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Natural Resource Program Center

Southeast Coast Network Groundwater Monitoring

Protocol Development and Analysis of Existing Data

Natural Resource Report NPS/SECN/NRR—2009/126

ON THE COVER
Spanish Pond well, located at Fort Caroline National Memorial.

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Glossary of Terms

Anthropogenic: Caused by human actions.

Aquiclude: A formation that contains water but cannot transmit it rapidly enough to furnish a significant supply to a well or spring.

Aquifer: Layer of water-bearing permeable rock, sand, or gravel capable of providing significant amounts of water.

Aquitard: A confining bed and/or formation composed of rock or sediment that retards but does not prevent the flow of water to or from an adjacent aquifer.

Artesian Well: Water held under sufficient pressure in a confined aquifer that the water flows to the surface without pumping.

Confined Aquifer: An aquifer that contains water under pressure due to an overlying geologic unit of lower permeability.

Datalogger: An electronic device that is used to automatically collect and store monitoring data.

Datum: A fixed reference point with known elevation.

Floridan Aquifer System: An aquifer system that is one of the most productive in the world. This aquifer system underlies an area of about 100,000 square miles in southern Alabama, southeastern Georgia, southern South Carolina, and all of Florida. It is mainly comprised of a thick sequence of carbonate rocks (limestone and dolomite) of Tertiary age.

Hydraulic Gradient: The slope of the fluid potential, used in conjunction with the hydraulic conductivity to determine the magnitude and direction of fluid flow in the subsurface.

Hydraulic Head: A measure of the fluid potential, used to determine the magnitude and direction of the hydraulic gradient.

Hydrograph: A graph showing the water level or flow rate for a given point on a stream or in a well with respect to time.

Lithologic Log: A record of the lithology of the soils, sediments and/or rock encountered in a borehole from the surface to the bottom.

Lithology: A description of geologic formations on the basis of such characteristics as color, structure, mineralogical composition and grain size.

Measuring Point: A point accessible on or near a well that is used for measuring the depth to water. The water surface elevation is calculated as the difference between the measuring point elevation and the depth to water.

Northern Atlantic Coastal Plain Aquifer System: An aquifer system that consists of six regional aquifers in sedimentary deposits that range in age from Early Cretaceous to Holocene. The aquifer system underlies an area of about 50,000 square miles, extending from the North Carolina-South Carolina State line northward to Raritan Bay, N.J.

Piedmont and Blue Ridge Aquifers: An underlain by dense, almost impermeable bedrock that yields water primarily from secondary porosity and permeability provided by fractures. The aquifer system extends from central Alabama to southern Pennsylvania.

Piezometer: A device that allows the measurement of the hydraulic head in the subsurface at a given point. It normally consists of an open, small-diameter tube or pipe that is emplaced vertically, with a sealed section near the top and a perforated interval in the part of the subsurface to be monitored.

Pressure Transducer: An electronic device that converts fluid pressure to electronic signals.

Recharge: The process by which water is added to a zone of saturation, usually by percolation from the soil surface; e.g., the recharge of an aquifer.

Southeastern Coastal Plain Aquifer System: An aquifer system that consists of four regional aquifers, composed predominately of clastic rocks ranging in age from Cretaceous to late Tertiary. The aquifer system underlies an area of about 90,000 square miles in the Coastal Plain of Alabama, Georgia, and South Carolina and extends for a short distance into northern Florida.

Surficial Aquifer: In general, the uppermost, unconfined aquifer. Alternatively, a designation by U.S. Geological Survey for water contained within the Hawthorne Formation.

Transmissivity: The rate at which water is transmitted through a unit width of an aquifer under a unit hydraulic gradient

Storativity: The volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head

Water Table Aquifer: The shallowest, permanent, unconfined aquifer below the land surface.

Abstract

The alteration of hydrologic conditions due to human and natural causes can affect water availability to U.S. National Park Service (NPS) facilities, and may also lead to adverse environmental impacts at NPS parks. This report summarizes an NPS-funded project that focused on groundwater conditions at twenty units within the Southeast Coast Network (SECN). Included in this report is an inventory of groundwater use, monitoring programs, and facilities at SECN parks, an analysis of existing groundwater data within or near these parks with respect to trends and potential influences, a monitoring protocol for developing additional data that can be used to assess short- and long-term variation in groundwater conditions and influences, and a set of recommendations for further investigations. Groundwater monitoring data are currently restricted to U.S. Geological Survey (USGS) wells because other wells have limited frequency (less than 350 daily observations per year) and duration (less than five years) of data collection. Also, USGS wells are not located sufficiently close to some NPS facilities to provide relevant data. Groundwater conditions are poorly understood at many NPS facilities because of limited hydrogeologic studies at these sites. Recommendations for further actions that have been developed based on park visits include; i) installation of water-level monitoring equipment in coastal-plain aquifers to obtain a long-term baseline that can be used to assess the effects of regional groundwater development; ii) the proper sealing or capping of inactive wells to prevent leakage as well as to reduce the likelihood of groundwater contamination; and iii) a RCRA facility investigation (Phase-1) should be considered where subsurface contamination is known or suspected to identify the source and to characterize the magnitude and extent of the contamination.

Introduction

Project Overview

The Southeast Coast Network (SECN) contains twenty parks, listed in Table 1. The parks span a wide diversity of cultural missions also, including four National Seashores, two National Historic Sites, two National Memorials, six National Monuments, two National Battlefields, as well as a National Park, National Recreation Area, National Military Park, and an Ecological and Historic Preserve. Seventeen of these parks contain significant and diverse natural resources. The parks range in size from slightly more than 20 acres to nearly 60,000 acres. In total, SECN parks encompass more than 178,000 acres of federally managed land across North Carolina, South Carolina, Georgia, Alabama, and Florida. When considered with non-federal lands jointly managed with SECN parks, the network encompasses more than 242,000 acres.

In accordance with the public's desire for potable and recreational water supplies, fundamental components of the NPS's Inventory and Monitoring (I&M) Program are designed to "understand, maintain, restore, and protect the inherent integrity of the natural resources", as outlined by Perkins et al. (2005; 2006). The SECN is one of the 32 networks included in the Servicewide I&M Program.

The groundwater hydrology at SECN parks is important because the integrity of these parks may be compromised by natural and anthropogenic alterations of the groundwater system. While the southeast United States has plentiful groundwater resources, the conditions of this resource may be threatened by increasing municipal, industrial, power supply, and agricultural water demands.

The impacts of natural and anthropogenic hydrologic alteration can be monitored using changes in the piezometric surface (or freshwater head) of individual aquifers. These aquifer groundwater levels are determined using measurements of water levels in observation wells. Spatial and temporal variations in the water table and piezometric surfaces are the most basic methods for analyzing these data. In addition, these data can provide relevant hydrogeologic characterization data such as the direction and magnitude of groundwater flow (McCobb and Weiskel, 2002).

It is the goal of the SECN to utilize groundwater data collected by existing programs (NPS and non-NPS) to meet its needs rather than developing its own network of groundwater monitoring stations. Utilizing existing data sources, this project analyzes data to determine the status and trends of groundwater levels in existing groundwater wells, identify potential relationships between changes in groundwater dynamics and changes in landscape dynamics, and proposes protocols for additional data collection activities related to groundwater monitoring for twenty parks within the SECN.

Table 1. Southeast Coast Network (SECN) National Park units. (Additional information about these park units can be found athttp://science.nature.nps.gov/im/units/secn/)

Alpha Code [†]	Park Unit
CAHA	Cape Hatteras National Seashore
CALO	Cape Lookout National Seashore
CANA	Canaveral National Seashore
CASA	Castillo de San Marcos National Monument
CHAT	Chattahoochee River National Recreation Area
CHPI	Charles Pinckney National Historic Site
CONG	Congaree National Park
CUIS	Cumberland Island National Seashore
FOCA	Fort Caroline National Memorial
FOFR	Fort Frederica National Monument
FOMA	Fort Matanzas National Monument
FOPU	Fort Pulaski National Monument
FORA	Fort Raleigh National Historic Site
FOSU	Fort Sumter National Monument
HOBE	Horseshoe Bend National Military Park
KEMO	Kennesaw Mountain National Battlefield Park
MOCR	Moores Creek National Battlefield
OCMU	Ocmulgee National Monument
TIMU	Timucuan Ecological and Historic Preserve
WRBR	Wright Brothers National Memorial

[†] The NPS assigns each park unit a unique Alpha Code, which is used throughout this report.

Project Objectives

1. Conduct a review of relevant literature related to groundwater monitoring and monitoring efforts at SECN parks, including the parameters collected or measured the types of instrumentation, and the existing protocols.
2. Identify and catalog existing wells and other data sources (NPS and non-NPS) relevant to SECN parks - including (but not limited to) the following parameters: site ID, description, well depth, geologic material, parameters measured, frequency of measurement, location information (e.g. UTM coordinates).
3. Acquire data from various State and Federal groundwater monitoring programs using web-based program archives or other sources as available. Acquired groundwater well data (and other relevant data types) will be incorporated into NPS holdings.
4. Refine existing methodology and incorporate analysis tools into SECN databases as appropriate to conduct trend analyses for each well in order to address the following long-term monitoring objectives:
5. Determine status and trends of groundwater levels in existing groundwater wells.

6. Identify potential relationships between changes in groundwater dynamics and changes in landscape dynamics.
7. Analyze current and historic groundwater data (from Step 3 above) to determine the status and trends in the SECN groundwater resources focusing on the two long-term monitoring objectives listed above.
8. Identify significant data gaps - including spatial distribution and temporal coverage.
9. Provide recommendations for equipment replacement, upgrade, and installation in cases where SECN parks currently maintain monitoring wells.
10. Develop a long-term monitoring protocol for SECN groundwater monitoring that utilizes existing data sources and follows NPS and I&M program guidance for protocol development.

Because the SECN lacked the internal resources to carry out the analysis of groundwater quantity trends, outside sources were needed. After consultation with private and public entities, SECN accepted a proposal from the University of Georgia. The cooperative effort began in August 2006 with the purpose of developing guidelines and protocol's for a groundwater-monitoring program. This study addresses groundwater conditions related to water levels, for the purpose of establishing a baseline condition for comparison to future alterations. Additionally, historical data, if available, are used to establish baseline conditions where current activities have altered the natural hydrologic conditions.

The purpose of this report, therefore, is to recommend groundwater quantity monitoring guidelines (procedures and techniques) and associated protocols (rules and methods) with which SECN might more efficiently and effectively conduct future water-monitoring activities. The development of guidelines and protocols for future monitoring activities necessitated the evaluation of existing data from previous monitoring efforts and a review of current groundwater quantity monitoring activities.

Since August 2006, primary investigators at the University of Georgia, John Dowd and Todd Rasmussen, along with graduate students Joey McKinnon, Brian Price, and Roy (Trey) Sherrell, III, have investigated the hydrogeologic, geologic, and geographic conditions of the SECN. This report first summarizes published groundwater literature, where available. The following section summarizes groundwater concerns and facilities at SECN parks using short- and long-term monitoring data to evaluate whether long-term trends can be statistically established. A subsequent section provides guidance related to groundwater monitoring protocols for a variety of aquifer and water-level conditions. A final section provides recommendations for obtaining additional groundwater monitoring data for the purpose of evaluating changes in subsurface hydrologic conditions at SECN parks.

Literature Review

This section summarizes available information in the literature relative to groundwater conditions at the relevant park units. In many cases, there is no specific information for the park, and only general groundwater conditions are provided.

Sources for this section include, in addition to those cited below, Johnston and Bush 1988), U.S. Geological Survey (1986; 2003), and Leeth et al. (2007). Maps and other data sources shown were obtained from National Park Service (2004a, 2004b).

Regional Groundwater Conditions

SECN parks are underlain by a variety of aquifers, and each aquifer has unique properties with respect to their ability to store and transmit water (Miller, 1990)[1]. All SECN parks and ecosystems are in some way connected to a shallow, watertable aquifer, which is potentially affected by short and long-term weather patterns (e.g., flooding and drought), tidal conditions for aquifers in coastal areas, as well as by anthropogenic hydrologic disturbances (e.g., impoundments and groundwater extraction).

In addition to water-table aquifers, many SECN parks are also underlain by deeper, coastal-plain aquifer systems, such as the Floridan, Southeastern Coastal Plain, Northern Atlantic Coastal Plain aquifer systems. These very-productive aquifer systems serve as industrial, commercial, and agricultural water supply sources, and may potentially alter dependent or connected ecosystems as demands for those resources increase over time. While less affected by short-term weather variations, these systems may show seasonal and long-term declines due to aquifer pumping as well as climate change.

Coastal-plain aquifers lie in sediments that generally trend to the East-Southeast in the study area, i.e., away from their uppermost extent at the Fall Line. While the sediments are generally prism-shaped from the Fall Line to the continental shelf, there are local deviations from this general trend (Miller, 1986). Local folds and fault systems induce regional warping and offsets in the geologic units, which affect regional groundwater flow.

Other SECN parks (i.e., CHAT, KEMO, and HOBE) are underlain by less-productive aquifers, such as the Piedmont and Blue Ridge, and Valley and Ridge aquifers. While these aquifers provide lesser amounts of water to wells, they can be locally important.

A general aquifer map is provided in Figure 1, which shows the regional SECN aquifers that are present at the surface. Multiple aquifers may be present in coastal aquifers (Figure 2). That is, other, deeper aquifers may underlie the aquifers present at or near the surface. Table 2 summarizes those aquifer systems anticipated to be present at each park. Note that aquifer

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[1] Available online at *http://capp.water.usgs.gov/gwa*

systems may contain multiple aquifers, which vary both in thickness and properties across the region.

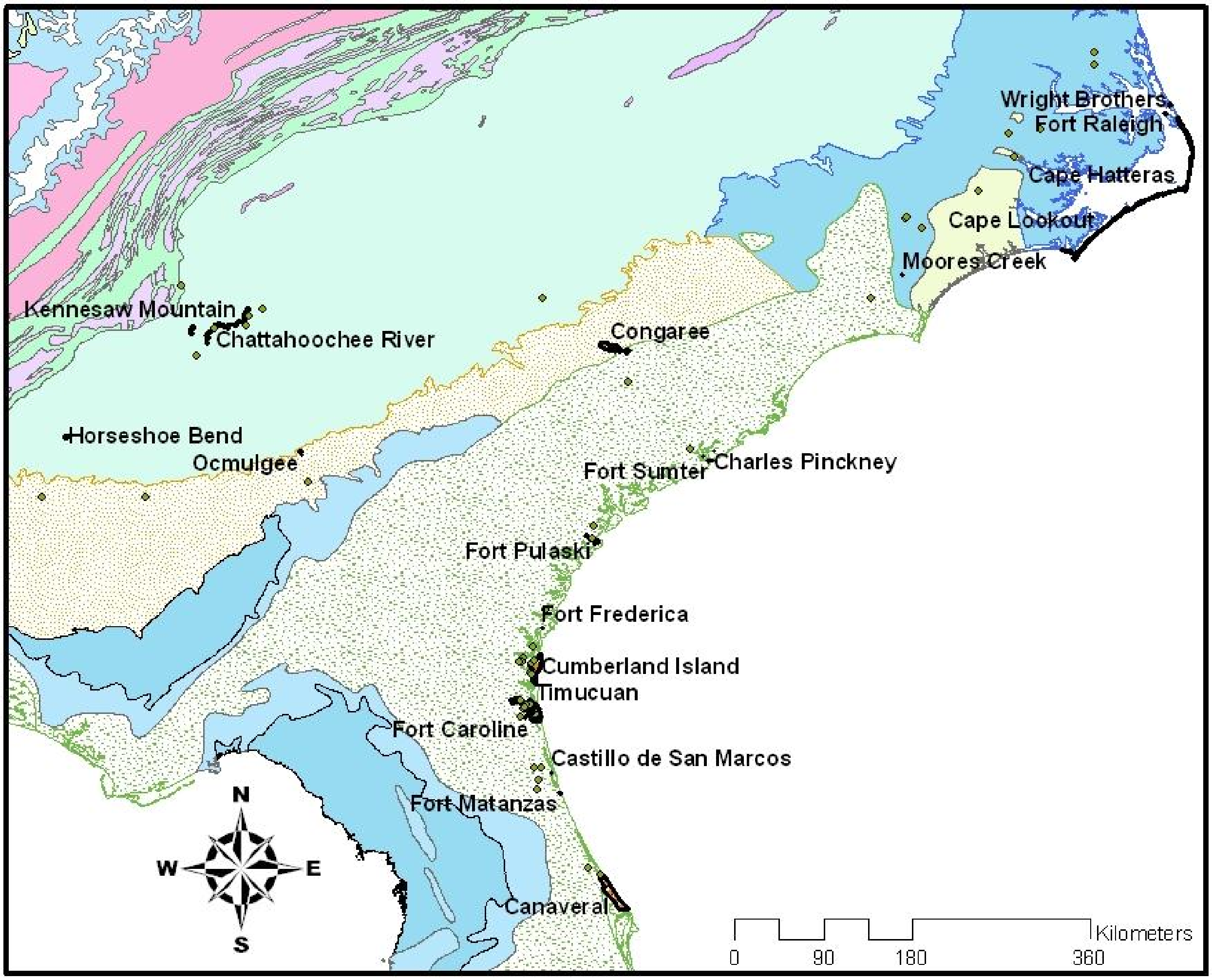

Figure 1. SECN park locations relative to major hydrogeologic units. Aquifers may overlay other, deeper aquifers.

Rapid population growth in coastal areas, increased tourism, and sustained industrial activity have adversely affected coastal water resources and limited the available water supply. The primary water supplies in these coastal areas are the confined aquifers because they are extremely productive. First developed in the late 1800, they have been used extensively in the area ever since. Pumpage from the aquifer has resulted in several problems including:

- substantial water-level declines
- migration of seawater into the aquifer at the northern end of Hilton Head Island, South Carolina;
- contamination of the aquifer from underlying brine-filled strata at Brunswick, Georgia;
- decreased groundwater inflow to springs, freshwater ponds, marshes, and wetlands, which could impact the balance of freshwater and saltwater in tidal rivers and estuaries.

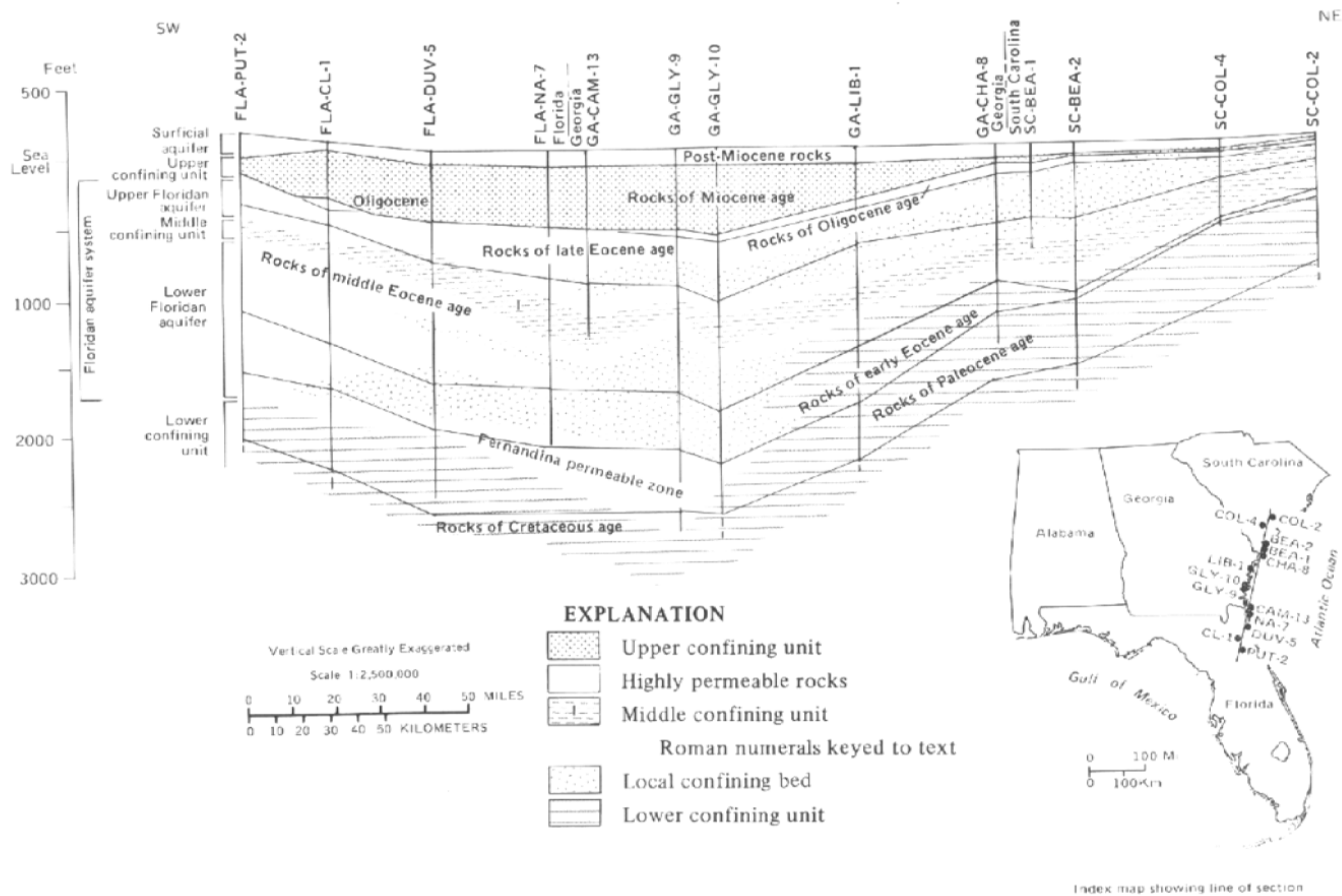

Figure 2. Hydrogeologic cross section along the SC-FL coast (Miller, 1986).Hydrogeologic cross section along the SC-FL coast (Miller, 1986).

Saltwater contamination in some areas has constrained further development of the confined aquifers in coastal areas and created fierce competing demands for the limited fresh water supply. The Georgia Environmental Protection Division released an interim strategy in April 1997 to manage saltwater intrusion in the Upper Floridan aquifer. As part of this interim plan, permitted withdrawal from the Upper Floridan aquifer have been capped at 1997 rates in the Savannah and Brunswick areas.

