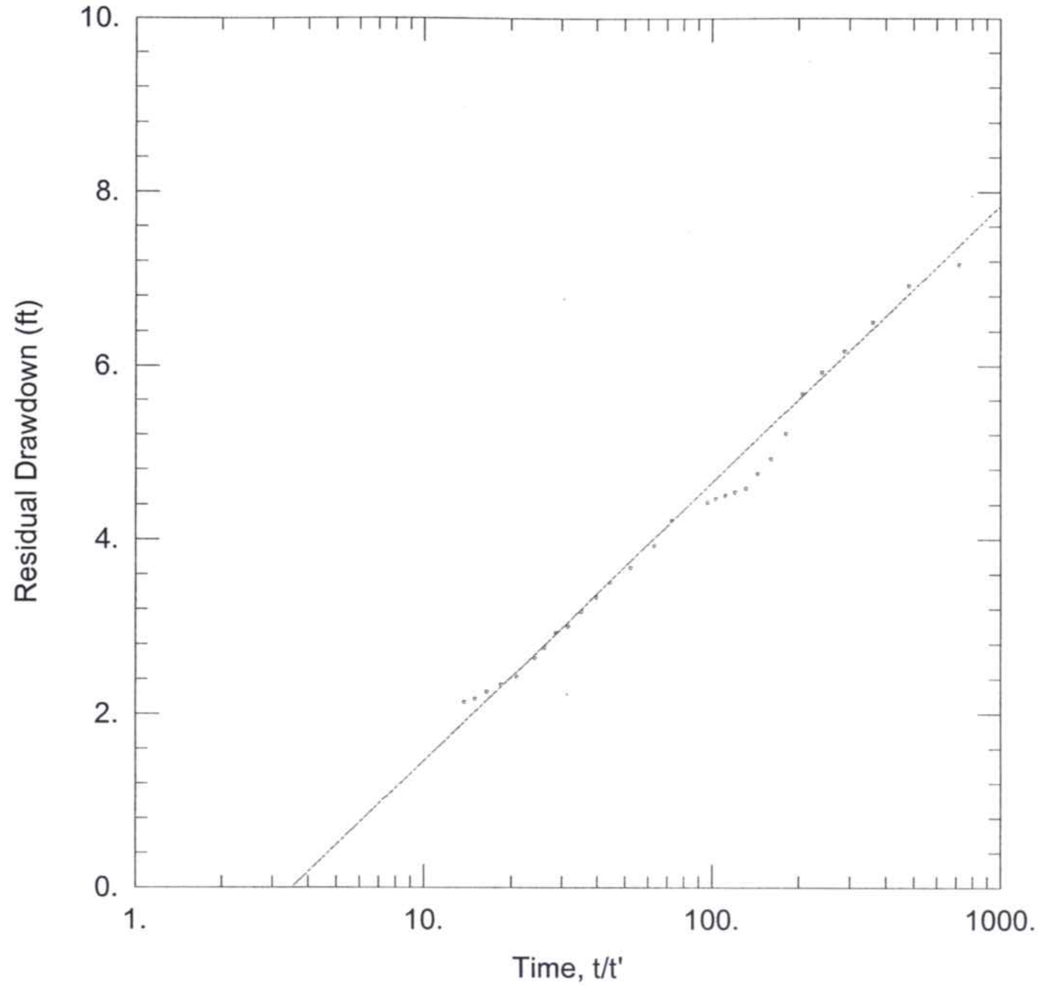
Observation Wells

Well Name	X (ft)	Y (ft)
PW12	0	0.33

SOLUTION

Aquifer Model: Confined
Solution Method: Cooper-Jacob

T = 1.255E+4 ft^2/day
S = 3.406E-15



ROANOKE IS. - SKYCO PW12, 24HR. TEST (1978)

Data Set: Z:\...\PW12 - 1978REC.aqt
Date: 07/02/08 Time: 08:56:55

PROJECT INFORMATION

Company: GMA
Client: Dare Co.
Project: 103501
Location: Roanoke Island
Test Well: PW12
Test Date: 2/9/78

AQUIFER DATA

Saturated Thickness: 50. ft Anisotropy Ratio (Kz/Kr): 1.

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
PW12	0	0

Observation Wells

Well Name	X (ft)	Y (ft)
PW12	0	0.33

SOLUTION

Aquifer Model: Confined Solution Method: Theis (Recovery)

T = 9941. ft^2/day S/S' = 3.514

Appendix C

One-Hour Specific Capacity Test Data from Skyco Production Wells

Skyco Well #2 - January 3, 2008			
Static Water Level = 14.71' from top of casing			
Flow Rate = ~560GPM			
Time (min.)	**W.L.**	**Drawdown**	**Specific Capacity**
2.5	43.75	29.04	19.28
5	43.6	28.89	19.38
10	44.04	29.33	19.09
15	45.19	30.48	18.37
20	45.05	30.34	18.46
24.5	46	31.29	17.90
30	46.08	31.37	17.85
45	45.78	31.07	18.02
60	44.96	30.25	19.83

Skyco Well #4 - January 3, 2008			
Static Water Level = 18.44' from top of drop tube			
Flow Rate = ~500GPM			
Time (min.)	**W.L.**	**Drawdown**	**Specific Capacity**
5	74.06	55.62	8.99
6.67	72.14	53.7	9.31
10	72.51	54.07	9.25
15	72.75	54.31	9.21
25	73.1	54.66	9.15
35	73.33	54.89	9.11
45	73.45	55.01	9.09
50	73.55	55.11	9.07
60	73.65	55.21	9.06

Skyco Well #5 - December 20, 2007			
Static Water Level = 15.38' from top of drop tube			
Flow Rate = ~590GPM			
Time (min.)	**W.L.**	**Drawdown**	**Specific Capacity**
5.67	80.59	65.21	9.05
10	81.67	66.29	8.90
15	82.23	66.85	8.83
30	82.9	67.52	8.74
45	83.3	67.92	8.69
60	83.57	68.19	8.65

Skyco Well #6 - January 3, 2008			
Static Water Level = 20.4' from top of drop tube			
Flow Rate = ~460GPM			
Time (min.)	**W.L.**	**Drawdown**	**Specific Capacity**
12	44.8	24.31	18.92
27	46.4	25.91	17.75
42	47	26.51	17.35
57	47	26.51	17.35
72	47.2	26.71	17.22