In January 2004, the U.S. Geological Survey began a three-year study to combine and update regional groundwater models of North and South Carolina to improve the understanding of groundwater availability in the Atlantic Coastal Plain aquifer system of both States. Increased groundwater withdrawals related to population growth and drought has emphasized the need for more accurate, detailed information describing the groundwater resources in the Coastal Plain. Currently North Carolina and South Carolina do not have up-to-date groundwater flow models of the entire Coastal Plain aquifer system. Since completion of the regional groundwater models, however, additional groundwater pumpage, water-level, and hydrogeologic framework data have been collected.

The scope of the U.S. Geological Survey modeling effort is the Atlantic Coastal Plain area extending north from eastern Georgia through South and North Carolina and possibly into southern Virginia, including the surficial, Tertiary, and Cretaceous aquifer systems. The groundwater flow model will be developed using MODFLOW-2000 (a standard groundwater modeling framework), and will incorporate a graphical user interface. New U.S. Geological Survey and state agency aquifer-property, groundwater level, and water-use data collected since the completion of the older models will be incorporated. A new regional hydrogeologic synthesis at the North Carolina - South Carolina State line will be produced.

The groundwater model will be calibrated to groundwater levels and stream discharges for both steady-state (pre-development) and transient (post-development) conditions. Calibration to transient conditions will be completed for at least two time periods, including calibration to data collected during a synoptic groundwater level and stream-discharge data collection effort planned for November 2004. The completed transient model will result from an integration of the most relevant, complete, and current hydrogeologic and water-use data available in Federal, State, and local agency databases. An essential part of the modeling effort will be collaboration with cooperators and stakeholders in both States and the formation of several project liaison committees early in the project. Harrelson and Fine (2006) provide an initial report summarizing data availability to be used in the modeling effort. **Additional information, publications, or reports related to this study are not currently available.**

Table 2. Southeast Coast Network National Park Units showing aquifer(s) present at each site [PBR – Piedmont and Blue Ridge Aquifers; FAS – Floridan Aquifer System; SECP – Southeastern Coastal Plain Aquifer System; NACP – Northern Atlantic Coastal Plain Aquifer System].

Park	PBR	FAS	SECP	NACP
CAHA				x
CALO				x
CANA		x		
CASA		x		
CHAT	x			
CHPI			x	
CONG			x	
CUIS		x		
FOCA		x		
FOFR		x		
FOMA		x		
FOPU		x		
FORA				x
FOSU			x	
HOBE	x			
KEMO	x			
MOCR				x
OCMU	x		x	
TIMU		x		
WRBR				x

CAHA: Cape Hatteras National Seashore

Cape Hatteras National Seashore consists of several barrier islands. Except for Pea Island, which is a National Wildlife Refuge, the barrier islands have considerable development and human impact. Surface water bodies within the park include the following: Salt Pond, Horseshoe Pond, Sedge Pond, Open Pond, Round Pond, Entrance Road Pond, Ramp 43 Pond, and numerous other areas of standing water (which depend on rainfall). A series of drainage ditches were dug in the 1970s to drain wetlands for the reduction of mosquito populations. They are no longer used but hold water. Near the park are rivers, streams and estuaries of the Albemarle-Pamlico estuarine system that are undergoing changes due to increasing population, urbanization and industrialization (Tucker, 1994). Tucker (1994) did not specifically address groundwater resources. Mallin et al. (2006) provides a brief summary of general groundwater conditions at CAHA, and reports that residents of southern Hatteras Island have historically relied on the Buxton Woods Aquifer by means of the Frisco well field, which is operated by the Cape Hatteras Water Association. No other reports were identified that would assist in groundwater characterization or management.

CALO: Cape Lookout National Seashore

Cape Lookout National Seashore comprises a series of undeveloped barrier islands along the Atlantic coast of North Carolina, with approximately 18,500 acres of non-submerged land. Surface water resources in the study area include large expanses of salt marsh, bays, the North and Newport Rivers, and the Atlantic Ocean. A rough estimate of estuarine marsh is 40 percent of the park. There are approximately 90 acres of maritime forest at the southern end of the park.

The park is co-located with towns and development including landowners, structures, and residents within park property. Cape Lookout hosts an average of 750,000 visitors per year.

At Cape Lookout, the Core Banks consist of long, narrow islands, with a sandy beach on the ocean side and tidal flats behind the ocean beach for the northern three miles. A dune field is situated behind the sandy beach. On the sound side lie a mixture of shallow bays, tidal creeks, salt marshes, short beaches, and sparse forest. While freshwater rivers and lakes do not exist on Core Banks, numerous freshwater ponds are found, particularly in the northern section called Portsmouth Island, as well as on Shackleford Banks, principally on the west end. Another water resource is a large (approximately one acre) brackish water pool about four-inches deep on the seaward beach of Cape Lookout (N 34° 59.452, W 76° 53.760) approximately one-half mile from the Coast Guard station. The pool contained an extensive benthic algal mat and appeared sometime during the three-year period prior to the 2004 report (Mallin et al., 2004).

Confined aquifers underlie the Seashore below the uppermost confining beds of clays and silt (Figure 3). These confined aquifers are composed of sand and loosely cemented shell beds, and sandy limestone, and are known to contain freshwater (Winner, 1978). Additional information regarding lithology and groundwater conditions is provided by Lautier (2001). The lithology consists, from the surface to the basement, of eight regionally significant aquifers and the intervening confining units, including the surficial, Yorktown, Castle Hayne, Beaufort, Peedee, Black Creek, Upper and Lower Cape Fear aquifers (Lautier, 2001).

Observation wells from the North Carolina monitoring network indicate water-level declines in the potentiometric surfaces of up to 5.6 feet per year, with greater declines near pumping centers (Lautier, 2001). Lautier also concludes that dewatering will become widespread in the Black Creek and Upper Cape Fear aquifers if pumping is allowed to continue on its present course. According to Mallin et al. (2004), the barrier islands contain a freshwater lens floating on saltwater below the island. Rainy periods increase freshwater recharge, thus expanding these lenses and increasing freshwater ponds. Groundwater withdrawals could adversely affect this freshwater recharge.

There are a number of ponds that form in or near marsh areas that highly depend on rainfall, but are not entirely freshwater. At Shackleford, there is a small pond, Mullet Pond, while at the defunct hunting club site, there is an excavated pond that was used for duck hunting. Mullet Pond - on the west end of Shackleford Banks - was formed by the closing of a former bay or lagoon, cutting it off from Back Sound (Mallin et al., 2004). Surface waters within the study area are generally of good quality with some indications of impacts from human activities. Potential sources of contaminants include industrial and municipal discharges from Beaufort and Morehead City, and public recreational use (National Park Service, 1995).

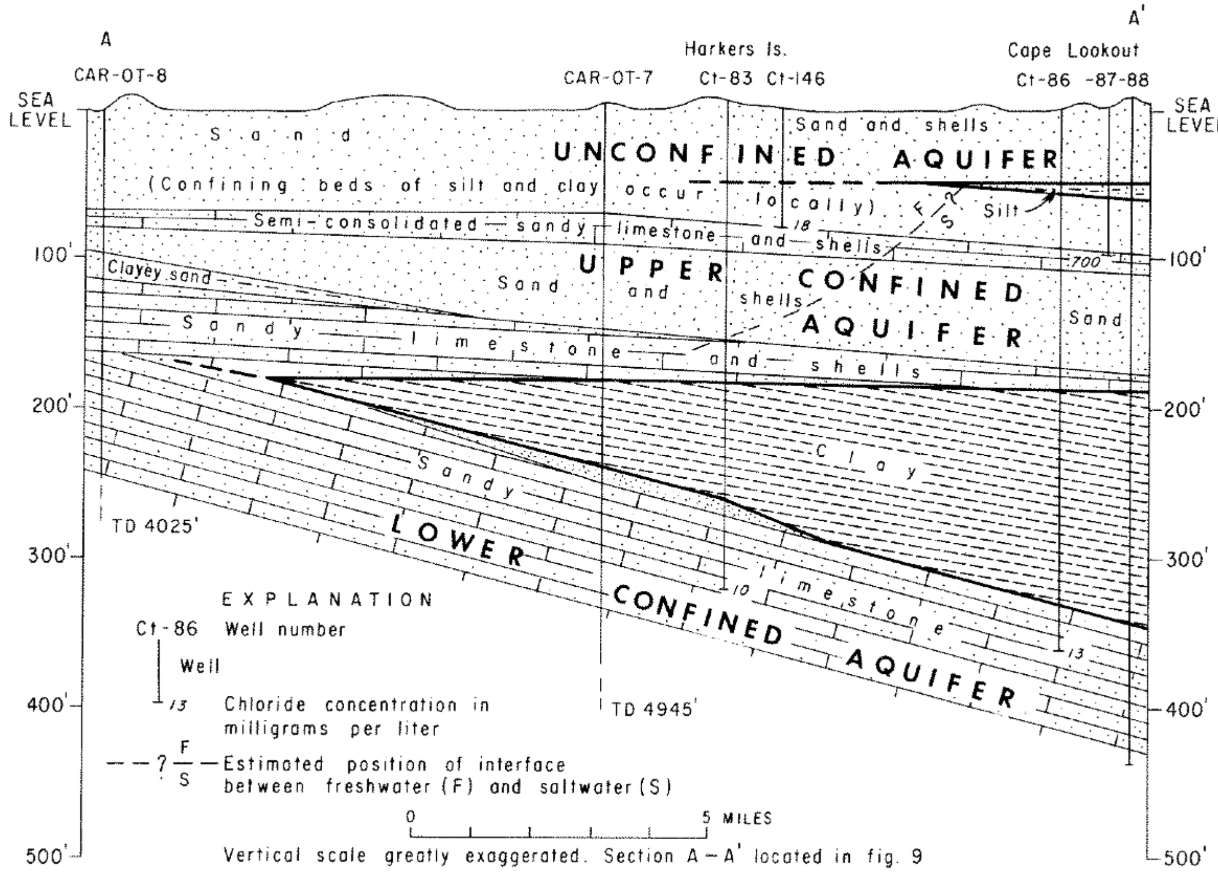

Figure 3. Hydrogeologic cross section at Cape Lookout National Seashore (Winner, 1978).Section is from five miles northwest of Morehead City to Cape Lookout.

Information relevant to water resources, point and nonpoint source pollution, land use, and surface water/well water withdrawals are reported in Mallin et al. (2004). Mallin et al. (2004) also report two areas of concern where former above-ground storage tanks, a former incinerator, and an active refueling pad have leaked some amount of pollutants (petroleum hydrocarbons, polynuclear aromatic hydrocarbons (PAHs), and metals) into soils and groundwater in the immediate vicinity of the sites.

With respect to land-use changes, human alteration of Core and Shackleford Banks is unlikely to intensify. The Park Service has purchased most of the private dwellings on Core Banks and their fate has yet to be determined. Many of the structures are historic buildings and will not be demolished, but either used by the Park or leased to the public (M. Rikard, NPS, personal communication). Well water is currently drawn from approximately 90 feet down for use at the Core Banks fish camps and park facilities. Because the private dwellings on Core Banks are coming under the jurisdiction of the Park Service use of the groundwater is not likely to increase, and shortages are not likely to become an issue. Surface waters on Shackleford Banks are not used for human consumption, nor is there any groundwater withdrawal except for two non-potable wells used for washing (Mallin et al., 2004)

CANA: Canaveral National Seashore

Canaveral National Seashore is situated in the Southeastern Coastal Plain on Florida's Atlantic coast between Daytona Beach and Melbourne on the eastern side of the intercoastal waterways near the Kennedy Space Center. The National Aeronautical and Space Administration (NASA) owns the southern half of the park. The park receives approximately 1,000,000 visitors a year.

Schmalzer and Hinkle (1990) describe the geology, hydrogeology, and soils of the nearby Kennedy Space Center (KSC), which is indicative of conditions at Canaveral National Seashore. Figure 4 shows a cross-section of the aquifers and formations at KSC. Sediments have accumulated in alternating deposition and erosion periods since the Eocene. Surface sediments are Pleistocene and Recent ages. Fluctuating sea levels with the alternating glacial-interglacial cycles shaped the formation of the barrier islands.

Canaveral National Seashore is made up of beach, marsh, wetland, and uplands. Sandy beach ridges with altitudes of about 25 feet alternate with low inter-ridge areas with altitudes of about five to ten feet. Soils range in variety from upland, wetland, and lagoon, and reflect the complexity of soil forming factors (parent material, topography, time, biota) on the landscape. Numerous soil series are represented. Within a given area, soils vary from well to poorly drained. Leaching has modified soil properties on well-drained sites of differing ages. Parent material differences (such as the sand, loam, clay, and coquina content) are also reflected in the soil pattern (Schmalzer and Hinkle, 1990).

Merritt Island is an older landscape that may have formed as much as 240,000 years ago, although most of the surface sediments are not that old. Cape Canaveral probably dates from <7,000 years B.P. as does the barrier strip separating Mosquito Lagoon (a large lagoon located south of the main office, also the site of several archeological studies) from the Atlantic Ocean. Merritt Island and Cape Canaveral have been shaped by progradational processes but not continuously so, while the Mosquito Lagoon barrier has been migrating landward (Schmalzer and Hinkle, 1990).

Surface water quality data were collected, reported, and summarized in Minter and Tucker (1996). Surface water resources include the Indian River and Mosquito Lagoon, and are, with the exception of certain metals, generally of good quality and typical of the area. The source of elevated silver concentrations in Mosquito Lagoon (which frequently exceed the acute marine criterion) are a potential topic for research by the park. Potential anthropogenic sources of contaminants include municipal and residential development, septic tank systems, and wastewater discharges (Minter and Tucker, 1996).

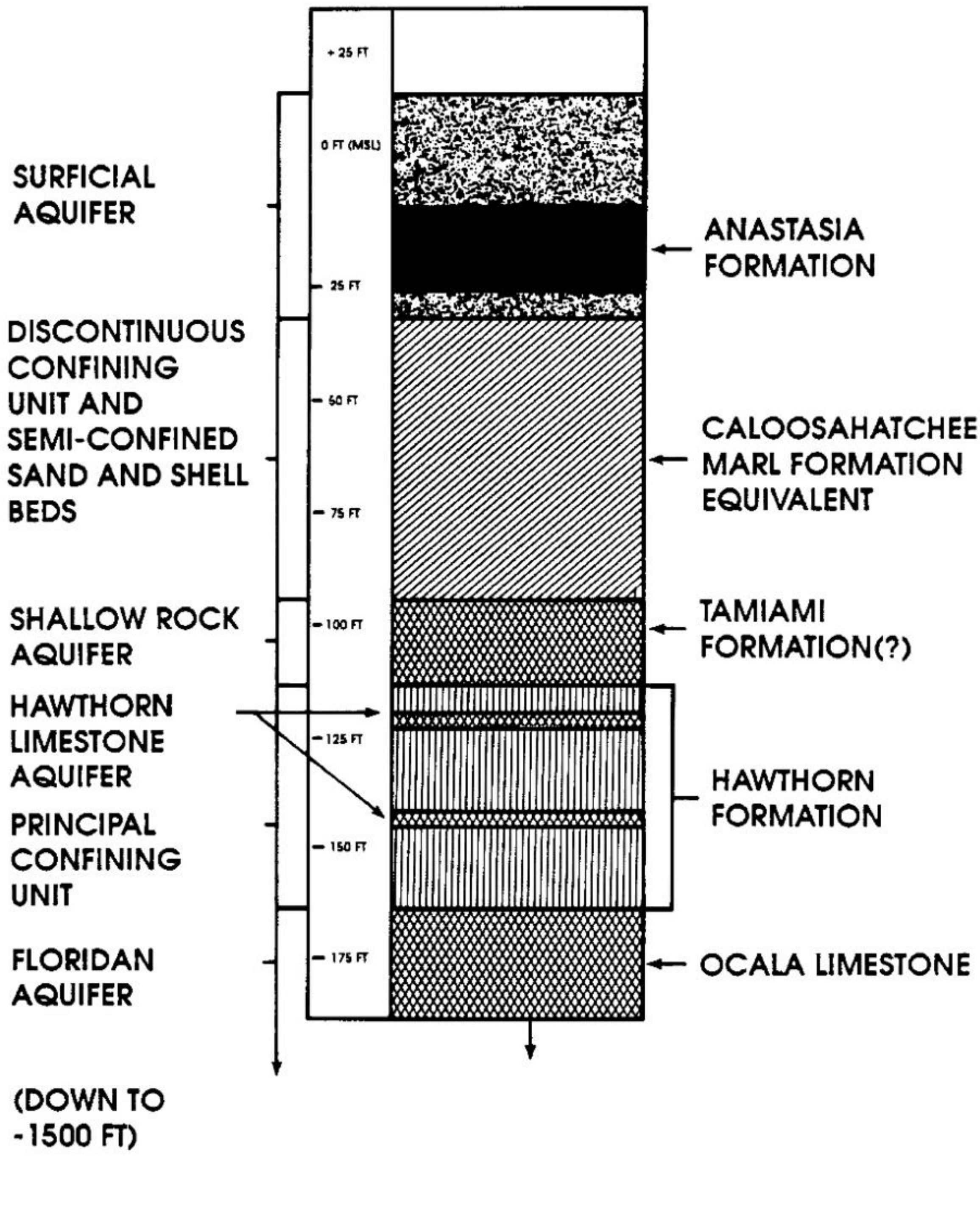

Figure 4. Hydrogeologic units at Kennedy Space Center (Schmalzer and Hinkle, 1990).

The hydraulics of the area in which the Mosquito Lagoon lies and summary statistics of the groundwater quality within the surficial, Upper Flordian, and Lower Floridan aquifers were described by Walters et al (2001). Meyer (1989) also described the regional flow characteristics, and lithology of the Floridan Aquifer system, which is composed of the Upper Floridan, the middle confining unit, and the Lower Floridan.

Groundwater movement in the Upper Floridan is south from areas of highest head in central Florida, east to the Straits of Florida, and West to the Gulf of Mexico. Groundwater movement in the Lower Floridan is inland from the Straits of Florida. Natural distributions uranium and carbon in the Lower Floridan confirm hydraulic gradients. Temperature, isotope, and salinity anomalies in the Upper Floridan suggest upwelling from the Lower Floridan. A thick dolomitic unit in the Lower Floridan with a very high transmissivity (referred to as the Boulder Zone) has been used as a waste injection receptacle for some time but has also been considered for cyclic freshwater storage.

Deep aquifers recharge inland and are highly mineralized in the coastal region and interact little with surface vegetation. The surficial aquifer lies in the Pleistocene and Recent deposits and is recharged by local rainfall. Sand ridges in the center of Merritt Island are important to its recharge. Discharge is from evapotranspiration, seepage to canals and ditches, seepage into interior wetland swales, and seepage into impoundments, lagoons, and the ocean. This aquifer exists in dynamic equilibrium with rainfall and with the fresh-saline water interface. Freshwater wetlands depend on the integrity of this aquifer, and it provides freshwater discharge to the lagoons and impoundments (Schmalzer and Hinkle, 1990).

Some wells in the study area, e.g., the lower permeable zone wells of the surficial aquifer and the upper Floridan Aquifer wells, have water levels that are about the same, indicating a good hydraulic link between the two. Water levels are different at other sites and the connection between zones is apparently poor. Both the magnitude and direction of the vertical hydraulic gradient between the surficial aquifer system and the upper Floridan Aquifer fluctuate seasonally, and the vertical gradient can switch direction where the gradient is small.

Water levels gradients also indicate whether a particular area is recharging to, or discharging from, the upper Floridan Aquifer. To the west of Mosquito Lagoon, some wells exhibit a higher hydraulic head in the upper Floridan Aquifer than in the surficial aquifer system, indicating a discharge area from the upper Floridan Aquifer. Also on the west, the lower surficial aquifer receives recharge from the upper zone of the surficial aquifer system and from the upper Floridan Aquifer. It is thus probable that groundwater discharge from the lower zone of the surficial aquifer system to Mosquito Lagoon represents a major input to the system (Phelps, 1990).

The potentiometric surface of the Upper Floridan aquifer is above the land surface in some areas, and generally no more than 15 feet below land surface. Runoff ranges mostly from six to eighteen inches per year, although on the Atlantic Beach Ridge (the barrier island), runoff is only one to six inches, probably reflecting a higher infiltration rate (Walters et al., 2001).

Additional technical studies associated with shallow groundwater contamination (Edward E. Clarke Engineers-Scientists, Inc., 1987; Schmalzer and Hinkle, 1990; Schmalzer et al., 2000) at KSC have used short-term data sets with limited spatial coverage.

CASA: Castillo de San Marcos National Monument
Fort Matanzas National Monument (FOMA) manages this park unit; information about this unit can be found in the FOMA section of this report.

CHAT: Chattahoochee River National Recreation Area
The Chattahoochee River National Recreation Area is made up of 6, 800 acres of mixed pine/hardwood forests and wetlands that buffer miles of the Chattahoochee River. Exact mapping of the park land designations has not been completed. The unit consists of slopes and floodplains bordering the Chattahoochee River. Surface water bodies within the park include the following: Chattahoochee River and associated tributaries, Bullsluice Lake, Sibley Pond (in the Cocker Shoals unit), and Island Ford Pond. Upstream of the park is Buford Dam, which impounds Lake Lanier. Below Lake Lanier is Morgan Falls Dam.

The Chattahoochee River NRA is located in the Piedmont geologic province. Rocks in the area are primarily schist, granite, and gneiss. Most wells in the area are drilled to 200-500 feet to reach significant water-bearing fractures. The Brevard Fault Zone follows along the river. The soils range in texture from gravelly sandy loam to clay loam.

The Water Resources Management Plan for this park unit (Kunkle and Vana-Miller, 2000) reviewed the water resources and principal water-related issues in the Chattahoochee River National Recreation Area (CHAT), and proposes management actions that address water resource issues. The data reported and the recommendations stated in the Water Resources Management Plan did not specifically address groundwater resources. No other reports were identified that would assist in groundwater characterization or management.

CHPI: Charles Pinckney National Historic Site
Fort Sumter National Monument (FOSU) manages this park unit; information about this unit can be found in the FOSU section of this report.

CONG: Congaree National Park
Congaree National Park is made up of 24,180 acres of currently owned land, and 26,776 acres of authorized area. The park consists of old-growth bottomland forests along the Congaree River, and comprises a floodplain ecosystem. The park averages 100,000 visitors per year. Congaree National Park lies in the floodplain of the Congaree River in the Coastal Plain physiographic province of South Carolina. Its soils are loamy and high in clays and silts that were deposited via fluvial processes, underlain by sands typical of the Coastal Plain. The Congaree River floods the park an average of ten times a year with varying degrees of severity. The parks surface is composed of Freshwater Wetlands and Forested Wetlands.

Surface water resources in the study area include the Congaree, Wateree, and Santee Rivers; Congaree, Wateree, and other swamps and wetland areas; Weston Lake Dam at Fort Jackson and numerous other reservoirs; Cedar, Toms, Gills, Congaree, and many other creeks; and numerous oxbow and other natural lakes and ponds. Biologically diverse, the Congaree Swamp area is

home to many species of plants, animals, and fish, including one historic species, the red-cockaded woodpecker, which is now endangered. Maintaining a functioning floodplain ecosystem is dependent upon the timing, duration, magnitude and extent of flooding from the Congaree and Wateree Rivers.

Patterson et al. (1985) indicate that groundwater inflow from upland areas sustain tributaries and associated riparian areas during droughts. These inflows are from the shallow, surficial aquifers which are are permeable sands with interbedded silts and clays in the flood plain. The larger, more deeply incised streams (e.g., the Congaree River) gain flows from the deeper, confined (Black Creek) aquifer system. Deep groundwater also discharges to the overlying surficial aquifers in the lower elevation areas near the major streams.

Surface water-quality data were collected, reported, and summarized in Matz and Tucker (1998) Additional conference presentations (Conrads et al., 2007; Feaster et al., 2008; Conrads et al., 2008a,b) also focused on surface water impacts. The data inventories and analyses contained in this report indicate that surface waters within the study area have been impacted by human activities. Potential anthropogenic sources of contaminants include municipal and industrial wastewater discharges; urban and residential development; stormwater runoff; agricultural and silvicultural operations; quarrying operations; recreational use; landfill operations; atmospheric deposition; and military operations." (Matz and Tucker, 1998)

Piezometers have been installed within various ecological communities, disturbance gradients, and geomorphic settings for the purpose of monitoring shallow (surficial) aquifer water levels. Data should serve as a reference point for pristine, non-tidal floodplains in the Southeastern Coastal Plain (Shelley et al., 2008).

Information contained in these and other published reports do not provide information or data relevant to groundwater monitoring and characterization in the deeper aquifers that underlie the park.

CUIS: Cumberland Island National Seashore

Cumberland Island National Seashore is part of Georgia's barrier islands and is about 38,000 acres, with about half of the area in uplands and the other half in salt marsh. The island has several uncapped and unused artesian wells, which are sources for small bodies of standing water on the island.

Cumberland Island National Seashore is one of the many islands that form the chain of barrier islands that parallel the Atlantic and Gulf coasts from Maine to Texas. The surficial soils and aquifers of Cumberland Island are composed of unconsolidated sands, clays, and gravels that were supplied by rivers on the mainland. The surficial aquifer varies seasonally and responds quickly to local changes in recharge and discharge. The surficial aquifers are greatly influenced by tides and wells in this area are susceptible to saltwater intrusion. Approximately 500 feet below the surface of Cumberland Island lies the Upper Floridan Aquifer. Here it is composed of limestone and dolomite and is capped by a confining layer. Cumberland Island surface is covered with saltwater marshes, freshwater wetlands (which are ecologically diverse), and forested uplands.

Surface water resources in the CUIS study area include the Atlantic Ocean; Cumberland and St. Andrew Sounds; the Amelia River, St. Mary's River, and several other rivers; and numerous creeks, marshes, and estuaries. Many of these water resources are influenced by tidal flow and contain fresh water and saline waters in transition.

The unconfined, surficial aquifer can be up to 280 feet thick and consists of Pliocene-Miocene sediment interspersed with younger clay, sand, and limestone. Below the surficial aquifer are confined aquifers (Brunswick and Floridan). The Brunswick aquifer is between 375-500 feet deep, and is predominantly Miocene. The Upper and Lower Floridan aquifers are composed of limestone and other Eocene or Oligocene carbonates and are 700-2,500 ft thick (Alber et al., 2005). The Upper Floridan aquifer is the primary source of fresh water for much of coastal Georgia including Cumberland Island. Groundwater withdrawals from this aquifer have resulted in saltwater contamination in several locations along the Georgia coast, and a cone of depression has developed near Cumberland Island as the result of groundwater withdrawals in the region.

Groundwater quality and quantity conditions were assessed by Alber et al. (2005). They report that:

> *"There are no identified water quality problems that affect the groundwater, and there is no current evidence for saltwater intrusion into the Floridan aquifer in the area underlying CUIS. The USGS continues to monitor established wells on a semi-annual basis. However, uncapped artesian wells are presently flowing on the island, with potential effects on nearby resources."* (Alber et al., 2005)

Priest and Clarke (2005) assessed the potential for water-table declines caused by pumping of the surficial aquifer on the island. They state that

> *"Using a non-equilibrium formula, estimated drawdown after 5 years of pumping at a rate of 0.2 million gallons per day along the western edge of Cumberland Island's wilderness area would be about 26 feet in the surficial aquifer confined zone, 39 feet in the upper Brunswick aquifer, and 3.7 feet in the lower Brunswick aquifer. Pumping from the lower Brunswick aquifer at a rate of 2 million gallons per day for 5 years would result in 37 feet of drawdown along the western edge of the wilderness area. Water-level declines in aquifers beneath wetland areas could reduce quantities of water discharging from confined units into the unconfined parts of the surficial aquifer system, which are important for sustaining freshwater wetland ecosystems on Cumberland Island."* (Priest and Clarke, 2005)

The Baseline Water Quality Data Inventory (National Park Service, 1997a) indicates that some surface waters within the study area have been affected by human activities. Potential anthropogenic sources of contaminants include municipal and industrial effluent. The inventory did not provide information or data directly relevant to groundwater monitoring and characterization.

FOCA: Fort Caroline National Memorial

This park unit is managed as part of Timucuan Ecological and Historic Preserve (TIMU); information about this unit can be found in the TIMU section of this report.

FOFR: Fort Frederica National Monument

Ft. Frederica National Monument stands on 241 acres of marsh and upland on St. Simons Island, Georgia. The marshland takes up approximately 150 acres. Aside from the standing water in the marshland, the Frederica River runs adjacent to the park. St. Simons Island is a part of system of barrier islands that parallel the Atlantic and Gulf coasts from Maine to Texas. Ninety percent of the land on St. Simons dates to the Pleistocene with the other ten percent (mainly the recent beach line) dating to the Holocene. The area of the Fort is part of the Silver Bluff Formation. The soils around the Fort are classified as belonging to the Cainhoy-Mandarin-Pottsburg soil group.

The soil map of the area around the Fort shows Cainhoy fine sands. These sands are described as being somewhat excessively drained sands that are nearly level to gently sloping. The typical soil profile for this group is a surface layer of dark gray fine sand to a depth of approximately four inches. A brownish-yellow, fine sand is found between four and 16 inches. Underlying these brownish-yellow sands is a layer of very pale-brown sand that extends to a depth of over three feet. Cainhoy sands are not naturally fertile, have little organic content, and are slightly to strongly acidic. The marshes surrounding the Fort are of the Bohicket-Capers association. These soils are generally found in tidal marshes and are very poorly drained.

The dominant influence in this area is the daily fluctuation of the tides. The tides affect the water levels and salinity in the marshes, creeks and rivers. Surface water quality data were collected, reported, and summarized in NPS (1998a). According the report, potential anthropogenic sources of contaminants include industrial and municipal wastewater discharges; stormwater runoff; recreational use; and atmospheric deposition (National Park Service, 1998a)

A review of park-specific literature did not provide any groundwater information consistent with the objectives of this work.

FOMA: Fort Matanzas National Monument

Fort Matanzas consists of approximately 300 acres of land and the associated Castillo de San Marcos consists of approximately 18 acres. The parks consist of 15 percent wetland, marshland, and estuarine waterway. The historic Spanish fort on Rattlesnake Island and a Visitor Center attract roughly 1 million visitors per year.

Surface water resources in the FOMA and CASA study areas include the Atlantic Ocean; portions of the Intracoastal Waterway; the Tolomato, Matanzas, and San Sebastian Rivers; the St. Augustine and Matanzas Inlets; Pellicer and other creeks; and numerous tidal swamps, marshes, and estuaries. Many of these water resources are influenced by tidal flow and contain fresh and saline waters in transition. Based on the data inventories and analysis contained in this report, surface water quality within the study area appears to have been impacted by human activities. Potential anthropogenic sources of contaminants include municipal wastewater discharges; commercial and residential development; waterway navigation activities; stormwater runoff; recreational activities; and atmospheric deposition. (National Park Service, 1998b)

FOMA and CASA are located within and between the cities of St. Augustine and Palm Coast on Florida's Atlantic coast in the Southeastern Coastal Plain geologic province. The parks consist of saltwater marshes, small freshwater wetlands, and forested uplands. The surficial soils and aquifers of Fort Matanzas National Monument are composed of unconsolidated sands, clays, and gravels. The surficial aquifer varies seasonally and responds quickly to local changes in weather and tides. The Upper Floridan aquifer system lies approximately 250 feet below the parks, and is composed of limestone and dolomite.

The barrier islands generally display the following geomorphologic description from seaward side to estuarine side: beach, grassy dunes, wax myrtle thicket, and marsh. The uppermost soil is primarily fine-medium sand. The surficial geology consists of perched barrier islands and lagoon and tidal marsh areas (Mehta and Jones, 1977). The rock layer underlying the Matanzas Inlet is the Anastasia formation (Pleistocene formation) and overlain by mixed Holocene sands. The Anastasia formation lithology varies from coarse rock composed of coquina shells to sandstone.

Testhole samples were drilled in 2002, and the lithology is described in "Field Services Construction Preliminary Data, Fort Matanzas," by SJRWMD Diversified Drilling, Inc. The nearby North Estuarine Research Reserve has river data for salinity, temperature, etc.

FOPA: Fort Pulaski National Monument

Ft. Pulaski National Monument is made up of 5400 acres of marsh/wetland and uplands (approx. 250 acres) in the Southeastern Coastal Plain. Ft. Pulaski is located on Cockspur Island at the mouth of the Savannah River near Savannah, GA. The park receives approximately 0.5 million visitors per year.

Surface water bodies, aside from the Savannah River, include two small ponds for mosquito control and the moat that encircles the fort. There are also many man-made dikes and drainage ditches located near the Fort. Other surface water features in the vicinity of the park include the Atlantic Ocean; Intracoastal Waterway; Wassaw Sound; the Savannah, Bull, Wilmington, and many other rivers; Oyster, Tybee, Fields, and numerous other creeks and cuts; a few canals; and many marshes, tidal swamps, and estuaries. Most of these surface-water resources are influenced by tidal flow and contain fresh and saline waters in transition (National Park Service, 1999)

Three groundwater flow models have been developed for the coastal area of Georgia (Clarke and Krause 2001). Model simulations of increased pumpage in the Savannah-Hilton Head area indicated a probable increase in leakage and greater saltwater contamination to underlying aquifers. Model results show that if pumping were to be reduced by about 65 mgd in Chatham County, the hydraulic flow at Savannah would shift seaward toward Hilton Head again. The effects of stopping all pumping in Chatham County are uncertain, however (McFarlin and Albers, 2005).

FORA: Fort Raleigh National Historic Site

This park unit is managed by the Cape Hatteras National Seashore (CAHA); information about this unit can be found in the CAHA section of this report.

FOSU: Fort Sumter National Monument

Fort Sumter National Monument is a small island located in the mouth of Charlestown Harbor. Soils on the island are composed of unconsolidated sands, clays, and gravels originating from the three rivers that are tributary to Charlestown Harbor. The hydrology of the island is greatly influenced by tides and recent weather.

Surface water resources in the FOSU study area include the Atlantic Ocean; portions of the Intracoastal Waterway; Charleston Harbor and other bays and coves; the Cooper, Ashley, and Wando Rivers; Shem, James Island, Hobcaw, and numerous other creeks and cuts; a few impoundments; and many marshes, tidal flats, and estuaries. Many of these water resources are influenced by tidal flow and contain fresh and saline waters in transition (National Park Service, 2001b).

Groundwater supplies from regional aquifers have historically served as a significant water resource to Charleston (Stephenson and Palmer, 1914), which extends to the present day. Campbell et al. (2004) evaluated the hydrologic and geochemical effects of aquifer storage recovery to determine the potential for storing water underground to be used later during times of emergency. Four injection and withdrawal cycles were performed and findings regarding water quality changes and chemical changes within the Tertiary Santee Limestone/Black Mingo confined aquifer were reported.

Campbell et al. (1996) report that industrial and commercial use of the NPS property in Charleston, SC has caused contamination of the soils and surficial aquifer. The report documented the use and results of a reactive transport model that simulated contaminant migration to the nearby Cooper River.

HOBE: Horseshoe Bend National Military Park

Horseshoe Bend National Military Park is made up of 2040 acres of mixed hardwood forest. Most of the park is upland, with approximately ten percent of the area representing wetlands. A portion of the forests is recovering farmland. There are many open fields that commemorate historic battlefronts. The park averages 100,000 visitors per year.

The park is located in a transitional area between the Piedmont and Coastal Plain physiographic provinces, but primarily Piedmont geology and hydrology. Soils are clay rich. Surface water bodies at the park include the Tallapoosa River and Whale Creek.

Surface water resources in the HOBE study area include the Tallapoosa River; Emuckfaw, Timbergut, Hillabee, Dobbs, and numerous other creeks; the northern areas of Martin Lake and other reservoirs; and many ponds and springs. (National Park Service, 1997b)

No information about groundwater resources was found for this park.

KEMO: Kennesaw Mountain National Battlefield Park

Kennesaw Mountain National Battlefield Park is located in the Allatoona Mountain Range within the Piedmont Physiographic Province. The park consists of approximately 3000 acres of mixed hardwood pine forest and open fields. Less than ten percent of the park is considered wetlands. Kennesaw Mountain is located in the northern portion of the park, while other portions

of the park are bounded and intersected by suburban developments. The park receives approximately 1.5 million visitors per year (includes passing traffic).

Multiple creeks are located within the park including John Ward Creek, Noses Creek and Allatoona Creek, which originate in Metro Atlanta. Soils are predominantly Ultisols with some Inceptisols. The bedrock of Kennesaw Mountain is composed mostly of gneiss. The aquifers under Kennesaw Mountain are composed of fractured bedrock and saprolite.

No information about groundwater resources was found for this park.

MOCR: Moores Creek National Battlefield

Moores Creek National Battlefield is located 20 miles northwest of Wilmington, North Carolina, and averages approximately 60,000 visitors per year. The park consists of 87.75 acres of forest, creek, wetland, and open fields on the Coastal Plain province of North Carolina. Moores Creek is the only significant stream within the park's boundaries. Freshwater and forested wetlands make up approximately 12-15 acres. There is a wetland restoration project in the middle of the park called the "savannah" that generally has standing water Soils are loamy and high in clays and silts that were deposited via fluvial processes, underlain by sands typical of the Coastal Plain

Surface water resources near the park include Black River; Moores Creek, Colly Creek, Lyon Creek; Big Branch, Bear Branch, Deer Valley Branch; Long Bay, Flat Bay, Black Bay; and other small creeks, marshes, and swamps (National Park Service, 1997c). Stockert (1985) provides information about the history of park wells, along with a timeline for public water use.

OCMU: Ocmulgee National Monument

Ocmulgee National Monument is located on the Fall Line, near Macon, GA. The 702-acre park is surrounded by development. Roughly 300 acres of the park are classified as emergent wetlands. The park has considerable biodiversity.

Area soils are classified as Bibb typic, fluvaquent, which is located on floodplains of streams in the Coastal Plain. The Bibb soils exhibit very deep, poorly drained, moderately permeable characteristics and formed in stratified loamy and sandy alluvium. The soil is on the Georgia list of hydric soils, indicating that they are flood prone and are likely indicators of wetland conditions.

Surface water resources in the area include the Ocmulgee River; Walnut, Swift, Town, and numerous other creeks; Edwards, Club, Nelsons, and other impounded lakes and ponds; and swamps and wetlands (National Park Service, 2001a). An environmental assessment (Rehabilitation of the River Trail) summarized the pros and cons of rebuilding the wooden boardwalk through the River Trail wetland (National Park Service, 2005).

The site hydrogeology consists of both Piedmont (in the uplands) and upper Coastal Plain (in the lowlands) characteristics. Dune sands are also present. Two soil cores were drilled to a depth of 20 feet in an Ocmulgee wetland. The top six feet were comprised of silty/silty fine sand. The bottom 14 feet was sandy clay. A layer of kaolin clay was observed.

TIMU: Timucuan Ecological and Historic Preserve

Timucuan National Ecological and Historic Preserve is a relatively new park, established in 1988. The 46,000 acre preserve consists of Fort Caroline National Memorial, the Theodore Roosevelt Area, Kingsley Plantation, and Cedar Point. The make-up of the park is roughly 70 percent saltmarsh and estuary, with mixed forested uplands.

There is limited freshwater on site. Fort Caroline has Spanish Pond, which is nearly dry. There is also Lake Timucuan, which is man-made. Rivers include St. Johns River and Nassau River. There are many saltwater creeks, estuaries, and the Intracoastal Waterway runs through the park.

Surface water resources in the area include the Atlantic Ocean; portions of the Intracoastal Waterway; St. Johns, Fort George, Nassau, South Amelia, and other rivers; Dunn, Clapboard, Browns, Cedar Point, Edwards, and other creeks; Sample, Clapboard, and other swamps and marshes; interconnected lakes and lagoons; and some small impoundments. Many of these water resources are influenced by tidal flow and contain fresh and saline waters in transition (National Park Service, 2000). Barlow (2003) describes the landward flow of saltwater and its intrusion into coastal freshwater aquifers using several case studies.

Aquifer systems at the parks include - from top to bottom - the surficial, intermediate and Floridan (National Park Service, 2000; Anderson et al., 2005). The surficial system consists of late- and post-Miocene sand, clay, shell beds, and limestone - resulting in spatially variable hydraulic characteristics. The surficial aquifer system consists of surficial deposits, and is generally unconfined (Toth, 1993), and the water table is generally at or near the land surface for most of the year in swampy lowland and flatland areas. The Hawthorn Formation creates an intermediate confining unit between the surficial and Floridan system.

The Floridan aquifer system is made up of limestone and dolomite formations from the Paleocene and Eocene epochs. The formations found in this aquifer include the Ocala, Avon Park, Oldsmar, and the upper part of the Cedar Keys limestone. The Floridan system can be further separated into an Upper Floridan aquifer and a Lower Floridan aquifer. A middle confining unit separates the Floridan into these two units (Miller, 1986). The Lower Floridan can be further divided into two water bearing zones separated by a less permeable unit. The upper zone is sometimes referred to as the middle aquifer and is about 500 feet thick. The lower water bearing unit, referred to as the Fernandina permeable zone, can be salty, making it less desirable for consumption.

WRBR: Wright Brothers National Memorial

This park unit is managed by the Cape Hatteras National Seashore (CAHA). Additional information about the park unit can be found in the CAHA section of this report.

SECN Groundwater Conditions

This section provides a summary of groundwater concerns and monitoring facilities at or near SECN parks. This information was obtained from SECN park personnel, and is reported for each park as Appendix A. Also included in the appendix are points of contact at each park along with others familiar with park facilities. The information was collected through site visits as well as telephone and email conversations with individuals with knowledge of park facilities and conditions.

This section also summarizes groundwater monitoring data availability within and near SECN parks. For those wells were sufficient duration and frequency of monitoring data are available, two computer programs are used to acquire data from online sources, and estimate trends within these data, respectively.

Groundwater Concerns

Interviews with NPS staff were used to develop a set of concerns related to onsite and offsite disturbances or alteration to the groundwater hydrology. The general types of concerns are provided in Table 3. Note that inactive wells and contamination are the leading concerns, with some coastal sites expressing concerns about saltwater intrusion, coastal flooding, and groundwater withdrawals due to increased water supply needs. There are also concerns about alteration of surface-water flooding at two parks (CONG and CHAT).

Table 3. Summary of reported groundwater concerns at SECN park units.

Park Unit(s)	Inactive Wells	Groundwater Contamination	Saltwater Intrusion	Flooding	Increased Demand
CAHA (FORA/WRBR)	x	x	x	x	
CALO		x		x	
CANA		x			
CHAT	x	x		x	
CONG	x	x		x	x
CUIS	x	x	x		x
FOFR	x	x			
FOMA (CASA)		x	x		
FOPU	x	x	x		
FOSU (CHPI)	x	x			
HOBE	x	x			
KEMO		x			
MOCR		x		x	
OCMU	x	x			
TIMU (FOCA)	x	x	x		x

Groundwater Monitoring Facilities

Table 4 summarizes the hydrologic monitoring facilities reported at each SECN park unit.

While the U.S. Geological Survey provides groundwater data suitable for regional trends, there is a paucity of data in the immediate vicinity of most SECN parks. In some cases, SECN park units

have, or have had, a groundwater-monitoring program, but most units lack such a program. Even where such monitoring programs exist, however, the temporal frequency is inadequate to evaluate whether long-term trends are present. Also, the lack of information about water levels in the various aquifers that underlie each site means that causes of hydrologic impacts cannot be specifically identified. Because groundwater levels can be affected by meteorological and surface water conditions (including tidal influence in coastal areas), information for nearby weather stations and tidal or surface water (stream) stations were also identified.

Depth to water data collected for wells can be accessed from:

- http://water.usgs.gov/waterwatch/
- http://ogw01.er.usgs.gov/AWLSites.asp?S=<stationid>

where <stationid> is the USGS station identification.

Weather data sources include:

- http://www.ncdc.noaa.gov/oa/climate/stationlocator.html
- http://www.ncdc.noaa.gov/oa/ncdc.html

Tidal stations data can be obtained from:

- http://tidesandcurrents.noaa.gov/station_retrieve.shtml
- http://tidesonline.nos.noaa.gov/monitor

Table 4. Summary of hydrologic monitoring facilities at SECN park units. The value in parentheses ( ) indicates number of inactive wells.