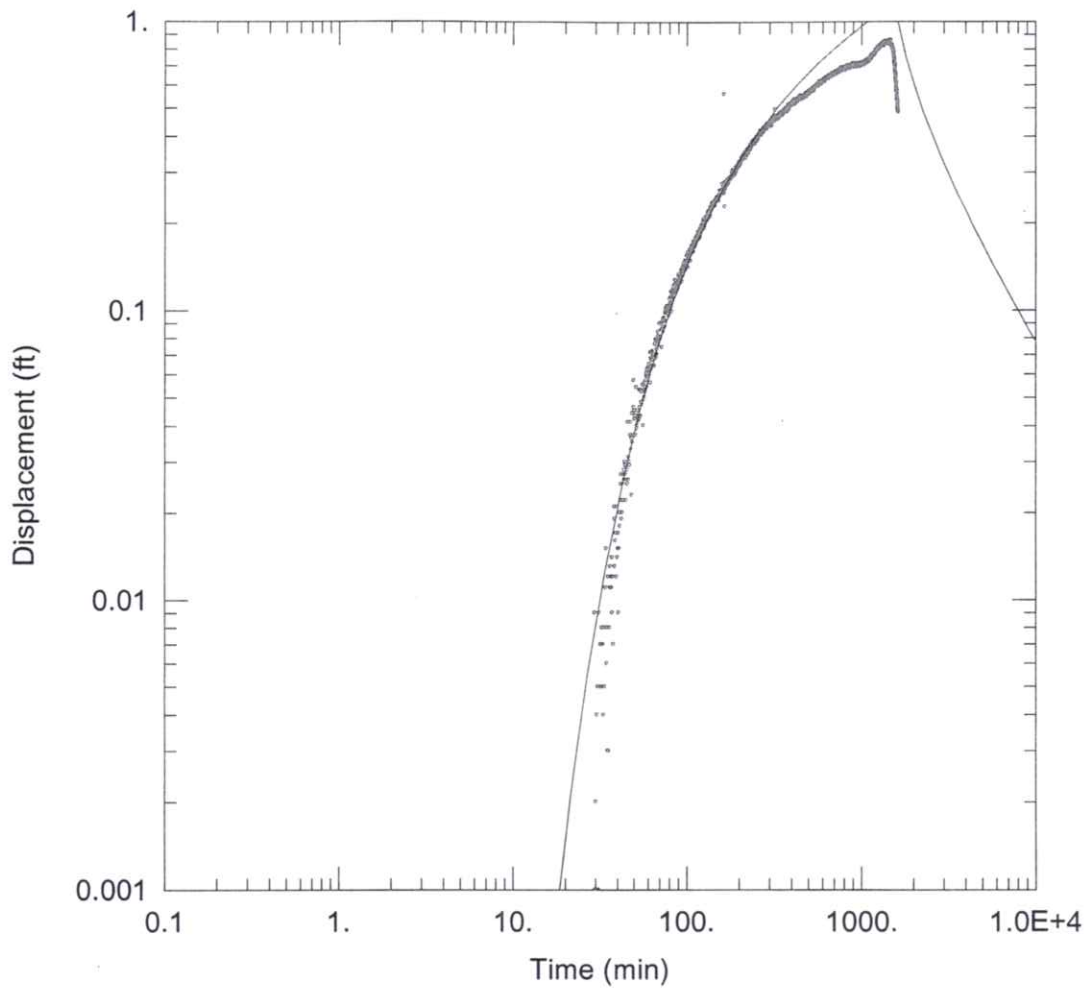
Skyco Well #7 - December 20, 2007			
Static Water Level = 15.27' from top of drop tube			
Flow Rate = ~530GPM			
Time (min.)	**W.L.**	**Drawdown**	**Specific Capacity**
30	115.5	100.23	5.29
45	117.05	101.78	5.21
60	117.52	102.25	5.18

Skyco Well #8 - December 21, 2007			
Static Water Level = 15.05' from top of drop tube			
Flow Rate = ~530GPM			
Time (min.)	**W.L.**	**Drawdown**	**Specific Capacity**
6.5	76.92	61.87	8.57
10.67	77.4	62.35	8.50
15	77.65	62.6	8.47
20.5	77.74	62.69	8.45
30	78.05	63	8.41
45	78.4	63.35	8.37
60	78.62	63.57	8.34

Skyco Well #10 - December 21, 2007			
Static Water Level = 14.27' from top of drop tube			
Flow Rate = ~480GPM			
Time (min.)	**W.L.**	**Drawdown**	**Specific Capacity**
2.5	89.01	74.74	6.42
5	89.98	75.71	6.34
10	90.31	76.04	6.31
16.75	90.6	76.33	6.29
30	90.79	76.52	6.27
45	90.89	76.62	6.26
60	91.03	76.76	6.25

Appendix D

Aquifer Test Data Analyses for the 24-hour Pumping Test at Skyco Well #11



ROANOKE IS. - SKYCO PW11 24HR. TEST

Data Set: Z:\...\PW6TH.aqt
Date: 07/02/08 Time: 08:44:47

PROJECT INFORMATION

Company: GMA
Client: Dare Co.
Project: 103501
Location: Roanoke Island
Test Well: PW11
Test Date: 1/16/08

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
PW11	0	0

Observation Wells

Well Name	X (ft)	Y (ft)
PW6	0	2479.4

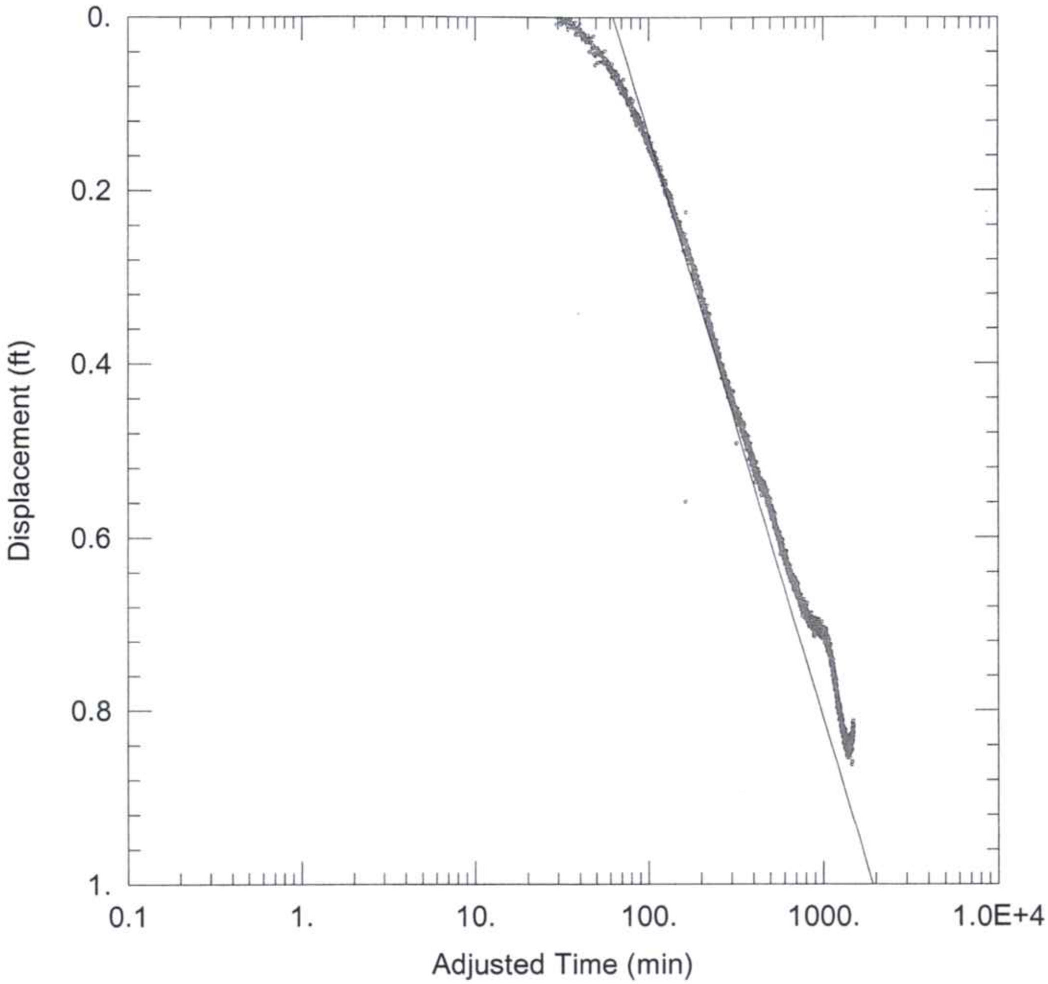
SOLUTION

Aquifer Model: Confined

Solution Method: Theis

T = 1.528E+4 ft^2/day
Kz/Kr = 1.

S = 0.0005798
b = 83. ft



ROANOKE IS. - SKYCO PW11 24HR. TEST

Data Set: Z:\...\PW6CJ.aqt
Date: 07/02/08 Time: 08:44:11

PROJECT INFORMATION

Company: GMA
Client: Dare Co.
Project: 103501
Location: Roanoke Island
Test Well: PW11
Test Date: 1/16/08

AQUIFER DATA

Saturated Thickness: 83. ft Anisotropy Ratio (Kz/Kr): 1.