Park Unit(s)	Water Supply Wells	Onsite Monitoring Wells	Weather Stations	Tidal or Stream Stations
CAHA (FORA/WRBR)	8 (2)	4 (≥10)		
CALO	7	2	1	
CANA		(≥51)	1	1
CHAT	(1-5)	2		1
CONG	2	22	1	2
CUIS	5 (12)	≥3	1	
FOFR	1 (4)			
FOMA (CASA)	1 (≥2)	1 (1)		1
FOPU	3 (7)	≥4	1	
FOSU (CHPI)	1 (1)	≥2		
HOBE	(1)	(1)		1
KEMO				
MOCR	1 (5)	14		
OCMU		(2)		
TIMU (FOCA)	10 (≥1)	≥4		

Inventory of Existing Wells

Several wells are located on each park unit some of which are monitored on a monthly, or at a minimum, a bi-yearly basis by various government agencies like the USGS. However, the period of record for these wells may only go back ten years and some of the data may still be denoted as "provisional" pending review by the agency's quality control/quality assurance protocol.

The USGS has a database of historic and recent temporal and spatial data on a number of wells within the park boundaries or near park boundaries that are continuously monitored by different government agencies, which can be found at *http://water.usgs.gov*. USGS wells that have been continuously monitored by various government (federal, state, and local) agencies exist in or near the SECN park boundaries, shown in Table 5 and Figures 5-8. Wells were selected based on their proximity (i.e., generally closer than 50 miles) from park facilities.

A summary of well attributes is presented in Table 6. Included in the table are the well location, depth, surface elevation, data of initial data collection, and number of observations. All wells are currently being monitored.

Table 6 presents those wells located within the general geographic area anticipated to be hydrologically similar to conditions at park facilities. Monitoring wells are generally more frequent near the coast, and are less abundant inland. There are few long-term monitoring wells in the immediate vicinity of several parks (e.g., KEMO, HOBE, CONG), but the likely influence of groundwater alteration at these facilities is not expected to be significant.

Two programs were used to manage and interpret groundwater data. The first program, *GWInput*, is used to provide information about the wells that are to be examined. The second program, *UpdateSW*, is used download monitoring data from USGS internet servers, store the data in a master database, and then perform an analysis of the data. Program documentation for both programs is provided in Appendix B.

Table 5. Groundwater monitoring locations. Park code(s) indicate the park(s) relevant to each well. [Aquifer system codes: PBR = Piedmont and Blue Ridge Aquifers, FAS = Floridan Aquifer System, SECP = Southeastern Coastal Plain Aquifer System, NACP = Northern Atlantic Coastal Plain Aquifer System]

USGS Well ID	Park Code(s)	Well Name	State	Aquifer	System
283835080424501	CANA	838042002 21S36E27 Merritt Isle Wildlife	FL	Floridan	FAS
284859080501002	CANA	V-0840 Migor Shiloh RD NR Oak Hill, FL	FL	Floridan	FAS
290103080551902	CANA	V-0508 New Smyrna Beach	FL	Floridan	FAS
294213081194401	CASA, FOMA	SJ-0602 DOT I95 South	FL	Floridan	FAS
295000081212702	CASA, FOMA	SJ-0824 Treaty Park Well at St Augustine, FL	FL	Floridan	FAS
295132081164801	CASA, FOMA	SJ-92 St. Johns Co. Parks-Rec Office	FL	Floridan	FAS
295604081223503	CASA, FOMA	SJ-0331 Woodlawn RD well NR Bakersville, FL	FL	Floridan	FAS
302307081293801	FOCA, TIMU	D-424 U.S. Park Service Well at Jacksonville, FL	FL	Floridan	FAS
302339081254702	FOCA, TIMU	D-464A City of Jacksonville Well at Jacksonville	FL	Floridan	FAS
302538081253101	FOCA, TIMU	D-164 J-228 Golf Course @ Ft. George Island, FL.	FL	Floridan	FAS
302550081331501	FOCA, TIMU	D-3840 St. Johns River Power Park Repl Well Jax FL	FL	Floridan	FAS
302709081311601	FOCA, TIMU	D-1307 Camden RD NR Eastport, FL	FL	Floridan	FAS
302724081244801	FOCA, TIMU	D-395 Florida Park Service Well at Jacksonville FL	FL	Floridan	FAS
304406081330502	CUIS	33D071	GA	Upper Brunswick	
304406081330503	CUIS	33D072	GA	Surficial	Surficial
304406081330504	CUIS	33D073	GA	Lower Floridan	FAS
304406081330505	CUIS	33D074	GA	Lower Floridan	FAS
304522081281301	CUIS	34E001	GA	Upper Floridan	FAS
304610081280901	CUIS	34E010	GA	Upper Floridan	FAS
304646081280901	CUIS	34E003	GA	Upper Floridan	FAS
304851081274001	CUIS	34E014	GA	Upper Floridan	FAS
305029081265101	CUIS	34E013	GA	Upper Floridan	FAS
305032081280101	CUIS	34E012	GA	Upper Floridan	FAS
305122081275601	CUIS	34E002	GA	Upper Floridan	FAS
305452081252301	CUIS	34F015	GA	Upper Floridan	FAS
310810081292801	FOFR	34H504	GA	Upper Floridan	FAS
310810081292802	FOFR	34H505	GA	Upper Floridan	FAS
310931081291002	FOFR	34H514	GA	Upper Floridan	FAS
311022081304601	FOFR	33H324	GA	Upper Floridan	FAS
311022081304602	FOFR	33H325	GA	Upper Floridan	FAS
311454081210503	FOFR	35H076	GA	Surficial	Surficial

USGS Well ID	Park Code(s)	Well Name	State	Aquifer	System
311711081283002	FOFR	34J077	GA	Upper Brunswick	
320150080540601	FOPU	38Q201	GA	Paleocene Series	SECP
320202080541202	FOPU	38Q208	GA	Surficial	Surficial
321302082243601	FOPU	26R001	GA	Upper Floridan	FAS
322036084590301	OCMU	06S001	GA	Blufftown Formation	SECP
322047086214301	HOBE	K 107 MTG-3	AL	Eutaw Formation	SECP
322500085551201	HOBE	LUSCR1-9	AL	Eutaw Formation	SECP
324729079472001	CHPI, FOSU	CHN-14	SC	Middendorf Formation	SECP
330247079340300	CHPI, FOSU	CHN-101	SC	Floridan	FAS
332706080332001	CONG	ORG-394	SC	Sand Deposits	Surficial
334207084254801	KEMO	10DD02	GA	Crystalline Rocks	PBR
335517084164001	CHAT, KEMO	11FF04	GA	Crystalline Rocks	PBR
335744084011601	CHAT	13FF20	GA	Crystalline Rocks	PBR
335902083565902	CHAT	14FF60	GA	Surficial	Surficial
340049083551101	CHAT	14GG02	GA	Crystalline Rocks	PBR
340743078202002	MOCR	BR-106 Bear Pen EE36k5 NR Supply, NC (Black Creek)	NC	Black Creek Formation	NACP
340743078202006	MOCR	BR-107 Bear Pen EE36k6 NR Supply, NC (Peedee)	NC	Peedee Formation	NACP
340837081173800	CONG	RIC-748	SC		
341913084325301	KEMO	09JJ02	GA	Crystalline Rocks	PBR
344922077484705	MOCR	DU-128 Chinquapin RS 5	NC	Castle Hayne Limestone	CH
345051078012108	MOCR	DU-136 (NC-222) Rose Hill RS NR Rose Hill, NC	NC	Post Miocene	Surficial
345051078012109	MOCR	DU-157 Rose Hill RS V32v9 (NC-222R) (Surficial)	NC	Post Miocene	Surficial
351019077184102	CALO	CR-543 Cove City RS 2	NC	Castle Hayne Limestone	CH
352545077012601	CAHA, CALO	BO-438 LU-14A	NC	Post Miocene	Surficial
352548077012701	CAHA, CALO	BO-413 LU-14	NC	Yorktown Formation	NACP
353747077052001	CAHA, CALO	BO-419 RSK NR Washington, NC	NC	Castle Hayne Limestone	CH
354418076463601	CAHA, CALO, FORA, WRBR	WS-100 (NC-158) NR Hoke, NC (Surficial)	NC	Post Miocene	Surficial
361829076163201	FORA, WRBR	PK-141 (NC-195) NR Elizabeth City, NC (Surficial)	NC	Post Miocene	Surficial
362527076163201	FORA, WRBR	CA-087A LU-03A	NC	Post Miocene	Surficial

Table 6. Well information for SECN Monitoring Well Network. Park code(s) indicate the park(s) relevant to each well.

USGS Well ID	Park Code(s)	Latitude	Longitude	Depth (ft)	Elevation (ft)	Beginning Date	Observations
283835080424501	CANA	28.64306	-80.71250	50	5	5/9/1977	58
284859080501002	CANA	28.81639	-80.83611	195	NA	6/26/1998	18
290103080551902	CANA	29.01750	-80.92194	210	8	11/21/1988	24
294213081194401	CASA, FOMA	29.70361	-81.32889	193	NA	6/16/1996	25
295000081212702	CASA, FOMA	29.83333	-81.35750	285	27.72	9/29/2001	14
295132081164801	CASA, FOMA	29.85889	-81.28000	248	11.11	5/4/1977	59
295604081223503	CASA, FOMA	29.93444	-81.37639	527	34.01	5/20/2003	11
302307081293801	FOCA, TIMU	30.38528	-81.49389	700	11.25	12/19/1966	245
302339081254702	FOCA, TIMU	30.39417	-81.42972	1000	6.78	5/3/1977	61
302538081253101	FOCA, TIMU	30.42722	-81.42528	619	15.54	8/19/1930	347
302550081331501	FOCA, TIMU	30.43056	-81.55417	750	13.67	10/1/1984	7,953
302709081311601	FOCA, TIMU	30.45250	-81.52111	978	NA	3/19/2003	11
302724081244801	FOCA, TIMU	30.45667	-81.41333	NA	7.57	5/10/1966	130
304406081330502	CUIS	30.73500	-81.55139	365	10	1/23/1998	3,563
304406081330503	CUIS	30.73500	-81.55139	255	10	1/24/1998	3,603
304406081330504	CUIS	30.73500	-81.55139	1500	10	3/2/2000	3,119
304406081330505	CUIS	30.73500	-81.55139	2004	10	5/6/2003	1,563
304522081281301	CUIS	30.75611	-81.47028	645	17	9/27/1984	34
304610081280901	CUIS	30.76944	-81.46917	750	10	5/31/1984	33
304646081280901	CUIS	30.77944	-81.46917	730	14	9/27/1984	32
304851081274001	CUIS	30.81417	-81.46111	NA	27	5/31/1984	31
305029081265101	CUIS	30.84111	-81.44750	NA	17	5/31/1984	35
305032081280101	CUIS	30.84222	-81.46694	NA	12	9/27/1984	35
305122081275601	CUIS	30.85611	-81.46528	600	14	9/27/1984	32
305452081252301	CUIS	30.91444	-81.42306	NA	15	5/15/1990	24
310810081292801	FOFR	31.13611	-81.49111	759	10	11/4/2001	549
310810081292802	FOFR	31.13611	-81.49111	1000	10	11/14/2001	548
310931081291002	FOFR	31.15861	-81.48611	685	10	2/21/2007	579
311022081304601	FOFR	31.17278	-81.51278	740	5	2/23/2007	308
311022081304602	FOFR	31.17278	-81.51278	1000	5	2/23/2007	308
311454081210503	FOFR	31.24831	-81.35150	175	19.03	3/14/2006	13
311711081283002	FOFR	31.23639	-81.47500	390	15	5/11/1998	3,677

USGS Well ID	Park Code(s)	Latitude	Longitude	Depth (ft)	Elevation (ft)	Beginning Date	Observations
320150080540601	FOPU	32.03056	-80.90167	1546	7	2/19/1986	7,641
320202080541202	FOPU	32.03389	-80.90333	62	4	2/3/1998	3,646
321302082243601	FOPU	32.21722	-82.41000	1000	287	4/2/1974	12,257
322036084590301	OCMU	32.34194	-84.98611	568	255	5/11/1950	17,846
322047086214301	HOBE	32.34639	-86.36194	270	167.2	8/7/1952	14,238
322500085551201	HOBE	32.41692	-85.91992	32	219	12/8/2000	767
324729079472001	CHPI	32.79139	-79.92861	2007	7.5	4/2/1990	6,321
330247079340300	CHPI	33.04639	-79.56750	91	22	2/15/1980	9,754
332706080332001	CONG	33.45266	-80.55592	17	151	7/21/1997	2
334207084254801	KEMO	33.70194	-84.43000	341	1013	11/17/1973	12,475
335517084164001	CHAT, KEMO	33.92139	-84.27778	620	963.05	2/20/1980	10,112
335744084011601	CHAT	33.96222	-84.02111	455	995	8/2/2001	117
335902083565902	CHAT	33.98394	-83.94975	9.5	952.8	1/23/2003	120
340049083551101	CHAT	34.01367	-83.91983	304	1120	7/7/2003	1,630
340743078202002	MOCR	34.12861	-78.33889	654	61.5	10/14/1999	7,500
340743078202006	MOCR	34.12861	-78.33889	110	61	4/6/2000	6,924
340837081173800	CONG	34.14369	-81.29397	250	367	1/17/2007	57
341913084325301	KEMO	34.32028	-84.54806	370	1060	11/6/1988	6,893
344922077484705	MOCR	34.82278	-77.81306	139	42.62	1/24/1980	38
345051078012108	MOCR	34.84778	-78.02222	14	86	6/9/1982	50
345051078012109	MOCR	34.84750	-78.02250	15.4	86	8/29/2003	32
351019077184102	CALO	35.17194	-77.31139	98	46	3/13/1985	29
352545077012601	CAHA. CALO	35.42917	-77.02389	28	33	7/3/2007	2
352548077012701	CAHA, CALO	35.42928	-77.02381	27	33	10/28/1993	12
353747077052001	CAHA, CALO	35.62972	-77.08889	82	35.85	8/14/2003	16
354418076463601	CAHA, CALO, FORA, WRBR	35.73889	-76.77528	15.53	35	12/17/1986	7,344
361829076163201	FORA, WRBR	36.30833	-76.27528	12.6	15	10/3/1991	94
362527076163201	FORA, WRBR	36.42417	-76.27556	10.65	13	5/9/2007	1

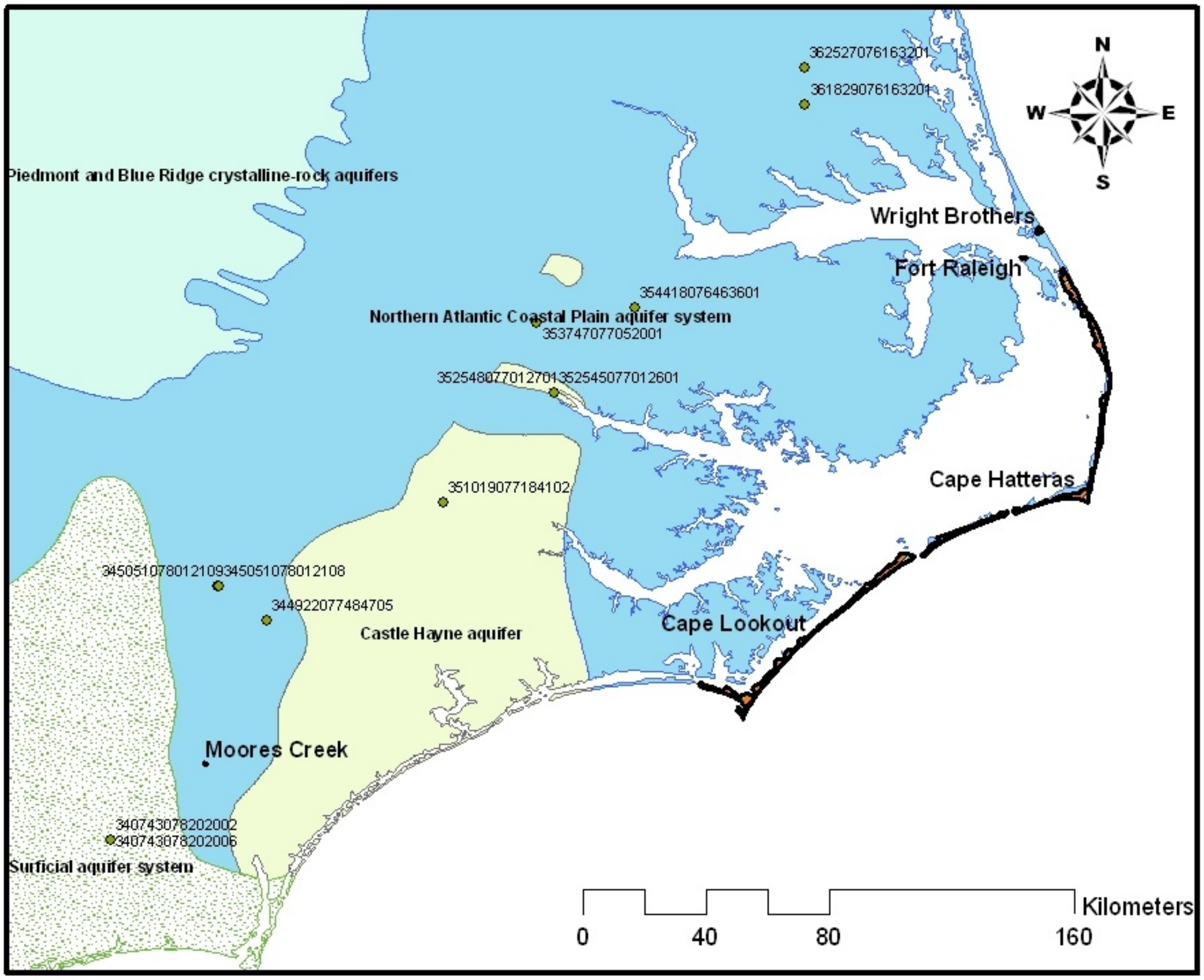

Figure 5. Well locations near CAHA, CALO, FORA, MOCR, and WRBR.

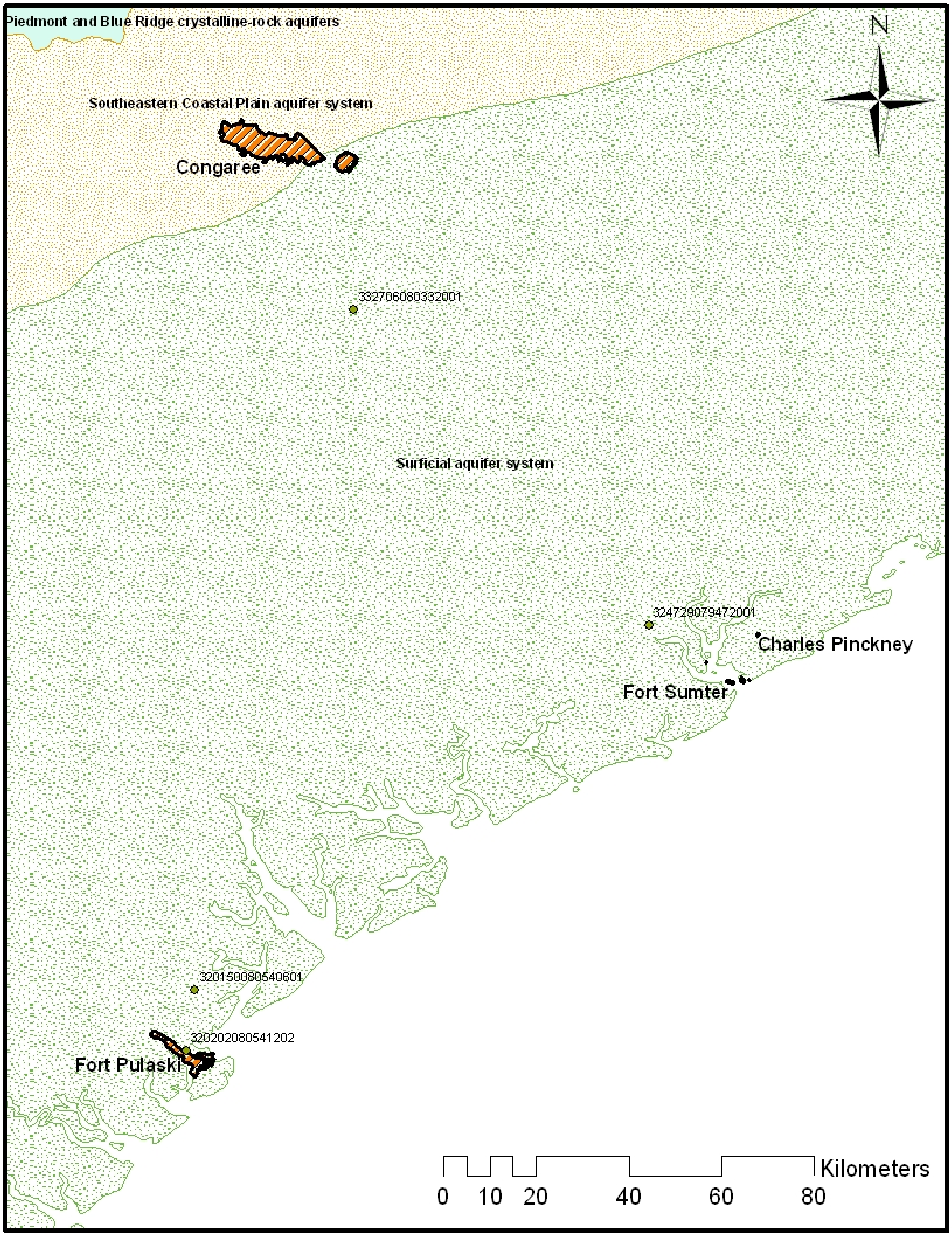

Figure 6. Well locations near CONG, FOPU, FOSU, and CHPI.

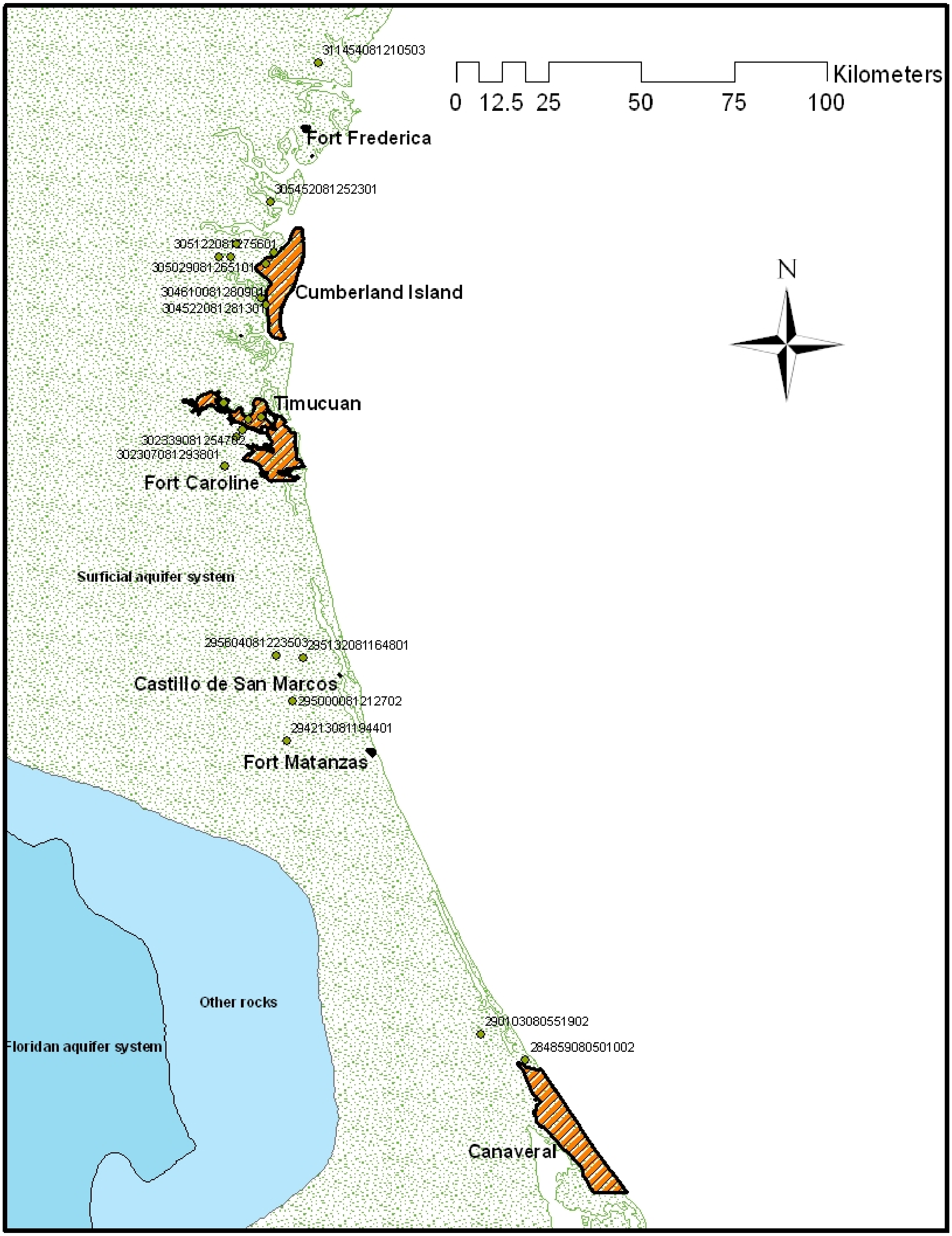

Figure 7. Well locations near FOFR, CUIS, TIMU, FOCA, CASA, FOMA, and CANA.

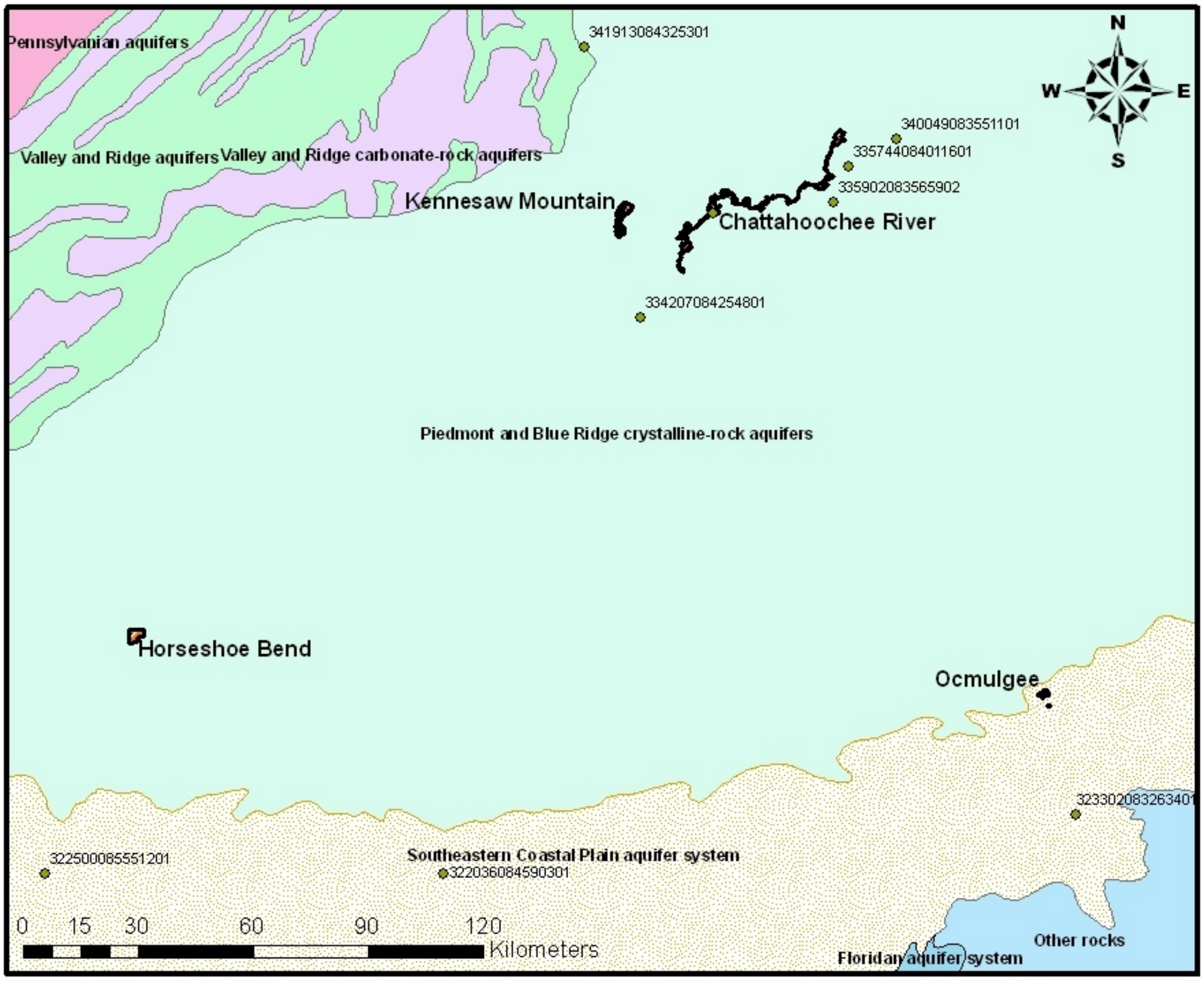

Figure 8. Well locations near HOBE, KEMO, CHAT, and OCMU.

Summary of Data Trends

A summary of water-level trends as measured in U.S. Geological Survey monitoring wells are presented in Tables 6 and 7. Wells were selected based on their proximity to SECN park units. Two statistical approaches were used. The first calculates the water-level trend (in feet per year) using all observations, regardless of the data density. These results are presented in Table 8. Note that many wells have no significant trend, either upward or downward. Yet there are many wells with highly significant, long-term declines in water levels.

In Florida, five wells in the Floridan Aquifer show no significant trend, yet eight show a significant downward trend.

Overall in Georgia, ten wells are trending upward, fourteen downward, and five show no change. Trends are mixed in the Floridan Aquifer, with five wells trending upward and five downward in the Upper Floridan, and one trending upward and one downward in the Lower Floridan. Trends in the surficial aquifers are also mixed, with two downward, one upward, and one with no significant trend. Trends in the crystalline rock aquifer are downward in four wells, and upward in one.

In Alabama, one well is trending upward and one downward. Both are in the Eutaw Formation.

Trends are again mixed in South Carolina, with one well in the Floridan trending upward, and one in the Middendorf trending downward. The other well with sufficient data does not show a significant change.

In North Carolina, the surficial, Post-Miocene aquifer is trending downward in three out of four cases (two wells have minimal data). The Yorktown is trending upward, one well in the Peedee is trending downward, and the Castle Haynes is mixed, with one well showing an upward trend, and two showing no change.

A second, more-rigorous approach uses a single, average water level observation for each year, with a minimum of ten years required for analysis, and twelve observations during the year. Table 9 presents these results. Fewer wells (12 out of 60 wells) meet this stricter requirement. That is, fewer wells have ten years of data with twelve observations within the year. Of the twelve wells that meet the minimum data requirements, three of the wells do not exhibit a significant trend, two show an upward (i.e., positive) trend, and the remaining seven show a downward (i.e., negative) trend. Two of the three wells that do not show a significant trend are located in the surficial aquifer in North Carolina, while the third is located in the Floridan in South Carolina. The wells that show an upward trend are located in crystalline rocks and the Paleocene Series in Georgia. Two of the seven wells that show significant declines are located in crystalline rocks in Georgia, while the remaining five are in the Floridan (FL), Upper Floridan (GA), Blufftown (GA), Eutaw (AL), and Middendorf (SC).

A significant problem is the lack of adequate monitoring wells in the proximity to many park units. While wells may be locally available, they are generally not monitored with sufficient frequency (at least 12 days per year) or over a sufficient period of time (at least ten years) to provide the minimum data required for the more rigorous trend analysis. Another problem is the possible influence of surface water fluctuations on aquifer water levels. Changes in streamflow

or tidal conditions are likely to affect groundwater levels. These short-term changes are unlikely to cause long-term changes in water levels, however. It is more likely that long-term changes are caused by landscape level disturbances, such as aquifer pumping or alteration of surface water by dams and land use practices. Yet data that can be used to account for the landscape level changes (e.g., regional aquifer withdrawal rates) are not available.

Table 10 summarizes the significant trends for each park unit. Note that many wells show a trend (either positive or negative) using all data, but a smaller number show a significant trend using a stricter data requirement of a minimum of ten years of data with twelve or more observations per year. Downward trends appear more commonly than upward trends. At CAHA (which also appropriate for FORA, WRBR, and CALO), the deeper, Yorktown Formation aquifer shows a positive (upward) trend, while the shallower, Post-Miocene (surficial) aquifer shows a downward trend. A downward trend is seen at one well in the Floridan aquifer at CANA. The crystalline rock aquifer near CHAT shows a downward trend, with one long-term data series supporting this finding. Plots of observed water levels along with the trend, even when not significant, are provided in Figures 9-20.

Water levels are generally rising in all aquifers at CUIS (except for one well in the Lower Floridan aquifer), but none of these are supported using the long-term data. This may be due to the recent closure of the paper mill at St. Marys. All wells are declining near FOFR in both the Upper Floridan and Upper Brunswick aquifers. At FOMA (and CASA), the Paleocene aquifer is rising, but surficial and Floridan aquifers are falling. Long-term data confirm rising water levels in the Paleocene aquifer near FOPU. The Floridan aquifer is rising at FOSU (and CHPI), but long-term data show that the Middendorf is falling. Long-term data also show the Eutaw aquifer to be falling at HOBE. Two wells are falling and one well is rising in the Crystalline Rocks aquifer near KEMO. All aquifers at MOCR are declining. The Blufftown aquifer near OCMU is declining. Water levels are declining in the Floridan aquifer near TIMU (and FOCA), one of them confirmed using long-term data.

These long-term declines in aquifer water levels are consistent with the observed regional depletion of groundwater due to increased utilization of this resource. One well examined (USGS 321302082243601) in the Upper Floridan aquifer near Vidalia, Georgia, is distant from any of the parks, but indicates that there are additional wells in the region that are declining as well.

Table 7. Statistical results of observed water-level trends using all data. Park code(s) indicate the park(s) relevant to each well. [PBR – Piedmont and Blue Ridge Aquifers; FAS – Floridan Aquifer System; SECP – Southeastern Coastal Plain Aquifer System; NACP – Northern Atlantic Coastal Plain Aquifer System].

UGSG Well ID	Park Code(s)	State	Aquifer	System	Obs	Slope	P	Sig †	Trend ‡
283835080424501	CANA	FL	Floridan	FAS	61	-0.0006	0.0001	xx	-
284859080501002	CANA	FL	Floridan	FAS	18	-0.0009	0.2477		
290103080551902	CANA	FL	Floridan	FAS	24	0.0000	0.8874		
294213081194401	CASA, FOMA	FL	Floridan	FAS	25	-0.0002	0.5335		
295000081212702	CASA, FOMA	FL	Floridan	FAS	14	-0.0008	0.4062		
295132081164801	CASA, FOMA	FL	Floridan	FAS	59	0.0000	0.5729		
295604081223503	CASA, FOMA	FL	Floridan	FAS	11	-0.0032	0.0282	x	-
302307081293801	FOCA, TIMU	FL	Floridan	FAS	245	-0.0009	0.0000	xx	-
302339081254702	FOCA, TIMU	FL	Floridan	FAS	61	-0.0006	0.0001	xx	-
302538081253101	FOCA, TIMU	FL	Floridan	FAS	347	-0.0008	0.0000	xx	-
302550081331501	FOCA, TIMU	FL	Floridan	FAS	7953	-0.0012	0.0000	xx	-
302709081311601	FOCA, TIMU	FL	Floridan	FAS	11	-0.0040	0.0128	x	-
302724081244801	FOCA, TIMU	FL	Floridan	FAS	130	-0.0002	0.0000	xx	-
304406081330502	CUIS	GA	Upper Brunswick		3564	0.0075	0.0000	xx	+
304406081330503	CUIS	GA	Surficial	Surficial	3604	0.0013	0.0000	xx	+
304406081330504	CUIS	GA	Lower Floridan	FAS	3120	0.0094	0.0000	xx	+
304406081330505	CUIS	GA	Lower Floridan	FAS	1810	-0.0023	0.0000	xx	-
304522081281301	CUIS	GA	Upper Floridan	FAS	34	0.0010	0.0031	xx	+
304610081280901	CUIS	GA	Upper Floridan	FAS	33	0.0008	0.0048	xx	+
304646081280901	CUIS	GA	Upper Floridan	FAS	32	0.0006	0.0219	x	+
304851081274001	CUIS	GA	Upper Floridan	FAS	31	0.0007	0.0611		
305029081265101	CUIS	GA	Upper Floridan	FAS	35	0.0004	0.0969		
305032081280101	CUIS	GA	Upper Floridan	FAS	35	0.0004	0.0353	x	+
305122081275601	CUIS	GA	Upper Floridan	FAS	32	0.0002	0.5397		
305452081252301	CUIS	GA	Upper Floridan	FAS	24	0.0022	0.0000	xx	+
310810081292801	FOFR	GA	Upper Floridan	FAS	547	0.0001	0.8440		
310810081292802	FOFR	GA	Upper Floridan	FAS	547	-0.0027	0.0000	xx	-
310931081291002	FOFR	GA	Upper Floridan	FAS	578	-0.0014	0.0006	xx	-
311022081304601	FOFR	GA	Upper Floridan	FAS	579	-0.0011	0.0176	x	-
311022081304602	FOFR	GA	Upper Floridan	FAS	580	-0.0121	0.0000	xx	-
311454081210503	FOFR	GA	Surficial	Surficial	13	0.0033	0.2912		
311711081283002	FOFR	GA	Upper Brunswick		3607	-0.0032	0.0000	xx	-
320150080540601	FOPU	GA	Paleocene Series	SECP	7555	0.0004	0.0000	xx	+
320202080541202	FOPU	GA	Surficial	Surficial	3574	-0.0001	0.0000	xx	-
321302082243601	FOPU	GA	Upper Floridan	FAS	12195	-0.0022	0.0000	xx	-
322036084590301	OCMU	GA	Blufftown Formation	SECP	17780	-0.0023	0.0000	xx	-
322047086214301	HOBE	AL	Eutaw Formation	SECP	14208	-0.0002	0.0000	xx	-
322500085551201	HOBE	AL	Eutaw Formation	SECP	755	0.0005	0.0345	x	+
324729079472001	CHPI, FOSU	SC	Middendorf Formation	SECP	6262	-0.0085	0.0000	xx	-
330247079340300	CHPI, FOSU	SC	Floridan	FAS	9855	0.0000	0.0000	xx	+
332706080332001	CONG	SC	Sand Deposits	Surficial	2				
334207084254801	KEMO	GA	Crystalline Rocks	PBR	12475	-0.0004	0.0000	xx	-
335517084164001	CHAT, KEMO	GA	Crystalline Rocks	PBR	10113	-0.0001	0.0000	xx	-
335744084011601	CHAT	GA	Crystalline Rocks	PBR	89	-0.0044	0.0000	xx	-
335902083565902	CHAT	GA	Surficial	Surficial	120	-0.0006	0.0000	xx	-
340049083551101	CHAT	GA	Crystalline Rocks	PBR	1630	-0.0021	0.0000	xx	-
340743078202002	MOCR	NC	Black Creek Formation	NACP	2500	-0.0010	0.0000	xx	-
340743078202006	MOCR	NC	Peedee Formation	NACP	2308	-0.0001	0.0004	xx	-

UGSG Well ID	Park Code(s)	State	Aquifer	System	Obs	Slope	P	Sig †	Trend ‡
340837081173800	CONG	SC			58	-0.0063	0.2369		
341913084325301	KEMO	GA	Crystalline Rocks	PBR	7012	0.0002	0.0000	xx	+
344922077484705	MOCR	NC	Castle Hayne Limestone	CH	38	0.0000	0.7229		
345051078012108	MOCR	NC	Post Miocene	Surficial	47	-0.0001	0.3529		
345051078012109	MOCR	NC	Post Miocene	Surficial	877	-0.0018	0.0000	xx	-
351019077184102	CALO	NC	Castle Hayne Limestone	CH	29	0.0003	0.0484	x	+
352545077012601	CAHA, CALO	NC	Post Miocene	Surficial	2				
352548077012701	CAHA, CALO	NC	Yorktown Formation	NACP	12	0.0034	0.0000	xx	+
353747077052001	CAHA, CALO	NC	Castle Hayne Limestone	CH	16	-0.0003	0.4471		
354418076463601	CAHA,CALO, FORA, WRBR	NC	Post Miocene	Surficial	7397	-0.0001	0.0000	xx	-
361829076163201	FORA, WRBR	NC	Post Miocene	Surficial	5946	-0.0001	0.0000	xx	-
362527076163201	FORA, WRBR	NC	Post Miocene	Surficial	1				

Notes:

† Significance: xx indicates significance < 0.01, x indicates < 0.05

‡ Trend: + indicates significant positive trend, - indicates significant negative trend.

Table 8. Statistical results of observed water-level trends using long-term data. (A minimum of ten years, with at least twelve observations per year.) Park code(s) indicate the park(s) relevant to each well. [PBR – Piedmont and Blue Ridge Aquifers; FAS – Floridan Aquifer System; SECP – Southeastern Coastal Plain Aquifer System; NACP – Northern Atlantic Coastal Plain Aquifer System].

Well ID	Park Code(s)	Aquifer	System	Years	Slope	SE	T-stat	P	Sig †	Trend ‡
302550081331501	FOCA, TIMU	Floridan	FAS	12	-0.0010	0.0002	-5.4594	0.0002	xx	-
320150080540601	FOPU	Paleocene Series	SECP	20	0.0004	0.0001	2.9826	0.0077	xx	+
321302082243601	FOPU	Upper Floridan	FAS	33	-0.0022	0.0001	-17.5815	0.0000	xx	-
322036084590301	OCMU	Blufftown Formation	SECP	51	-0.0023	0.0001	-16.0034	0.0000	xx	-
322047086214301	HOBE	Eutaw Formation	SECP	32	-0.0005	0.0001	-3.7551	0.0007	xx	-
324729079472001	CHPI, FOSU	Middendorf Formation	SECP	17	-0.0091	0.0016	-5.8083	0.0000	xx	-
330247079340300	CHPI, FOSU	Floridan	FAS	27	0.0000	0.0000	0.1384	0.8910		
334207084254801	KEMO	Crystalline Rocks	PBR	33	-0.0004	0.0001	-4.9949	0.0000	xx	-
335517084164001	CHAT, KEMO	Crystalline Rocks	PBR	27	-0.0001	0.0000	-7.4042	0.0000	xx	-
341913084325301	KEMO	Crystalline Rocks	PBR	19	0.0003	0.0001	4.4970	0.0003	xx	+
354418076463601	FORA, WRBR	Post Miocene	Surficial	21	0.0000	0.0001	0.6253	0.5388		
361829076163201	FORA, WRBR	Post Miocene	Surficial	16	-0.0001	0.0001	-0.5039	0.6217		

Notes:
† Significance: xx indicates significance < 0.01.
‡ Trend: + indicates significant positive trend, - indicates significant negative trend.

Table 9. Summary of significant water-level trends for SECN parks.