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
PW11	0	0

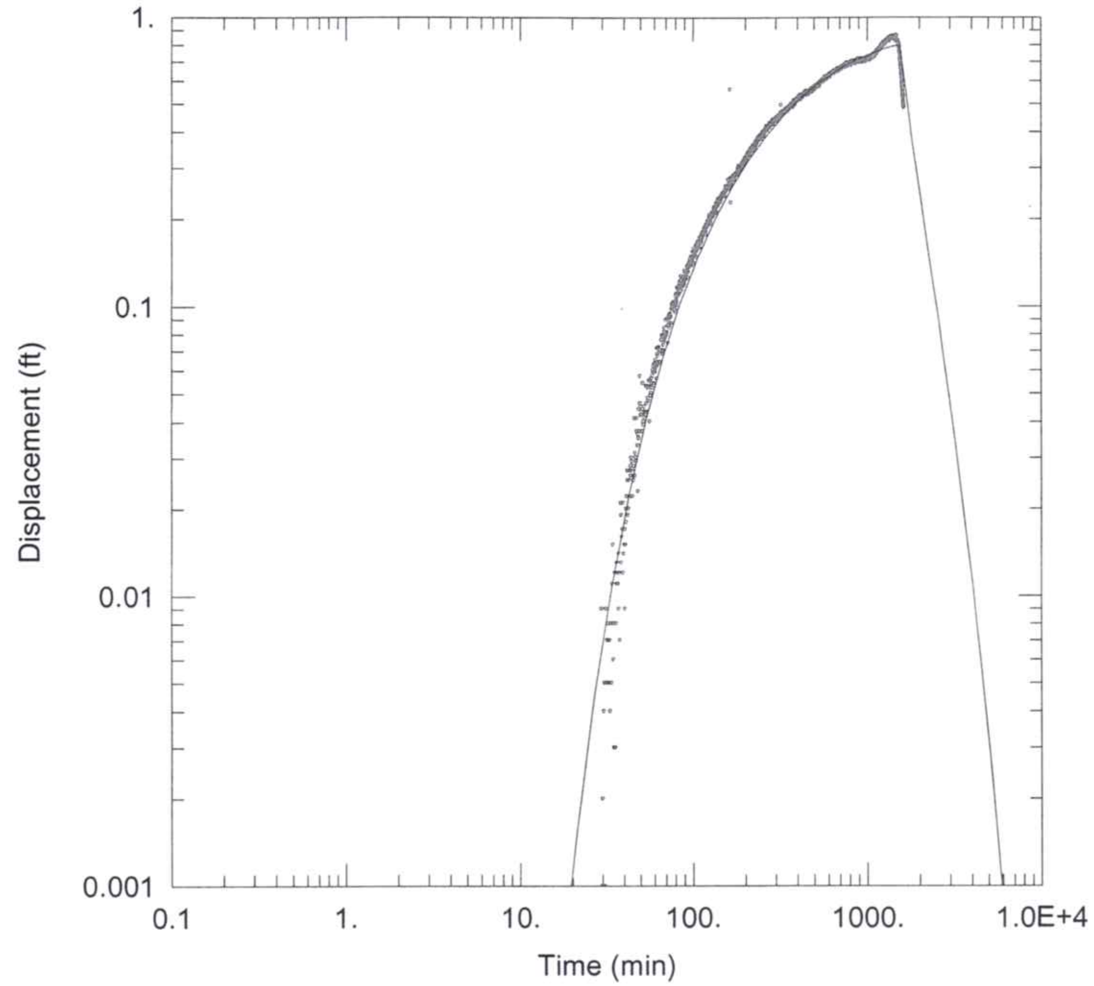
Observation Wells

Well Name	X (ft)	Y (ft)
PW6	0	2479.4

SOLUTION

Aquifer Model: Confined Solution Method: Cooper-Jacob

T = 2.533E+4 ft^2/day S = 0.0004041



ROANOKE IS. - SKYCO PW11 24HR. TEST

Data Set: Z:\...\PW6.aqt
Date: 07/02/08 Time: 08:43:50

PROJECT INFORMATION

Company: GMA
Client: Dare Co.
Project: 103501
Location: Roanoke Island
Test Well: PW11
Test Date: 1/16/08

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
PW11	0	0

Observation Wells

Well Name	X (ft)	Y (ft)
PW6	0	2479.4

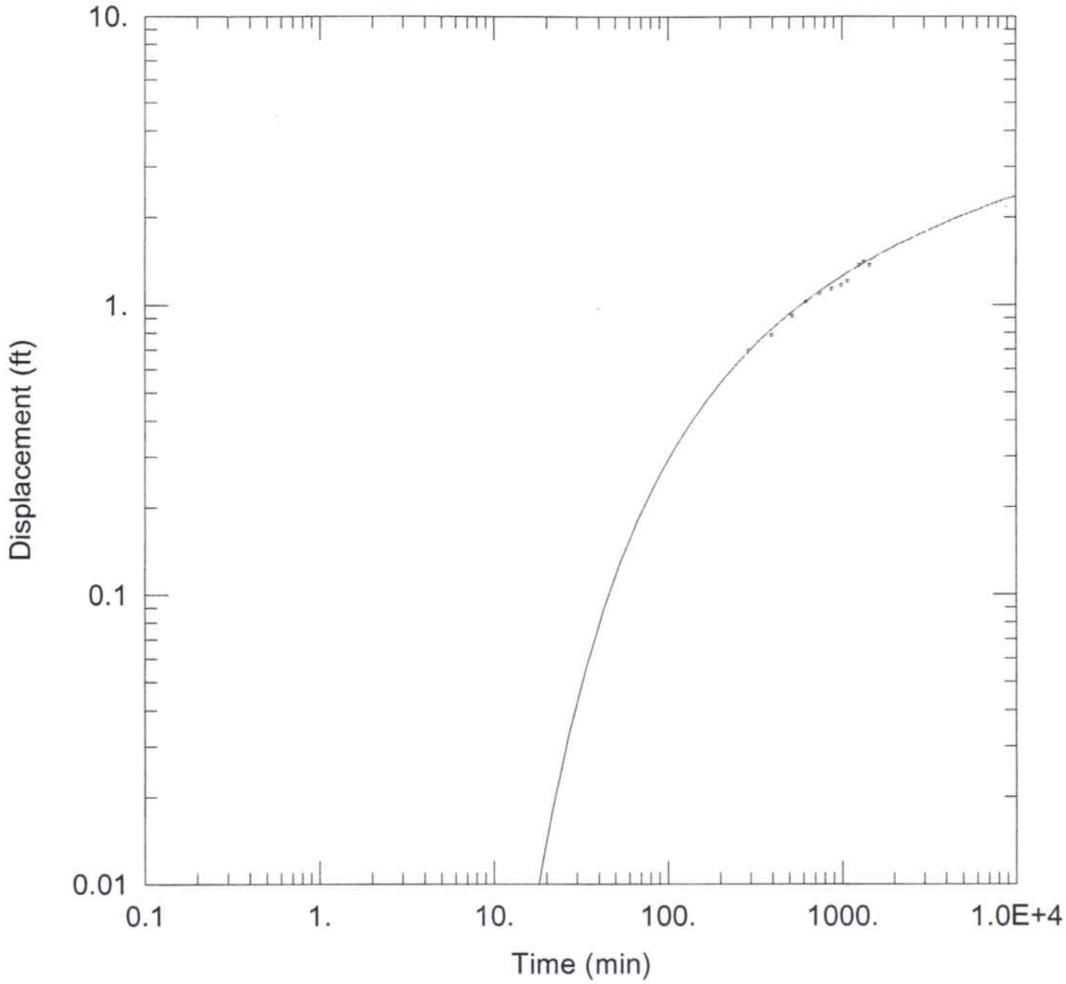
SOLUTION

Aquifer Model: Leaky

Solution Method: Hantush-Jacob

T = 1.355E+4 ft^2/day
r/B = 0.5978
b = 83. ft

S = 0.0005543
Kz/Kr = 1.