Park Unit(s)	USGS Well ID	Aquifer	Trend †	
CAHA (FORA/WRBR)	352548077012701	Yorktown Formation	+	
	354418076463601	Post Miocene	-	
	361829076163201	Post Miocene	-	
CALO	352548077012701	Yorktown Formation	+	
	354418076463601	Post Miocene	-	
	361829076163201	Post Miocene	-	
CANA	283835080424501	Floridan	-	
CHAT	335517084164001	Crystalline Rocks	-	xx
	335744084011601	Crystalline Rocks	-	
	335902083565902	Crystalline Rocks	-	
	340049083551101	Crystalline Rocks	-	
CONG	(none)			
CUIS	304406081330502	Upper Brunswick	+	
	304406081330503	Surficial	+	
	304406081330504	Lower Floridan	+	
	304406081330505	Lower Floridan	-	
	304522081281301	Upper Floridan	+	
	304610081280901	Upper Floridan	+	
	304646081280901	Upper Floridan	+	
	305032081280101	Upper Floridan	+	
	305452081252301	Upper Floridan	+	
FOFR	310810081292802	Upper Floridan	-	
	310931081291002	Upper Floridan	-	
	311022081304602	Upper Floridan	-	
	311711081283002	Upper Brunswick	-	
FOMA (CASA)	320150080540601	Paleocene Series	+	xx
	320202080541202	Surficial	-	
FOPU	321302082243601	Upper Floridan	-	
	320150080540601	Paleocene	+	xx
FOSU (CHPI)	324729079472001	Middendorf	-	xx
	330247079340300	Floridan	+	
HOBE	322047086214301	Eutaw	-	xx
KEMO	334207084254801	Crystalline Rocks	-	xx
	335517084164001	Crystalline Rocks	-	xx
	341913084325301	Crystalline Rocks	+	xx
MOCR	340743078202002	Black Creek Formation	-	
	340743078202006	Peedee Formation	-	
	345051078012109	Post Miocene	-	
OCMU	322036084590301	Blufftown	-	xx
TIMU (FOCA)	302307081293801	Floridan	-	
	302339081254702	Floridan	-	
	302538081253101	Floridan	-	
	302550081331501	Floridan	-	xx
	302724081244801	Floridan	-	

† xx = confirmed using long-term data

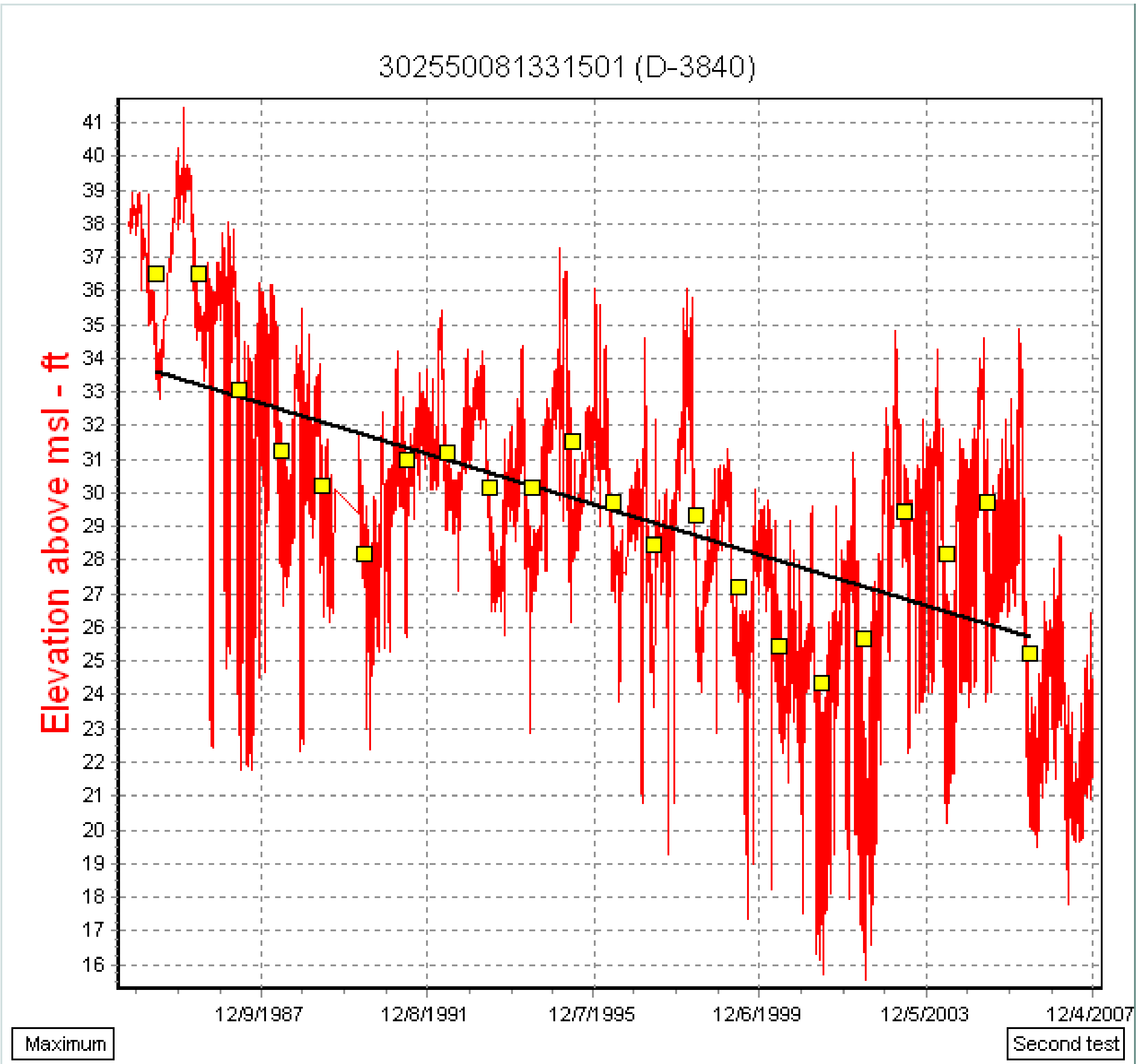

Figure 9. Water levels and calculated trend line for 30255081331501. (Floridan Aquifer near FOCA and TIMU)

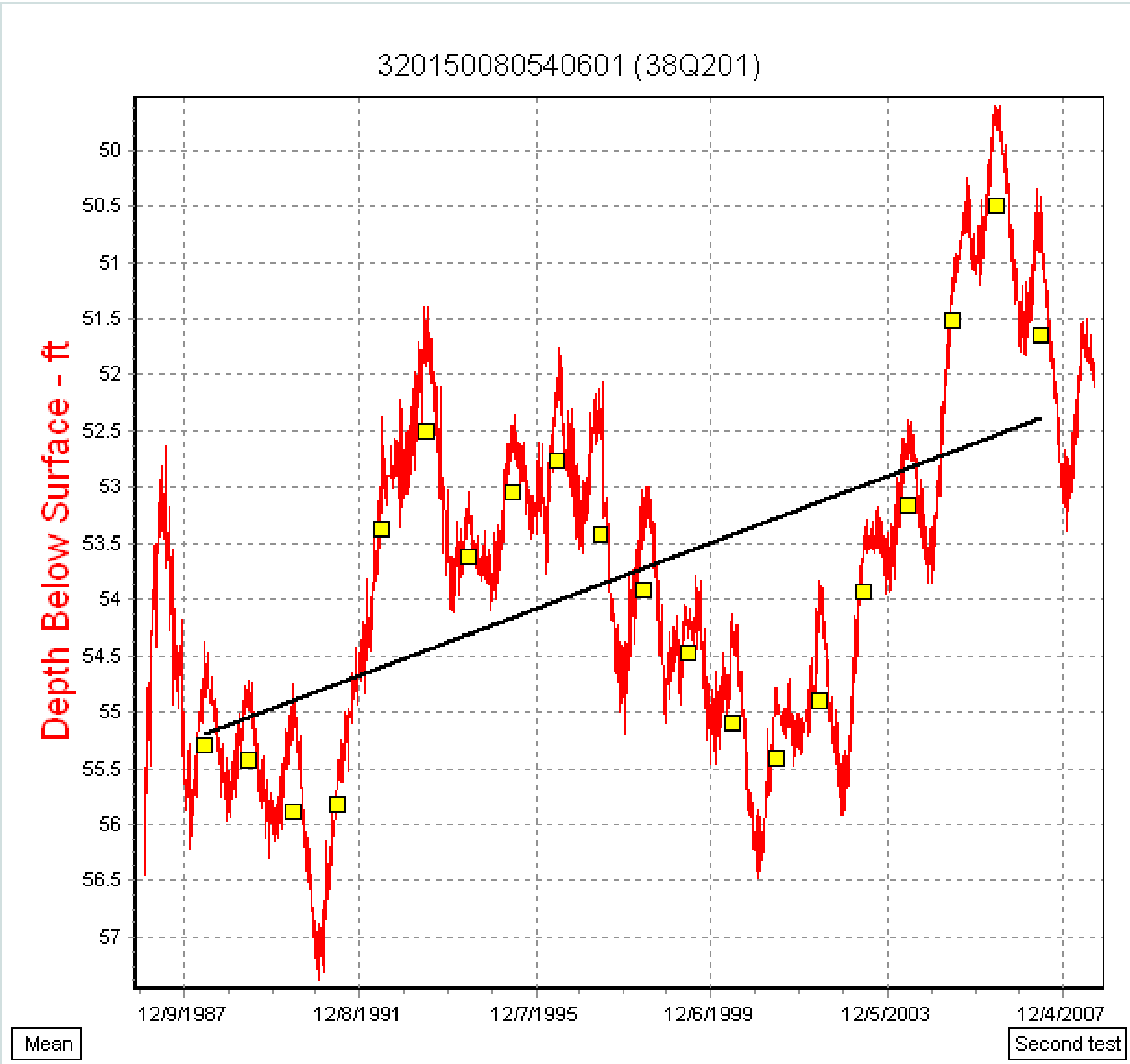

Figure 10. Water levels and calculated trend line for 320150080540601. (Paleocene Series near FOPU)

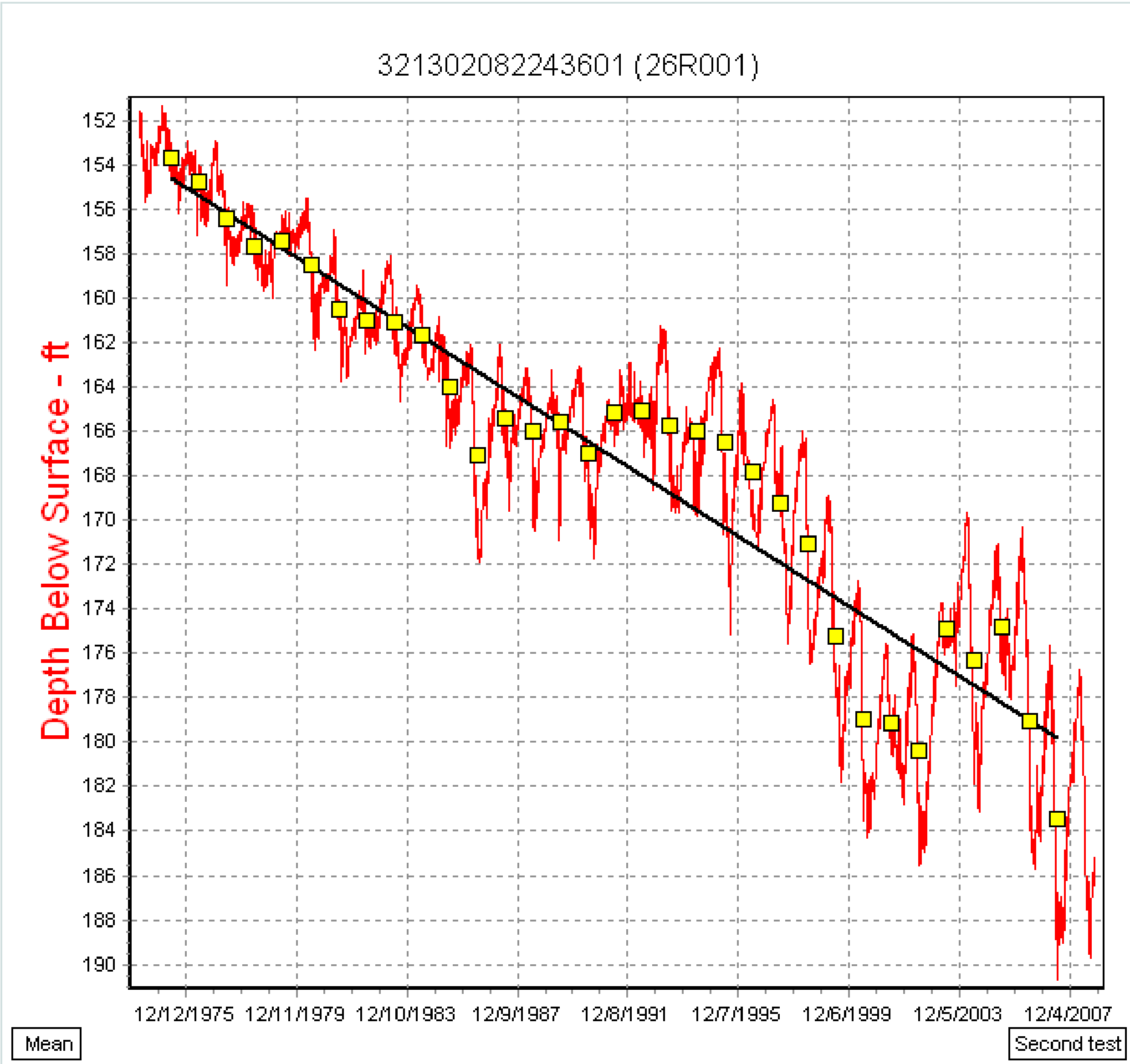

Figure 11. Water levels and calculated trend line for 321302082243601. (Upper Floridan Aquifer near FOPU)

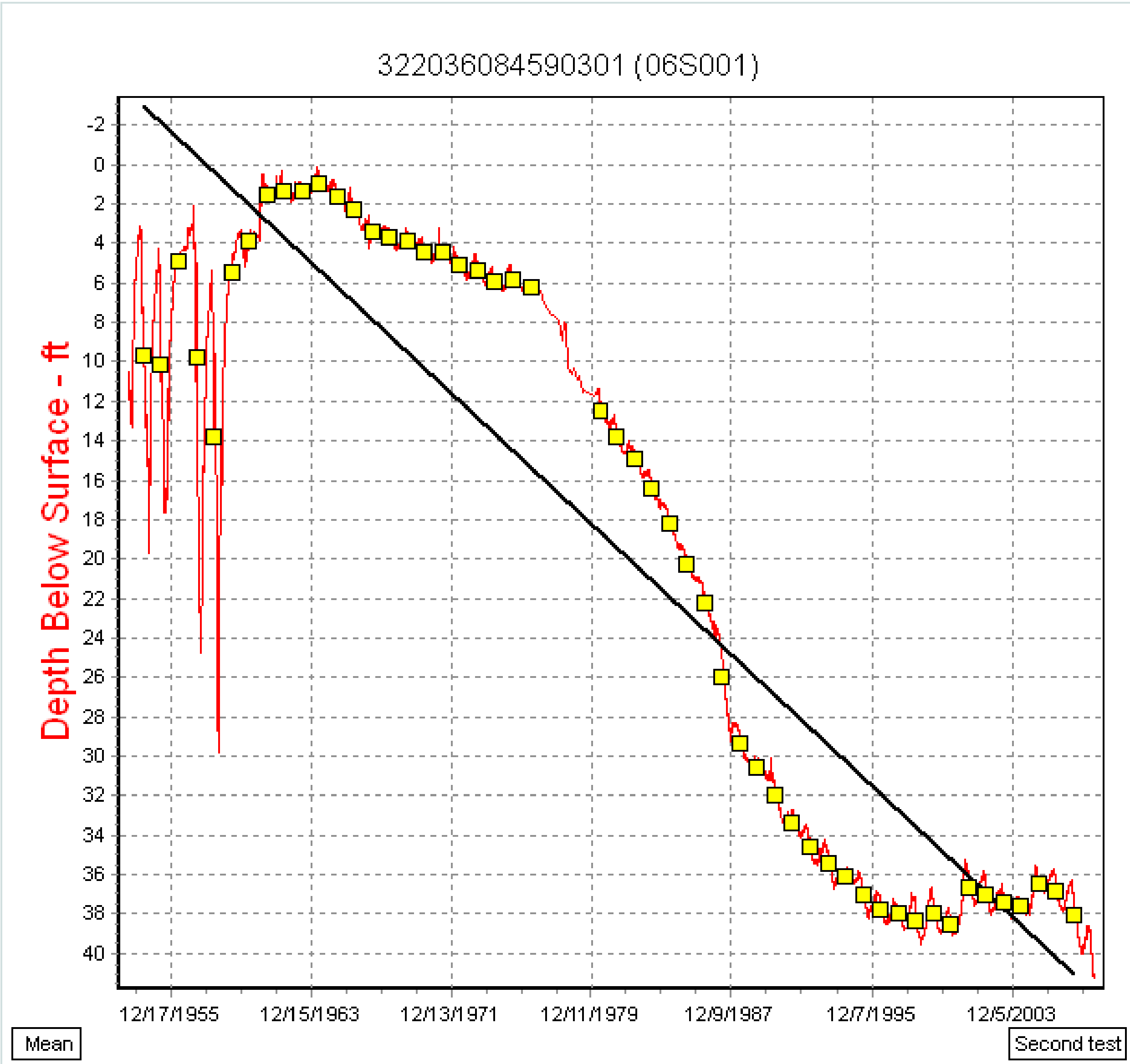

Figure 12. Water levels and calculated trend line for 322036084590301. (Blufftown Formation near OCMU)

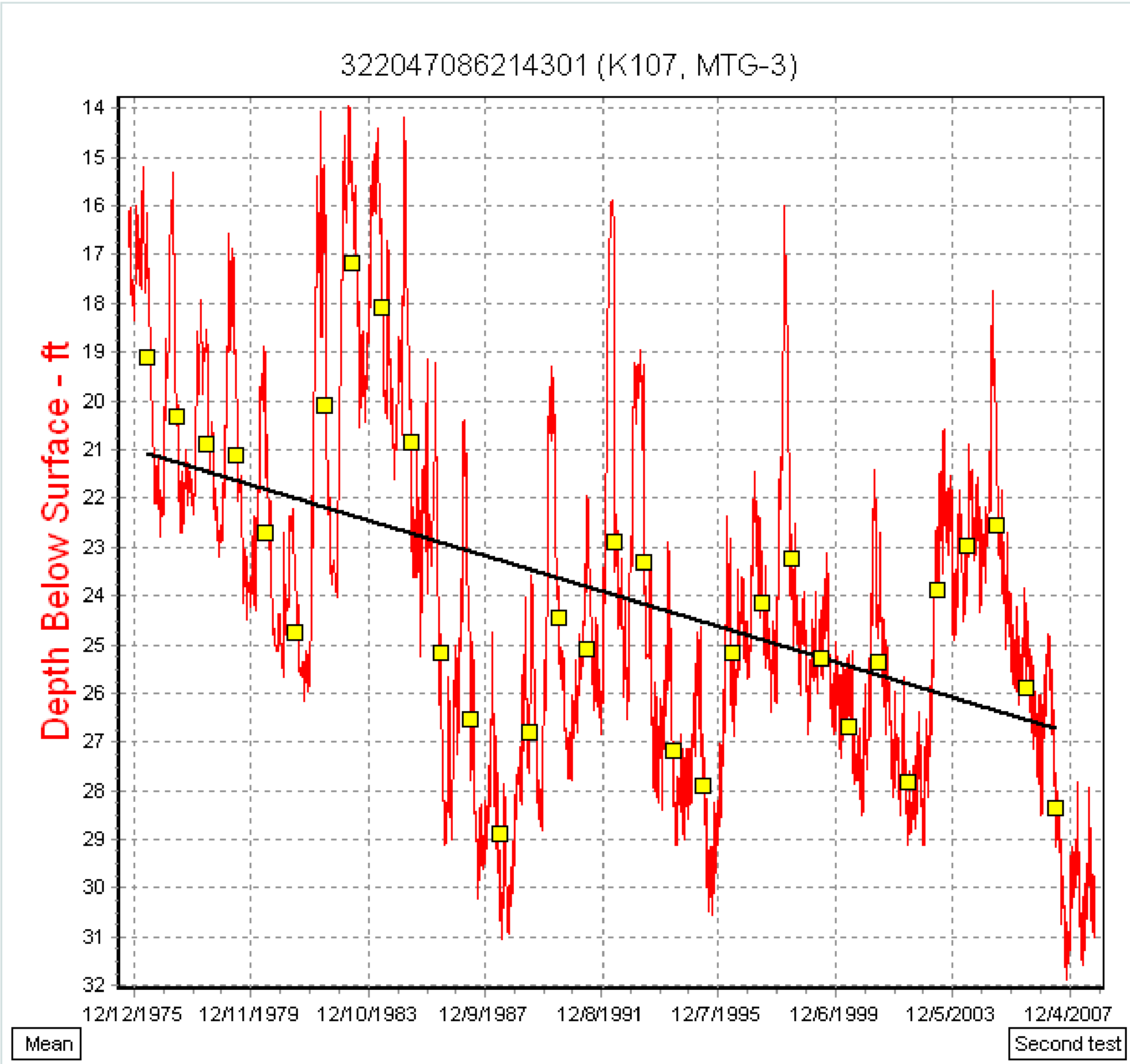

Figure 13. Water levels and calculated trend line for 322047086214301. (Eutaw Formation near HOBE)

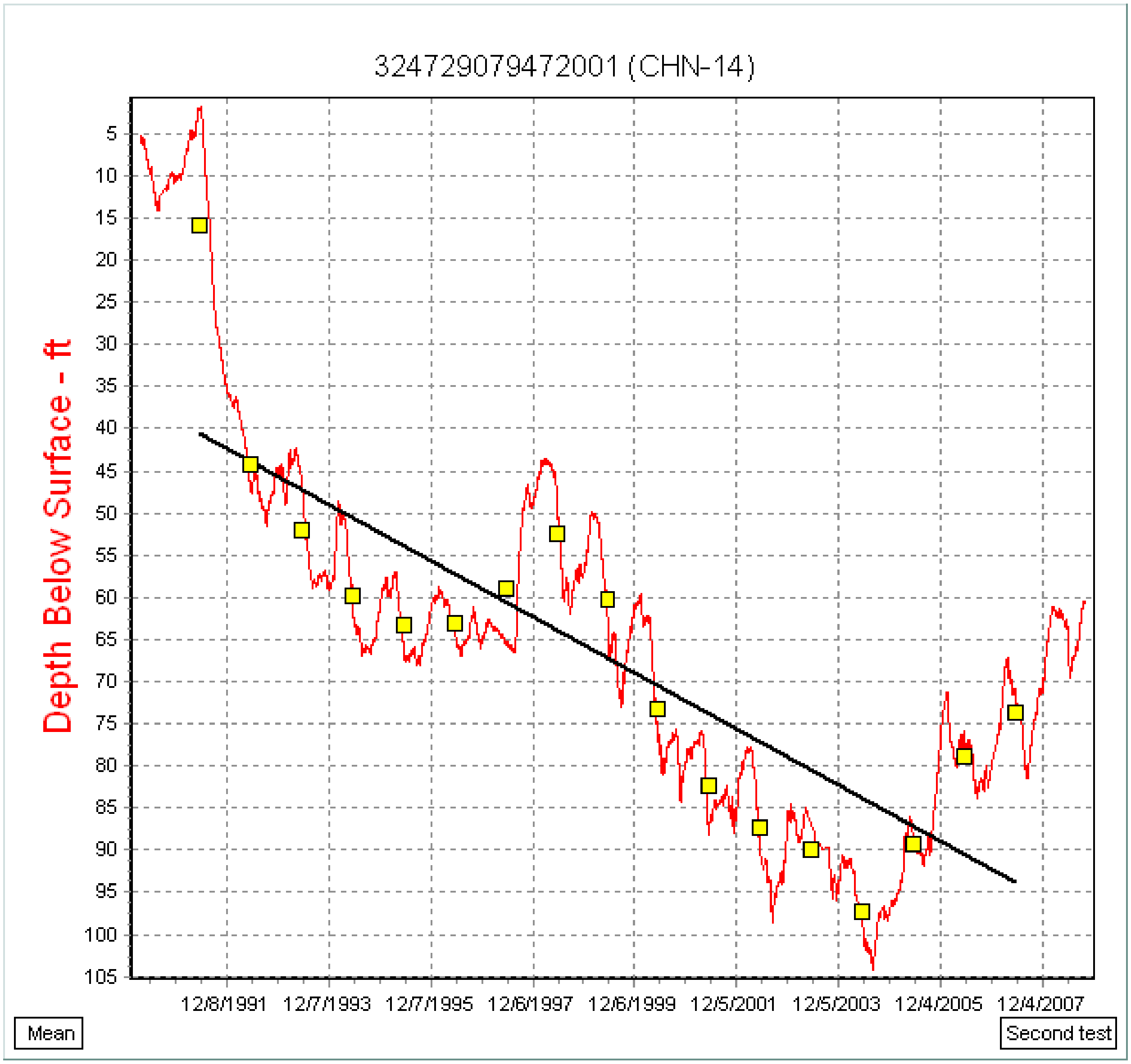

Figure 14. Water levels and calculated trend line for 324729079472001. (Middendorf Formation near CHPI and FOSU)

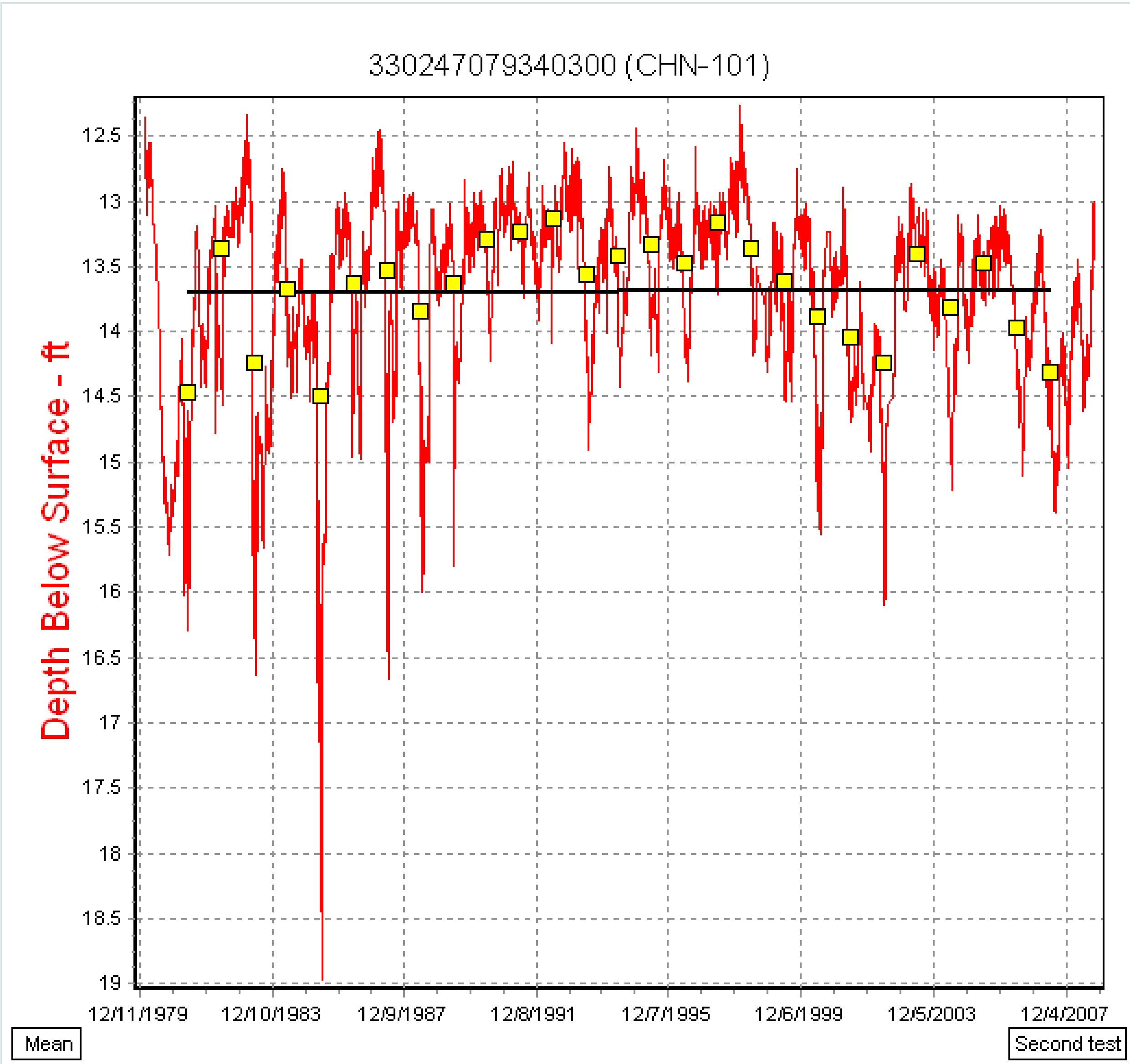

Figure 15. Water levels and calculated trend line for 330247079340300. (Floridan Aquifer near CHPI and FOSU)

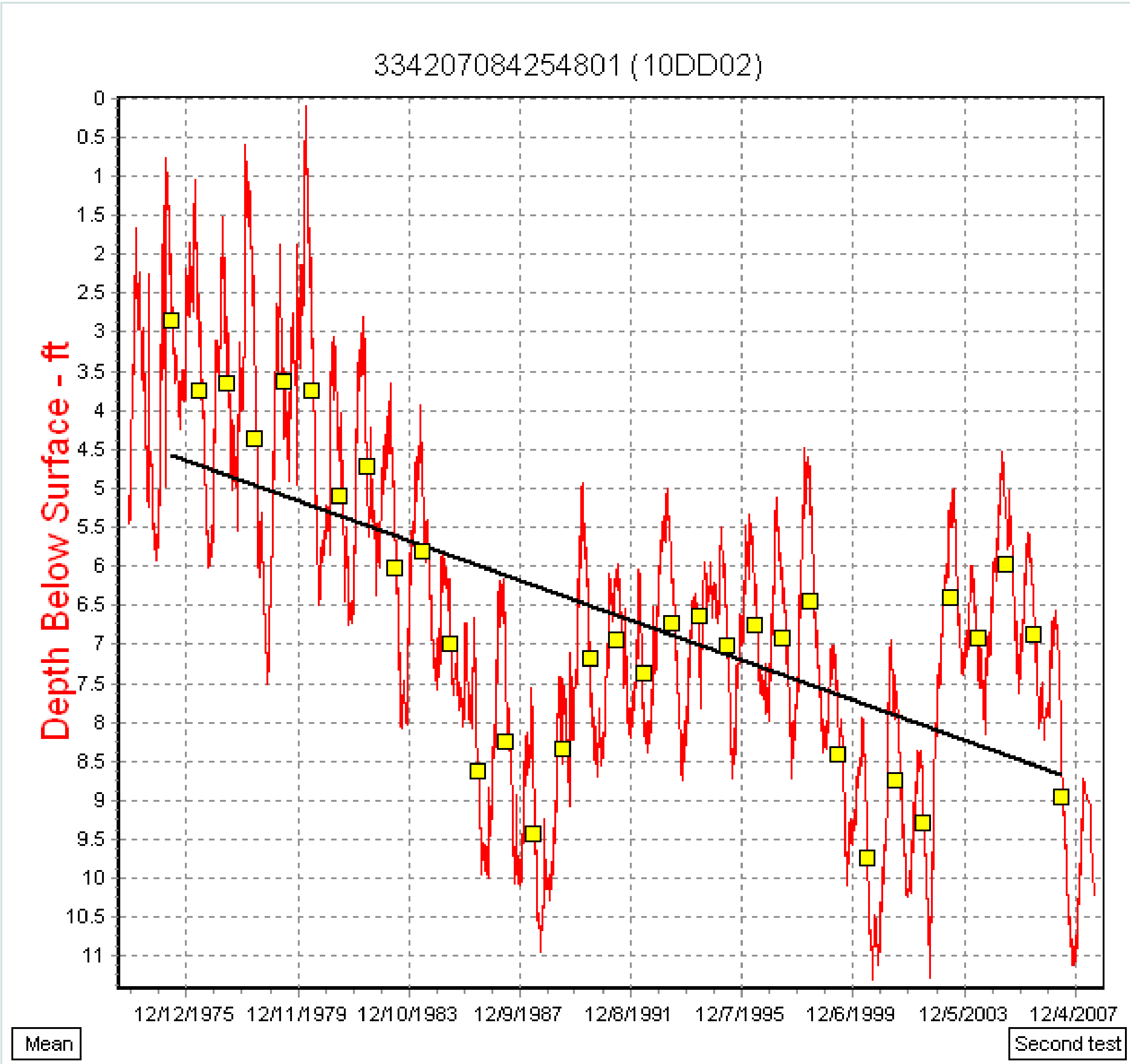

Figure 16. Water levels and calculated trend line for 334207084254801. (Crystalline Rock Aquifer near KEMO)

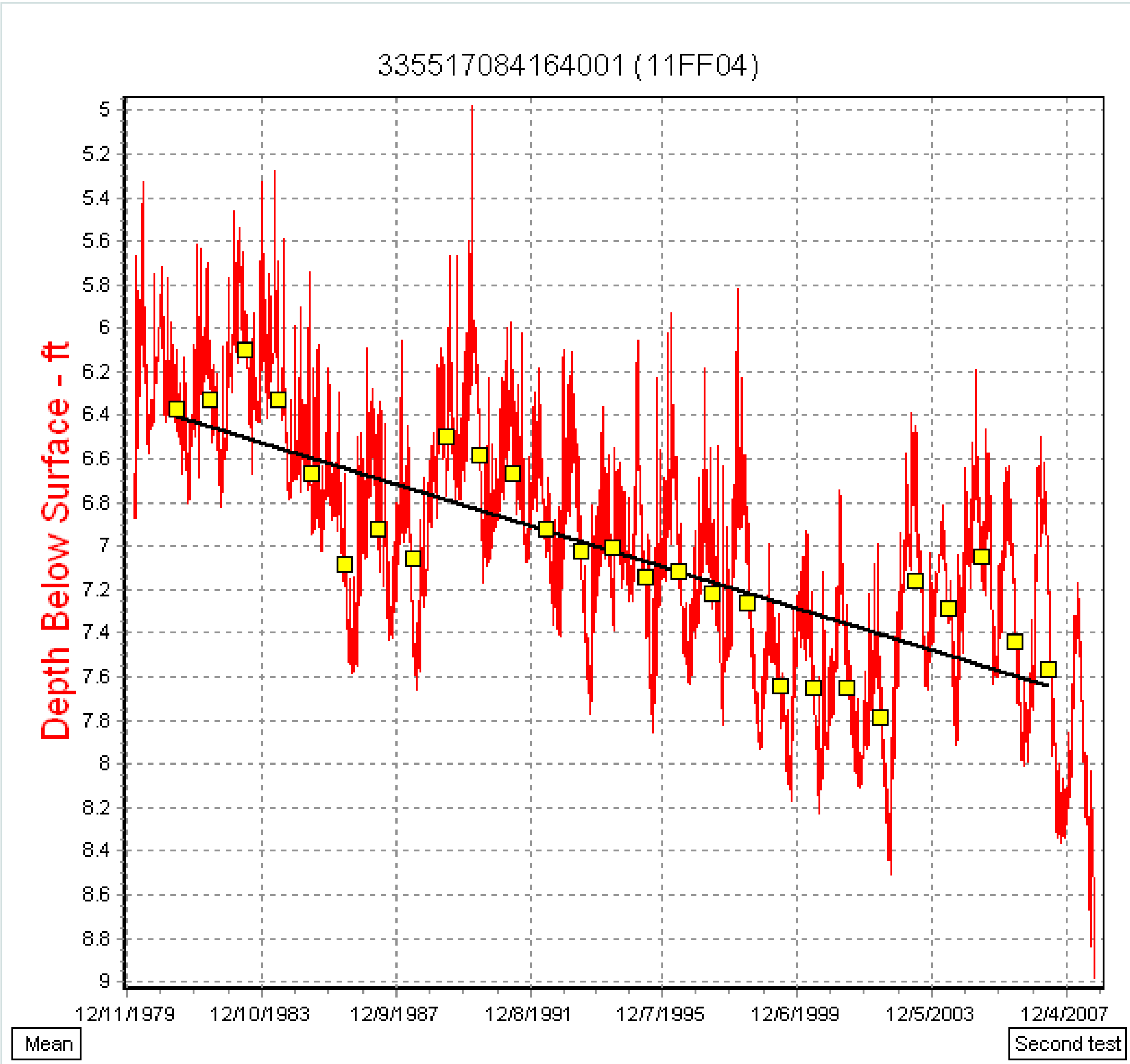

Figure 17. Water levels and calculated trend line for 335517084164001. (Crystalline Rock Aquifer near CHAT and KEMO)

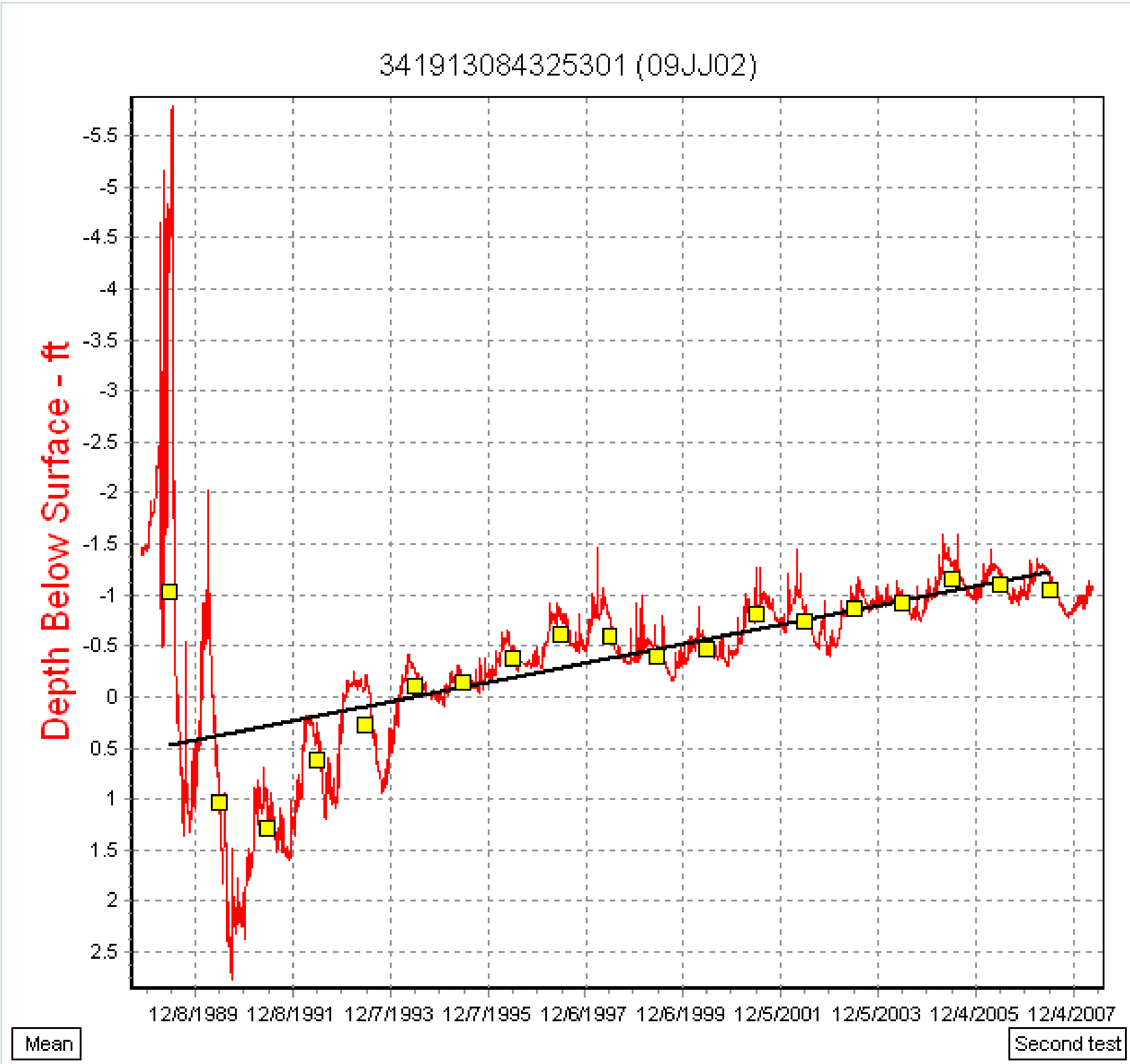

Figure 18. Water levels and calculated trend line for 341913084325301. (Crystalline Rock Aquifer near KEMO)

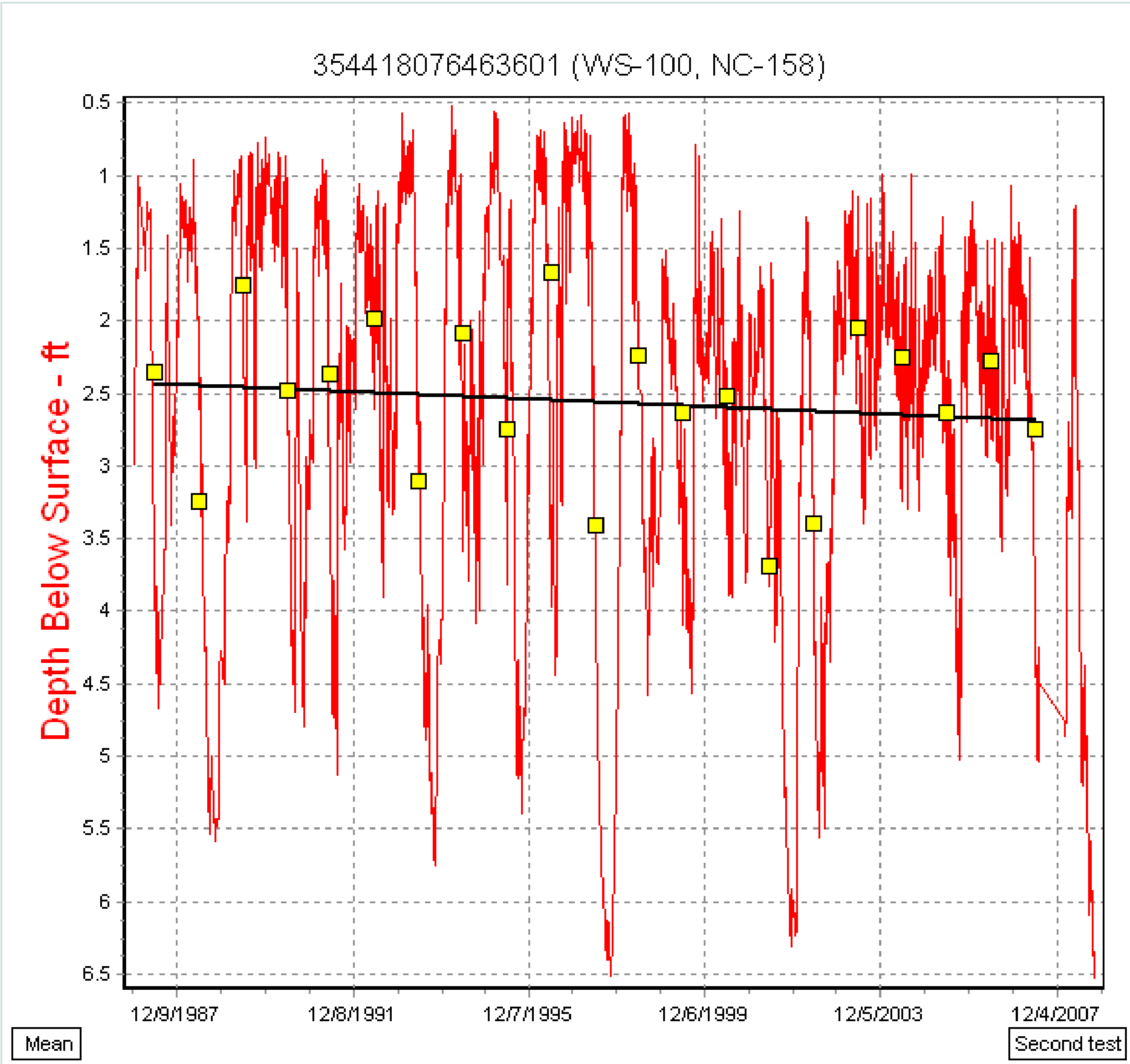

Figure 19. Water levels and calculated trend line for 354418076463601. (Surficial Aquifer near CAHA, CALO, FORA, and WRBR)