ROANOKE IS. - SKYCO PW11 24HR. TEST

Data Set: Z:\...\PW10.aqt
Date: 07/02/08 Time: 08:45:16

PROJECT INFORMATION

Company: GMA
Client: Dare Co.
Project: 103501
Location: Roanoke Island
Test Well: PW11
Test Date: 1/16/08

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
PW11	0	0

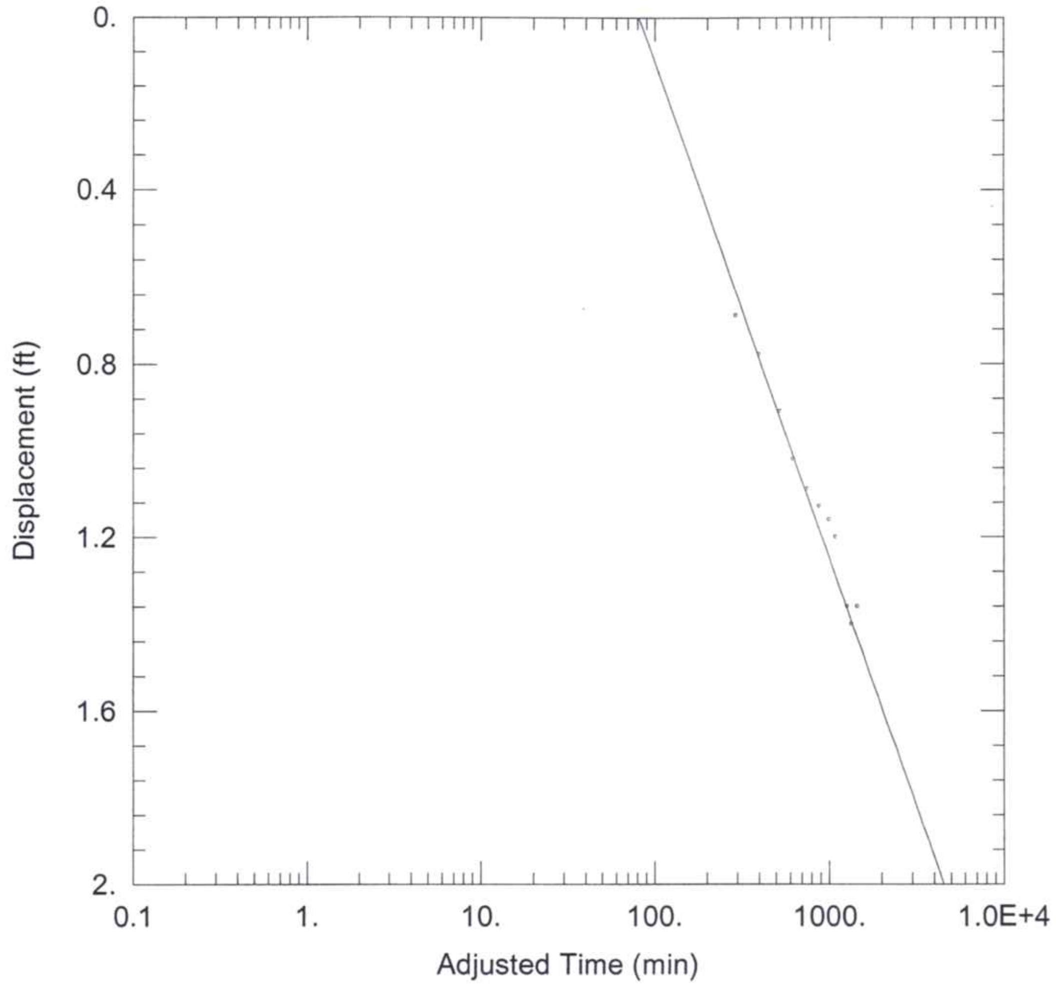
Observation Wells

Well Name	X (ft)	Y (ft)
PW10	0	1503

SOLUTION

Aquifer Model: Confined
Solution Method: Theis

T = 1.483E+4 ft^2/day
Kz/Kr = 1.
S = 0.0008829
b = 83. ft



ROANOKE IS. - SKYCO PW11 24HR. TEST

Data Set: Z:\...\PW10CJ.aqt
Date: 07/02/08 Time: 08:45:35

PROJECT INFORMATION

Company: GMA
Client: Dare Co.
Project: 103501
Location: Roanoke Island
Test Well: PW11
Test Date: 1/16/08

AQUIFER DATA

Saturated Thickness: 83. ft Anisotropy Ratio (Kz/Kr): 1.

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
PW11	0	0

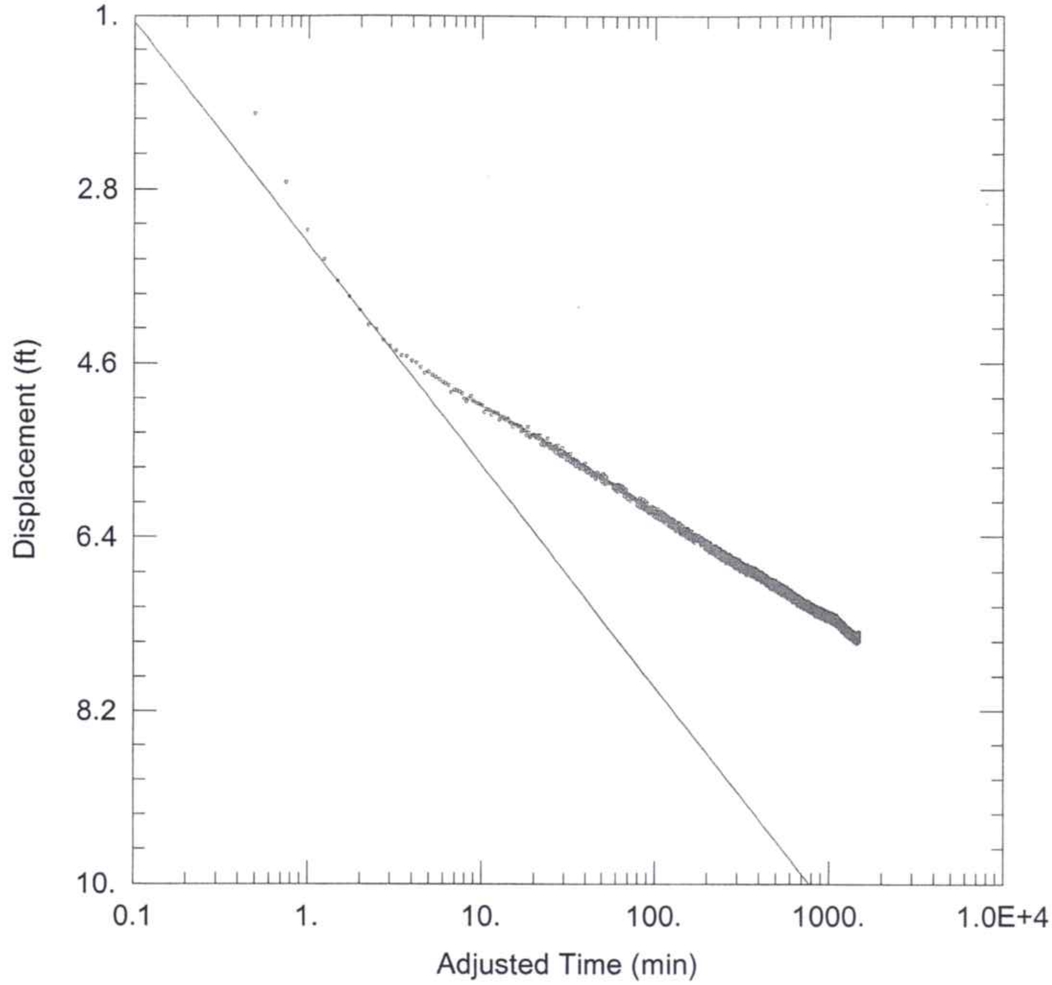
Observation Wells

Well Name	X (ft)	Y (ft)
PW10	0	1503

SOLUTION

Aquifer Model: Confined Solution Method: Cooper-Jacob

T = 1.486E+4 ft^2/day S = 0.000835



ROANOKE IS. - SKYCO PW11 24HR. TEST

Data Set: Z:\...\OW11CJ.aqt
Date: 07/02/08

Time: 08:47:03

PROJECT INFORMATION

Company: GMA
Client: Dare Co.
Project: 103501
Location: Roanoke Island
Test Well: PW11
Test Date: 1/16/08

AQUIFER DATA

Saturated Thickness: 83. ft

Anisotropy Ratio (Kz/Kr): 1.

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
PW11	0	0

Observation Wells

Well Name	X (ft)	Y (ft)
OW11	0	49.3

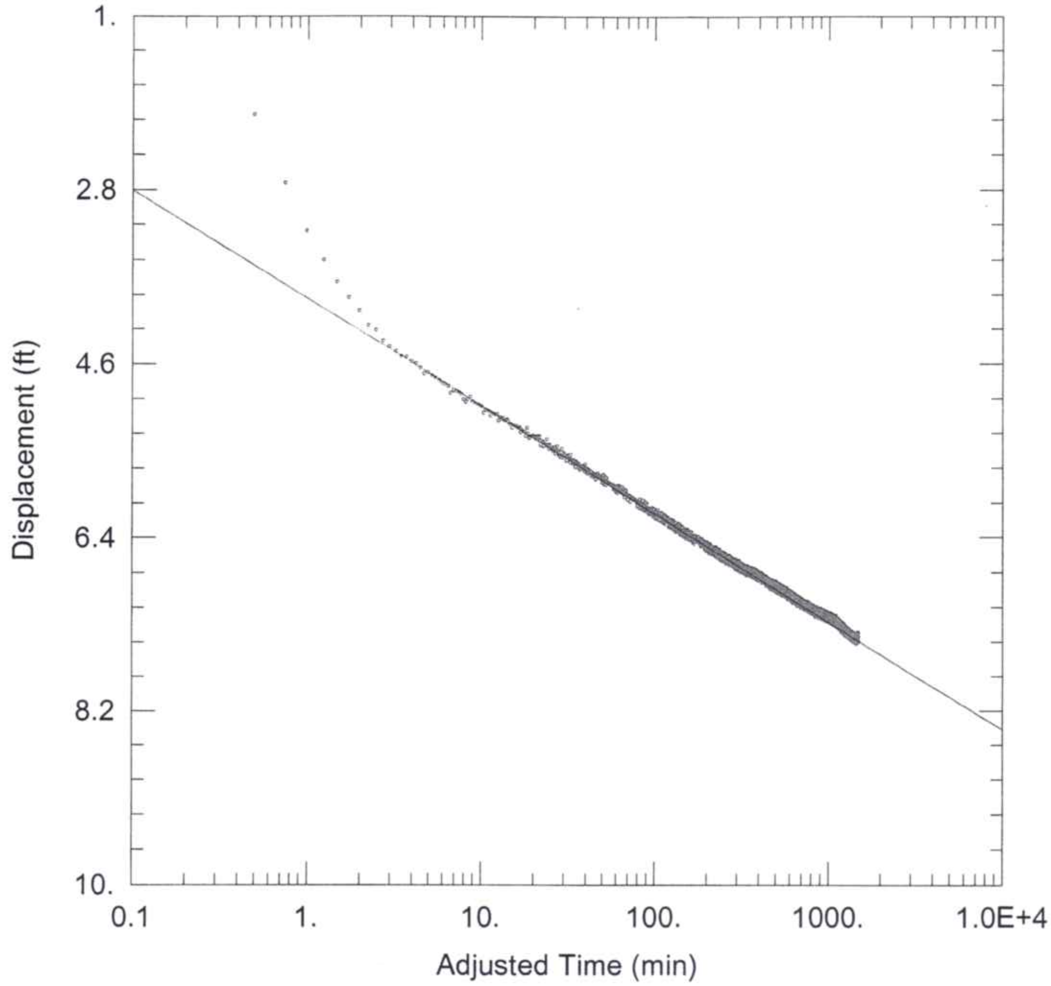
SOLUTION

Aquifer Model: Confined

Solution Method: Cooper-Jacob

T = 7407.2 ft^2/day

S = 0.0001632



ROANOKE IS. - SKYCO PW11 24HR. TEST

Data Set: Z:\...\OW11CJ.aqt
Date: 07/02/08 Time: 08:48:17

PROJECT INFORMATION

Company: GMA
Client: Dare Co.
Project: 103501
Location: Roanoke Island
Test Well: PW11
Test Date: 1/16/08

AQUIFER DATA

Saturated Thickness: 83. ft Anisotropy Ratio (Kz/Kr): 1.

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
PW11	0	0

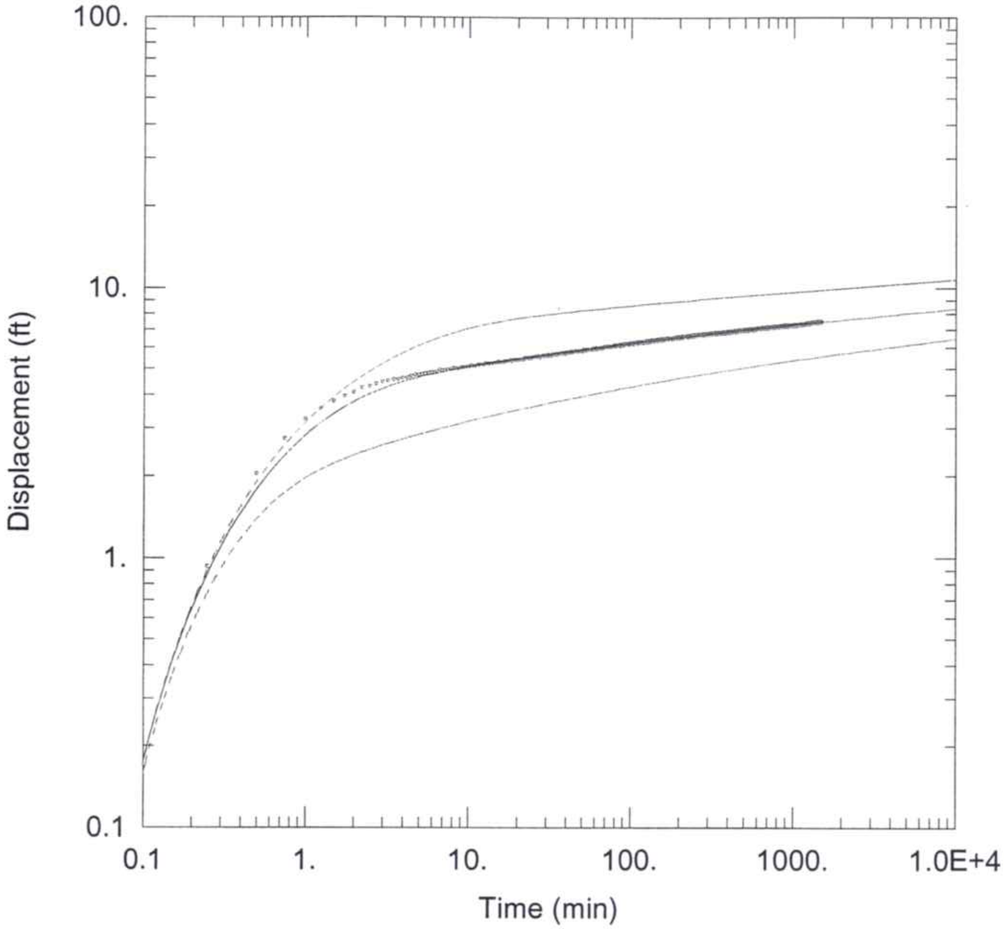
Observation Wells

Well Name	X (ft)	Y (ft)
OW11	0	49.3

SOLUTION

Aquifer Model: Confined Solution Method: Cooper-Jacob

T = 1.522E+4 ft^2/day S = 3.0E-6



ROANOKE IS. - SKYCO PW11 24HR. TEST

Data Set: Z:\...\OW11NW.aqt
Date: 07/02/08 Time: 08:49:17

PROJECT INFORMATION

Company: GMA
Client: Dare Co.
Project: 103501
Location: Roanoke Island
Test Well: PW11
Test Date: 1/16/08

AQUIFER DATA

Saturated Thickness: 83. ft Anisotropy Ratio (Kz/Kr): 0.1

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
PW11	0	0

Observation Wells

Well Name	X (ft)	Y (ft)
OW11	0	49.3

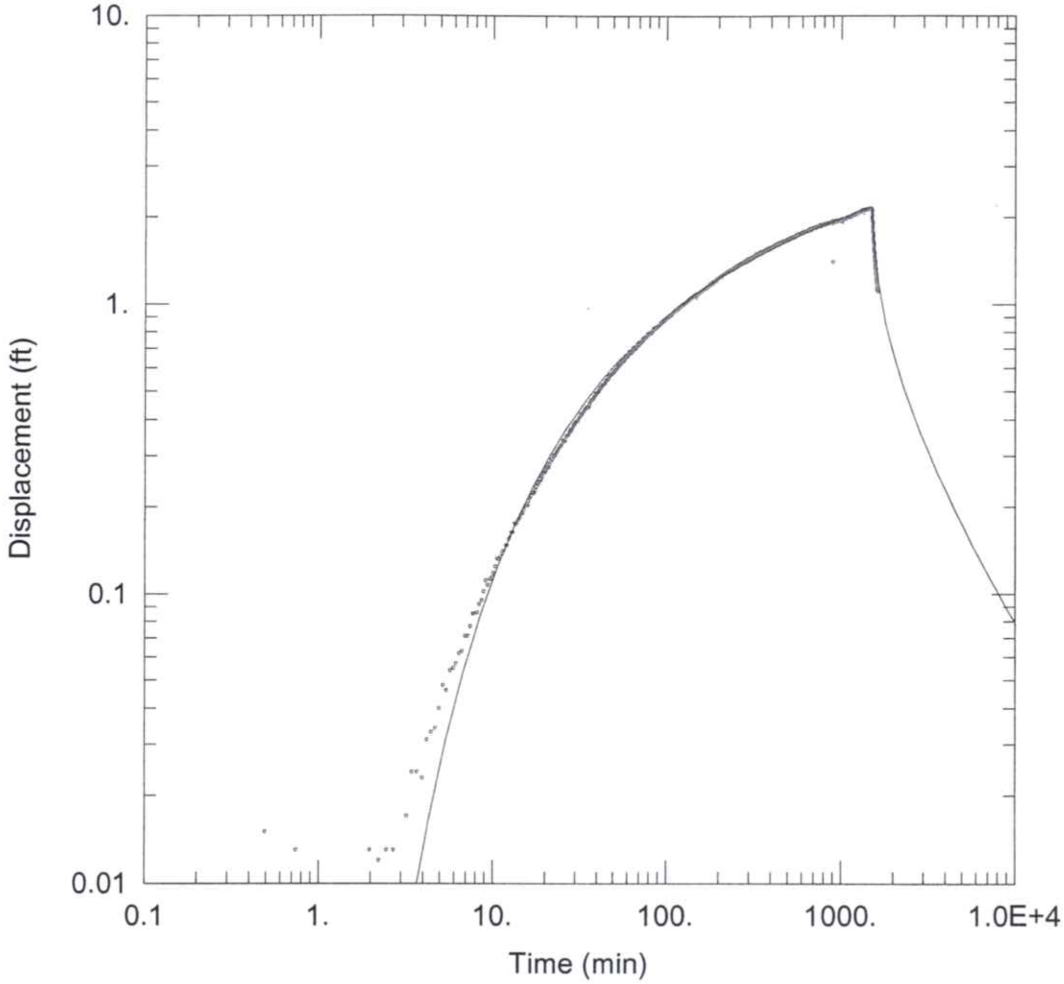
SOLUTION

Aquifer Model: Leaky

Solution Method: Neuman-Witherspoon

T = 3014.8 ft^2/day
r/B = 0.4967
T' = 1.259E+4 ft^2/day

S = 0.0006
ß = 1.0E-5
S' = 0.001945



ROANOKE IS. - SKYCO PW11 24HR. TEST

Data Set: Z:\...\OW12.aqt
Date: 07/02/08 Time: 08:49:40

PROJECT INFORMATION

Company: GMA
Client: Dare Co.
Project: 103501
Location: Roanoke Island
Test Well: PW11
Test Date: 1/16/08

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
PW11	0	0

Observation Wells

Well Name	X (ft)	Y (ft)
OW12	0	1064

SOLUTION

Aquifer Model: Confined

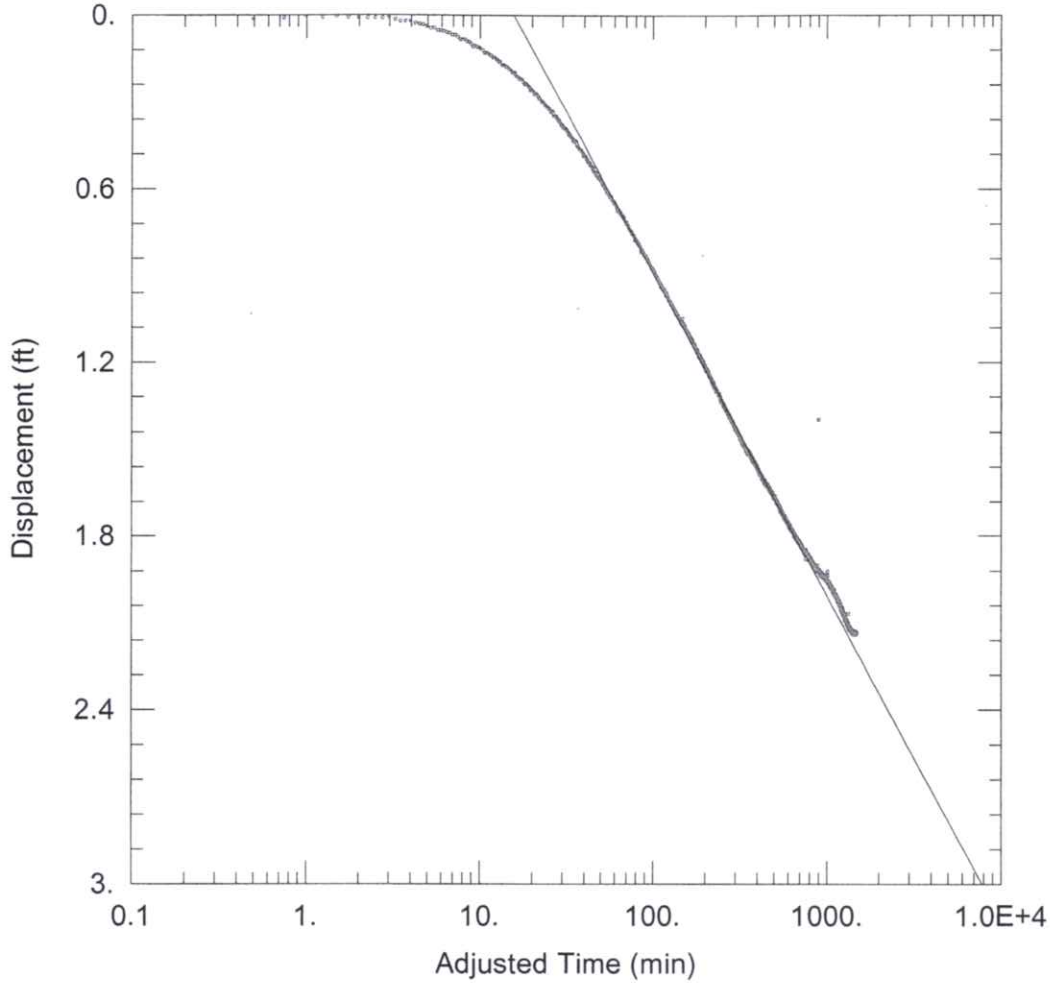
Solution Method: Theis

T = 1.512E+4 ft^2/day

Kz/Kr = 1.

S = 0.0003645

b = 83. ft



ROANOKE IS. - SKYCO PW11 24HR. TEST

Data Set: Z:\...\OW12CJ.aqt
Date: 07/02/08
Time: 08:49:57

PROJECT INFORMATION

Company: GMA
Client: Dare Co.
Project: 103501
Location: Roanoke Island
Test Well: PW11
Test Date: 1/16/08

AQUIFER DATA

Saturated Thickness: 83. ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
PW11	0	0

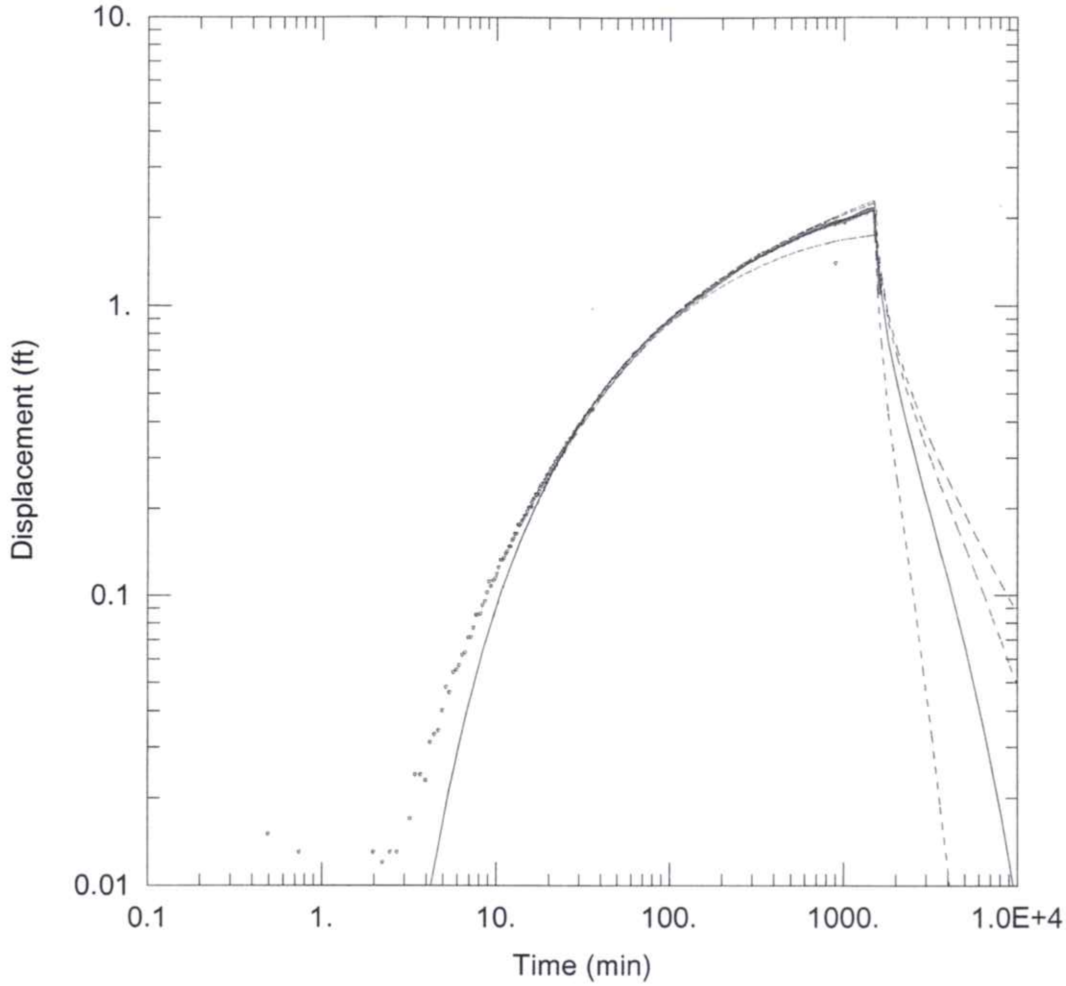
Observation Wells

Well Name	X (ft)	Y (ft)
OW12	0	1064

SOLUTION

Aquifer Model: Confined
Solution Method: Cooper-Jacob

$T = 1.53E+4\ ft^2/day$
S = 0.0003312



ROANOKE IS. - SKYCO PW11 24HR. TEST

Data Set: Z:\...\OW12HJ.aqt
Date: 07/02/08 Time: 08:50:12

PROJECT INFORMATION

Company: GMA
Client: Dare Co.
Project: 103501
Location: Roanoke Island
Test Well: PW11
Test Date: 1/16/08

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
PW11	0	0

Observation Wells

Well Name	X (ft)	Y (ft)
OW12	0	1064

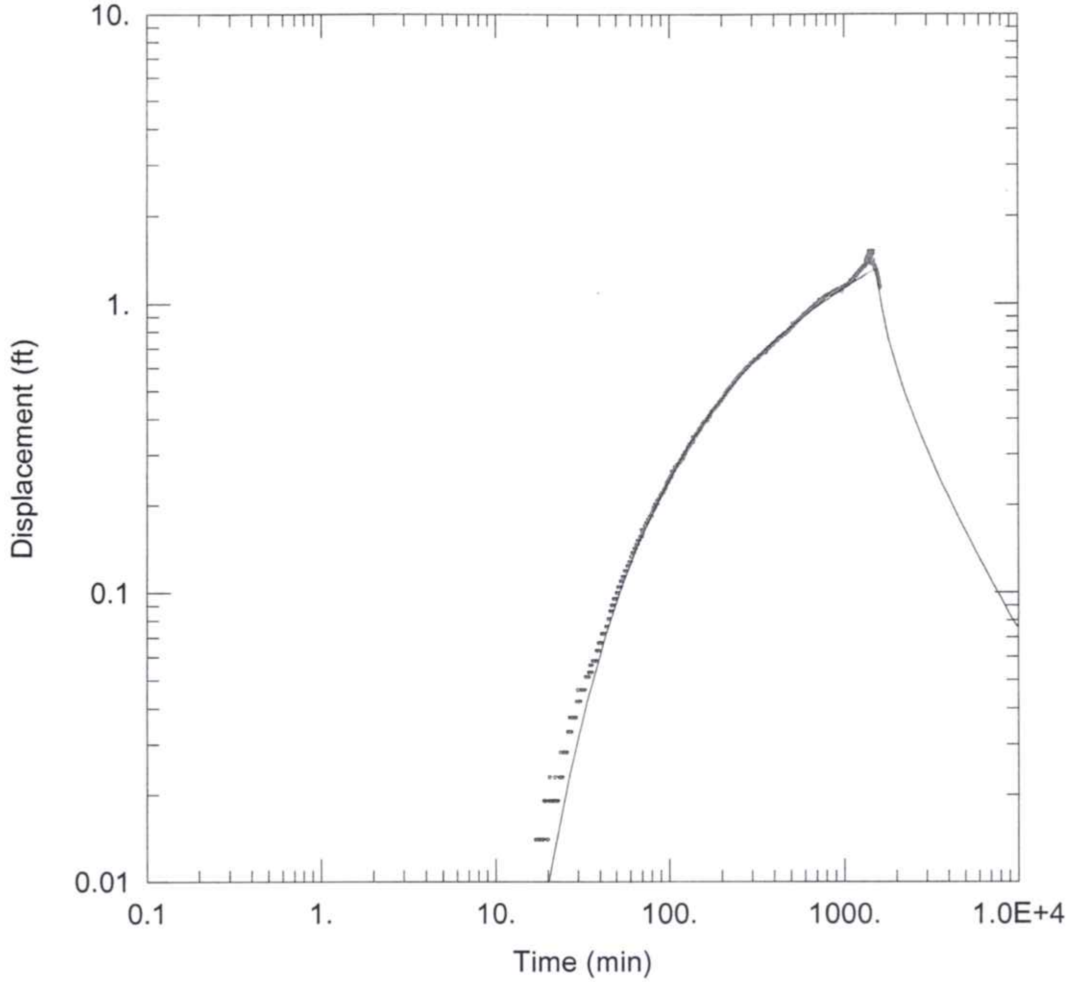
SOLUTION

Aquifer Model: Leaky

Solution Method: Hantush-Jacob

T = 1.373E+4 ft^2/day
r/B = 0.1085
b = 83. ft

S = 0.0003935
Kz/Kr = 1.



ROANOKE IS. - SKYCO PW11 24HR. TEST

Data Set: Z:\...\OW14.aqt
Date: 07/02/08 Time: 08:51:27

PROJECT INFORMATION

Company: GMA
Client: Dare Co.
Project: 103501
Location: Roanoke Island
Test Well: PW11
Test Date: 1/16/08

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
PW11	0	0.33

Observation Wells

Well Name	X (ft)	Y (ft)
OW14	0	2167.9

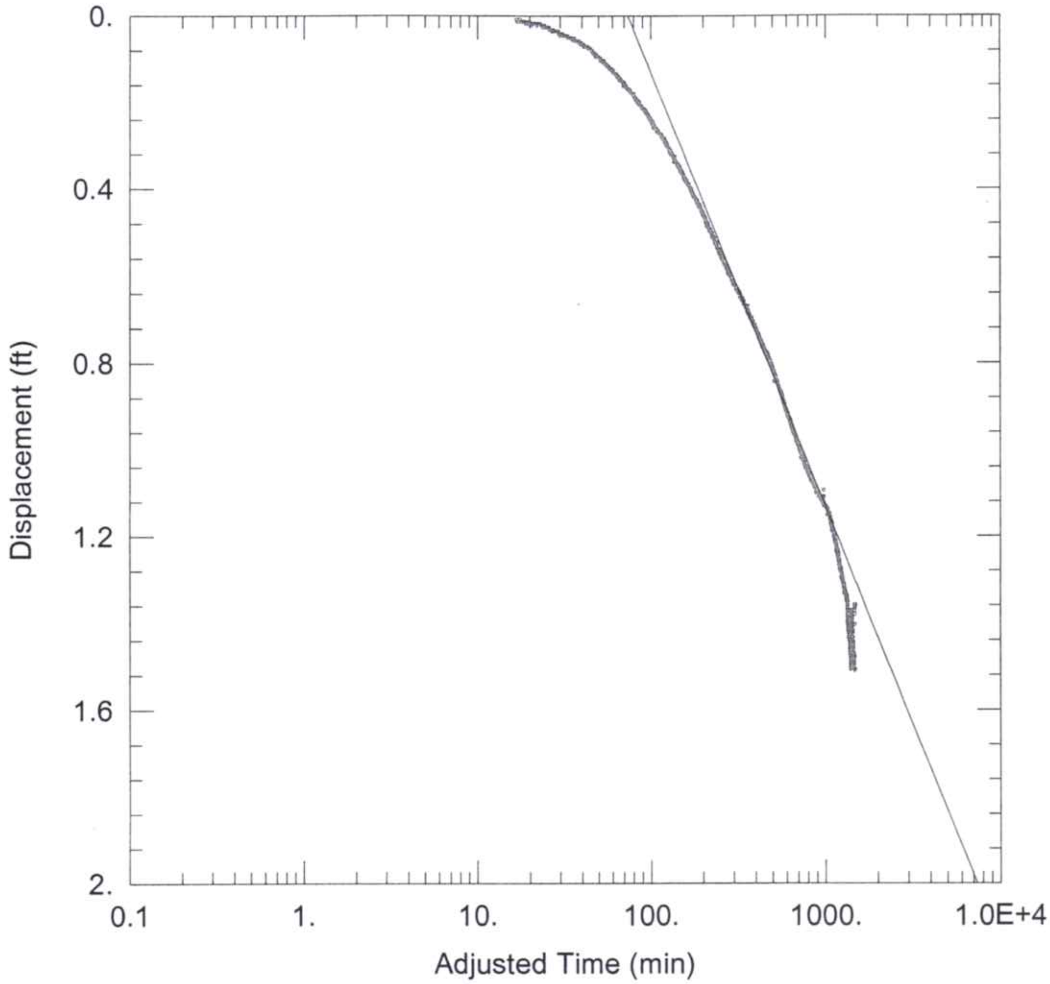
SOLUTION

Aquifer Model: Confined

Solution Method: Theis

T = 1.588E+4 ft^2/day
Kz/Kr = 1.

S = 0.0005
b = 20. ft



ROANOKE IS. - SKYCO PW11 24HR. TEST

Data Set: Z:\...\OW14CJ.aqt
Date: 07/02/08 Time: 08:51:48

PROJECT INFORMATION

Company: GMA
Client: Dare Co.
Project: 103501
Location: Roanoke Island
Test Well: PW11
Test Date: 1/16/08

AQUIFER DATA

Saturated Thickness: 83. ft Anisotropy Ratio (Kz/Kr): 1.

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
PW11	0	0

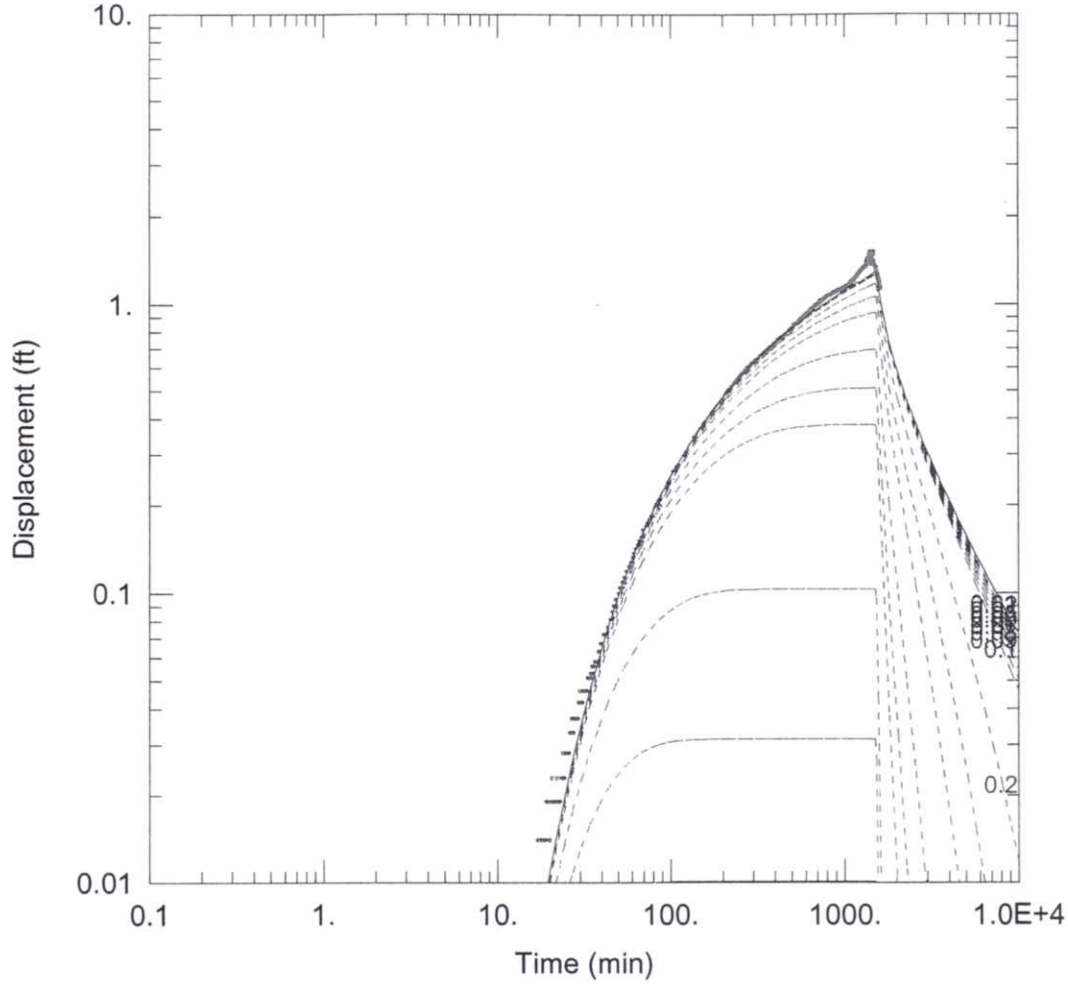
Observation Wells

Well Name	X (ft)	Y (ft)
OW14	0	2167.9

SOLUTION

Aquifer Model: Confined Solution Method: Cooper-Jacob

T = 1.7E+4 ft^2/day S = 0.0004179



ROANOKE IS. - SKYCO PW11 24HR. TEST

0.3

Data Set: Z:\...\OW14HJ.aqt
Date: 07/02/08 Time: 08:52:12

PROJECT INFORMATION

Company: GMA
Client: Dare Co.
Project: 103501
Location: Roanoke Island
Test Well: PW11
Test Date: 1/16/08

0.4

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
PW11	0	0

Observation Wells

Well Name	X (ft)	Y (ft)
OW14	0	2167.9

SOLUTION

Aquifer Model: Leaky

Solution Method: Hantush-Jacob

T = 1.637E+4 ft^2/day
r/B = 1.0E-5
b = 83. ft

S = 0.0004902
Kz/Kr = 1.