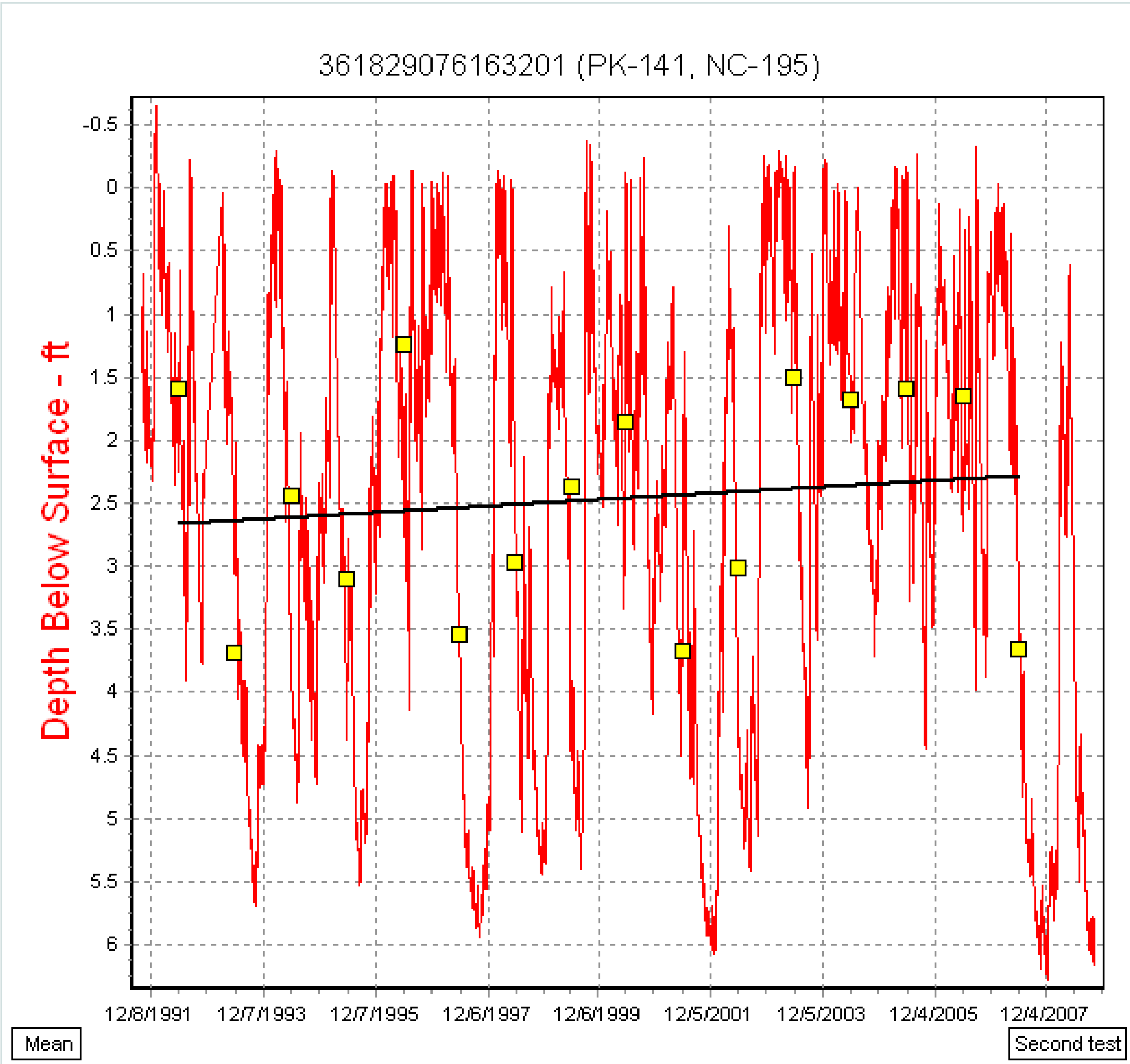

Figure 20. Water levels and calculated trend line for 361829076163201. (Post Miocene near CAHA, FORA and WRBR)

Groundwater Monitoring Protocols

The recommended groundwater monitoring protocol presented here relies on the U.S. Geological Survey guidelines developed in Roman and Barrett (1999) and McCobb and Weiskel (2002) for the Cape Cod National Seashore as primary references. Additional guidance from a range of additional sources is used because this primary reference focuses exclusively on the monitoring of shallow, water-table aquifers. These additional references include Garber and Koopman (1978), Koterba et al. (1995), Lane (2007), Taylor and Alley (2002), Thornhill (1989), U.S. Bureau of Reclamation (2001), U.S. Geological Survey (1974, 1980, 1984, 2002, 2005, 2006, 2008), and Wilde and Radtke (2006).

Sampling Design

The predominant goal of groundwater monitoring is the determination of the spatial and temporal distribution of hydraulic head. The hydraulic head is used in conjunction with hydraulic parameters (e.g., hydraulic conductivity, transmissivity, storage coefficient, storativity, leakance) to determine local and regional flow conditions.

Groundwater levels within an aquifer (also referred to as the hydraulic head) are determined using measurements of water levels in observation wells. These data provide information on the direction and magnitude of the hydraulic head and groundwater flow, which are useful for evaluating water resources. Water-level data can assist in the interpretation of the effects of global and local agents of change, provide data for the management of water supplies, and assist with interpretations of ecological change.

Mapping of the hydraulic head requires a network of piezometers with sufficient resolution such that they can be used to understand and predict the influence of local and regional hydrologic perturbations, such as land-use changes, sea-level change, recharge, pumping, etc. The construction of watertable and piezometric maps, along with observation well hydrographs are the most basic methods for analyzing these spatial and temporal trends.

Determining the optimal sampling resolution in time and space is a key initial step in the sampling design. With automated water-level equipment, it is now possible to record data at frequent intervals - an hourly interval being sufficient for most groundwater applications. The determination of spatial frequency is often based on knowledge of the hydrogeologic system. For deep aquifers where water levels vary slowly within each aquifer, then a single monitoring location is likely to be sufficient. Additional monitoring is required in shallow aquifers where complex relationships between surface water and groundwater are likely to be present.

Sampling Locations

The design of the groundwater monitoring system should begin with a conceptual model that identifies the regional and local causes of groundwater movement, along with the general hydrogeologic setting. The use of numerical models with initial parameter estimates is helpful in determining the potential impacts to various hydrologic alteration scenarios. Well placement is then determined by evaluating the sensitivity to water level changes for the alternative hydrologic scenarios.

The steps required to specify the monitoring location include:

1. Identify the monitoring objectives and the extent of the monitoring area.
2. Identify and inventory existing instrumentation, public-supply wells, observation wells, and existing networks in area of interest.
3. Select sites based on minimum recommended criteria as stated in Table 11. Note that the number of sampling sites depends in part upon the amount of time budgeted per sampling round. Each monitoring field trip should be accomplished as a single *snapshot* event with no precipitation events immediately prior to or during measurements.
4. Prior to network implementation, visit field site, perform depth sounding of well, check response to aquifer, and create site map. Altitude and positional surveying should be done if necessary.
5. Map network using a geographic information system.

Wells should be evenly distributed over the complete monitoring area. Wells at high points, intermediate points, and low points in the flow system should be represented in the network. Examples of selected locations of wells include areas at the tops of water-table mounds, at intermediate points, near discharge areas such as streams, and near water-supply wells. Guidance from U.S. Environmental Protection Agency (1987), Thornhill (1989), Koterba et al. (1995), Lapham et al. (1995) and U.S. Geological Survey (1980) can assist in developing water monitoring plans, but a hydrologist, hydrogeologist, or geohydrologist should be consulted prior to well site location selection. In general, the selection of monitoring well locations (both in terms of surface location as well as the monitoring depth) and the measurement accuracy are a function of goals of the monitoring effort, and the well as the hydrologic conditions at the site.

The design requires a thorough review of existing data for the region of concern. This includes a review of existing water-table maps, well networks, water-supply studies, and published and unpublished reports. These data should be reviewed to identify:

- Thickness and characteristics of saturated zones
- Depth to the water table
- Probable groundwater-flow directions
- Presence of vertical gradients
- Hydrologic features and human stresses which may cause groundwater levels to fluctuate, such as water-supply pumping, fluctuating river stages, and tidal influence
- Probable frequency of fluctuations in levels
- Observation wells that are available for use
- Regions that lack previous water-table definition

Table 10. General criteria for selection of observation monitoring well sites.

Criteria	Rationale
Well-construction information is available	Material, depth, screen specification data are critical for well use
Well has a sound connection to the aquifer	Screened zone inside the well should be representative of the aquifer outside the casing
Hydrologic unit of well screen is known	Well operation is dependent on the geologic conditions at the screen
Well site has long-term accessibility	Multiple site visits over many years will be necessary with minimal interruption to the network
Screen is positioned near (within 20 feet of the lowest recorded water level) water table for measuring variations due to climatic changes	Screen position must provide the unconfined static water level
The monitoring well is not susceptible to going dry	Well must be operational under all hydrologic extremes of the region
In order to represent a large hydrologic area; the well occupies an optimized placement in the aquifer	With a limited number of sites possible, each site must represent a large area in the network
A detailed lithologic log is available for the borehole	Full lithologic logs provide vertical information at each site which can be used as the framework to build a hydrologic model

Prior to implementation of the monitoring network, information on each well must be obtained and a master information sheet created. This information must include all of the following:

- National Park Unit
- Well identification number
- Latitude and longitude
- Casing diameter and material
- Land surface elevation
- Measuring point elevation
- Total depth of the hole
- Depth to the top of the screen
- Depth to the bottom of the screen
- Length of the screen
- A description of the well site with directions and a well-site sketch map
- Driller's log with geophysical logs, development tests, and aquifer performance tests.

Using existing wells is a convenient method for monitoring groundwater levels. Unfortunately, the condition of the well, its location and the hydrogeologic unit(s) in which it is completed may not be acceptable. In some cases, an older well can be refurbished.

For sites where existing wells are not suitable, the most common method of installing monitoring wells is to contract with a local well driller who is familiar with local hydrogeologic conditions. In this case, the well driller should be consulted about the optimal drilling method, site access, and potential problems associated with monitoring well installation in that area. The casing should be completed above ground level with adequate protection from inadvertent damage by vehicles or wildlife.

Sampling Frequency

A comprehensive program to monitor groundwater-levels also requires consideration of the frequency that these wells will be measured. Water-level rounds, or “snapshots”, provide a concurrent view of the water-table surface that can be used, for example, to analyze long-term trends and changes in flow directions, and to provide calibration data for groundwater models. Each snapshot should consistently include the same well set.

The sampling frequency is determined by the frequency fluctuations of the water table produced by factors such as recharge, withdrawal of water from supply wells, transpiration, tidal effects, and other factors. The frequency of measurements in any monitoring program depends on the observation objectives. Daily observations in most wells would be adequate. More frequent measurements would be required for an intensive investigation for trends with responses shorter than other annual or longer-term time frames. In this case, the hourly measurements may be justified to capture the daily tidal fluctuations that occur; the daily measurements capture only some of these fluctuations. If the longer term, seasonal fluctuations are of primary importance, then in this case, daily measurements are adequate.

At a minimum, twelve monthly water-level snapshots for non-automated long-term hydrologic monitoring, and a minimum of 350 daily observations for automated monitoring, should be made to encompass varying hydraulic conditions (such as high water in the spring, late summer low-water periods, and intermediate conditions). If possible, the monthly sampling interval should be similar so that the interval between measurements is constant. For non-automated monitoring, water-level measurements should be made as close to simultaneously as possible. That is, all measurements should be made over a one-to-two day period with no hydrologic events, such as precipitation, during the measurement period. If monitoring questions are asked that go beyond the response of groundwater levels to seasonal and climatic trends, then an increase in sampling frequency may be warranted. Data should be evaluated over at least a one-year period to optimize these considerations.

Water-Level Measurements

Water-level measurements are a routine aspect of hydrologic monitoring. Only a summary of possible procedures and protocols (rules and methods) for obtaining groundwater level are presented below. Detailed procedure and protocol guidelines relevant to various real-world conditions and circumstances are available (Heath, 1987; Freeman et al., 2002; Drost, 2005; Lapham et al., 1995).

An established *measuring point* must exist at each groundwater observation well to ensure comparability of water-level measurements taken on different dates or at different times from the same well and among all wells in a study area. Therefore, the first step in establishing an observation well is identifying and describing a measuring point to which all groundwater measurements will be referred (Drost, 2005, p.19). The measuring point should be established as permanently as possible, clearly defined, and easily located.

The top of the well is typically selected as the most convenient place from which to measure the depth to groundwater, and it must be clearly and permanently marked. This point is usually the top of the casing, well cap, or access port, whose position is referenced in terms of its elevation distance above mean sea level. The determination of the hydraulic head, and subsequently of the

groundwater-flow direction, flow rate, hydraulic gradient, and location of groundwater discharge and recharge areas depends on the accuracy of the leveling of the measuring point elevation and the depth-to-water measurement.

Water-level measurements can be made by means of a variety of methods, as described below. The most common method for manually determining the depth to water is the *electric-tape* (also called the *sounder*) method. The most common method for automatically determining the depth to water is the *pressure transducer* method, which is connected to a *datalogger* to record the measurements. The *steel-tape* method is another manual method that is no longer commonly employed.

Electric-Tape Method

Electric tapes are relatively simple continuity detectors designed for lowering into a borehole. The most common devices consist of a two-conductor 16-22 gauge electrical cable wound inside a hand-cranked reel. The device operates on the principle that a circuit is completed when electrodes at the end of each cable are immersed in water. The reel contains space for a battery and an ammeter and/or buzzer for signaling when the circuit closes. Electrodes are generally contained in a weighted probe that keeps the tape taut while providing some shielding of the electrodes against short circuiting as the probe is lowered into the borehole. The electric tapes generally are marked at 5-foot intervals with clamped-on metal bands.

The probe should be lowered slowly into the well until contact with the water surface is indicated by a deflected ammeter needle and/or audio signal. The electric tape is pinched opposite the measuring point and partly withdrawn; the distance between that pinched mark and the next higher tape marker is measured and subtracted (from the value that next higher marker) to obtain the depth to water below the measuring point. A pocket tape or carpenter's rule (graduated in tenths and hundredths) is used to measure the distance between the measuring point and the next higher marker. This distance is subtracted from the value of the next higher marker to determine the depth to water.

Instructions for taking water-level measurements using the electric-tape method are made as follows:

1. Water-level measurements are recorded on a groundwater level measurement form (Table 12). Required data include the national park unit along with the well name and location. These data should be entered for each monitoring well. The date, time, and depth-to-water measurement, along with any comments, are provided for each well. Having a unique form for each well is helpful in identifying trends or erroneous entries. Turn on the electric-tape sensor and slowly lower the probe down the well. When an audible indicator and surface light are triggered, pull the electric tape back to feel for the water line and fine-tune the position of the water table. Read the graduated line at the top-of-casing position and record the depth-to-water.
2. For any water-level measurement, the depth to water should be measured for two or more consecutive measurements to an accuracy of 0.01 ft.
3. Compare the observations to previous measurements. For observations that display anomalous results, additional measurements should be taken.

4. Notes should be taken regarding well maintenance, changes to the site layout, and well damage. New field sketches should be created if features such as roads or trees in the vicinity of the well change.

Steel-Tape Method

Graduated steel tapes are considered the most accurate for measuring the water level in non-flowing wells. Steel tape readings under the best of conditions are generally accurate to within 0.01 feet. The most popular steel (surveying or engineer's) tapes are commonly available in lengths of 100, 200, 300, and 500 feet. The lower few feet of the tape is coated with blue carpenter's chalk. The obvious difference between dry (unsubmerged) and wet (submerged) portions of the chalked section of steel tape denotes the length of tape immersed in water.

Table 11. Example Groundwater Level Monitoring Form.

National Park Unit: ____

Well Name / Location: ____

Date and Time	Depth to Water	Comments	Observer

The method employs a graduated steel tape that is typically used with a narrow weight or probe attached to its end (Drost, 2005, p. 9). The weight section - which is typically composed of stainless steel, copper, or lead (as dictated by water quality concerns) - is used to provide maximum plumbness and, hopefully, permit some feel for negotiating past down-hole obstructions. The graduations on the lower section of the tape are coated with blue carpenter's chalk, which improves the visibility of the water line and helps verify that it has contacted the groundwater surface.

The tape is lowered into the well until the lower part of the tape is submerged while an exact distance mark is held directly opposite or against the measuring point. The tape is then quickly withdrawn; the value held at the measuring point and the amount of tape that was submerged is recorded appropriately. The amount of tape that was submerged is obvious from the change in color of the chalk coating. The depth to groundwater below the measuring point is determined by subtracting the length of wetted (submerged) tape from the total length of tape lowered into the well.

Pressure Transducers

Pressure transducers are automated water-level monitoring devices that are lowered into wells on the end of a cable. The pressure transducer measures the pressure associated with the overlying column of water and transmits this information to a datalogger located in an instrument shelter on the surface via the attached cable. Alternatively, pressure transducers can be combined with the datalogger in a watertight enclosure designed for long-term underwater deployment.

In recent years, as the need to monitor baseline and (or) document changing groundwater levels over time has increased, so has the use of pressure transducers. These systems can be deployed and left to operate continuously in the field without attention for months, collecting water-level data at user-defined intervals and storing it digitally into datalogger memory. By operating in a continuous 24/7 monitoring mode, water-level loggers minimize the need for manual data-collection approaches and facilitate the simultaneous monitoring of multiple data-collection sites.

Each datalogger and pressure transducer manufacturer will have different software and operating instructions. Therefore, the appropriate operation manual must be consulted regarding the operation of the specific datalogger and pressure transducer that will be used. Pressure transducers are constructed to operate in various pressure ranges. It is extremely important that the pressure transducer be used in a manner consistent within the designed operating range of the instrument, or damage may occur. To prevent damage, it is important not to lower the transducer below the designed water depth and associated pressure range. A piezometer is strongly recommended to provide a protective housing around the transducer and to aid in its placement.

An uphole datalogger should be placed within an instrument shelter so that it is protected from the elements. A desiccant should normally be placed within the shelter, along with barriers to prevent insect penetration (e.g., fire ants and wasps). A recording (tipping bucket) rain gage and barometric pressure sensor are vital ancillary equipment needed for monitoring local hydrologic processes. If appropriate, then local surface water levels (e.g., rivers, ponds, ocean surfaces, etc.) should also be monitored.

The information collected includes hydrologic measurements along with a time/date stamp that can be stored for periods of days to months depending on the frequency of sampling. Using a laptop computer and software, the pressure measurements can be converted to water levels and viewed directly on the computer or downloaded from the datalogger into a number of different spreadsheet or text formats.

Air-Line Method

Air lines are small diameter pipes (tubes) that drop from the tops of wells, through their casings, down several feet below the lowest anticipated water level. The air line works on the principle that the air pressure required to expunge all water from the submerged portion of the tube equals the water pressure of a column of water of that height (assuming one pound per square foot of air pressure equals 2.31 feet of water). An air-gauge reading is converted to the height of water column equaling the distance between the water level in the well and the bottom of the air line.

The air-line method is especially useful in pumped wells or in wells where water turbulence precludes using one of the generally more accurate steel- or electric-tape methods. Besides requiring an air-tight installation and knowing the exact length of air line, the accuracy of this method depends on the precision to which air pressure can be measured.

To determine the depth to water with an air line, an air pump (or air compressor or tank) and a pressure gauge are attached to the top of the air line. Next, air is pumped into the air line until the pressure on the gauge increases to a maximum and stops. This means that all water has been forced out of the bottom of the air line and the air pressure in the line just balances the water pressure. Any additional air is released as bubbles from the base of the air line. As long as there are no leaks in the system, the pressure will hold at the maximum gauge reading, at least temporarily. The gauge reading is the pressure required to force water out of the air line, which is also the pressure of the water column in the well above the bottom of the air line.

Flowing Wells

Pressure gages or transparent tubes can be used to measure hydraulic head in flowing wells. In topographically low areas underlain by confined aquifers, groundwater levels may stand in wells at some height above land surface. Referred to as areas of artesian head, these areas are characterized by sealed well installations and (or) flowing wells or springs. The measurement of groundwater heads in such areas (where the casings of wells do not extended above the static level) requires specialized equipment.

For wells equipped with a shut-off valve and fittings to which a pressure gauge or transparent (typically plastic) tube can be connected, the effective hydraulic head can be determined by connecting the gauge or tube to the appropriate fitting. In this case, the hydraulic head is measured directly (Heath, 1987, p.73).

The simplest method used to determine artesian head from a flowing well is to attach a pressure gauge near the top of a sealed observation well. With care, experience, and an appropriate gauge, pressure measurements can be obtained to within an accuracy of 0.1 foot. The gauge can often be secured to a pipe connected through the casing wall. Use a valve to first bleed all entrapped air from the closed system.

Ideally, the discharge from a flowing well should be shut off until the well equilibrates so that a static water level can be obtained. However, due to a variety of possible conditions, this may not always be possible. When the discharge from a flowing well is controlled with a valve or removable plug, it must be done gradually.

Depending on how the gauge is calibrated, the water level will be read directly or recorded as a pressure head and later converted to feet. If the pressure gauge used is calibrated in pounds per square inch, simply multiply the gauge reading by 2.31 to obtain the head of water above the gauge. Ideally, if conditions permit, a flow measurement should accompany a pressure reading.

Measuring the water level of a flowing well that is not equipped with a valve or threaded fitting requires a soil-test plug or similar device to control the flow and allow the temporary connection of a portable gauge. In such a case, the height of static water above a specified well-head datum might also be determined with a transparent plastic tube, assuming relatively low-pressure conditions prevail (Drost, 2005, p.17).

Data Management

Data collected for water-resource-related projects are usually processed, documented, organized, and archived to meet the particular requirements of the project that collected the data. Even data determined to be unusable for a particular project's objectives could be invaluable for a future project if the information was properly documented and stored. Incomplete data documentation in computer databases and paper files limits the utility of the data collected. For this reason, a comprehensive data-management plan must be established to ensure that all data documentation is consistent and thorough.

All required field data should be recorded on an established field sheet during each site visit. The mark of an excellent field hydrologist is the creation of first-class field notes. Field notes should be clear, descriptive, legible, and well organized so that others can obtain the information easily. In addition to the pre-designed field sheets, the field hydrologist should carry a general field-log notebook that holds the basic information of the field trip. The field log should note the following:

1. Date
2. Personnel
3. Time of personnel arrival
4. Weather conditions of the day
5. Objectives and brief description of the work to be performed
6. Any observations of events that were out of the ordinary
7. General summary of accomplishments
8. Time of personnel departure

In addition to these data, additional information should be provided to field personnel. Data collection forms should be clear about the measurements taken Local site conditions may warrant that data forms be customized for each site. Ideally, a site map should be provided with monitoring well locations, hazards, and safety areas in the event of adverse weather should be noted. Well construction details (screened intervals) should be available to field personnel as well. Information about monitoring well locations and intra-well distances should be provided.

Well-head elevation and stand-pipe height used to calculate groundwater table elevation should also be available.

Recommendations

Burgeoning populations and economic development are placing additional demands on Southeastern water resources. The resulting alteration of surface- and groundwater resources may adversely affect hydrologic conditions at SECN parks. While groundwater conditions at most SECN parks are not monitored, this lack of monitoring can be justified in parks that are not sensitive to groundwater alteration. Yet some parks units are sensitive to groundwater alteration. In these cases, expanding the SECN groundwater-monitoring network would provide a more detailed picture of the hydrogeologic system. These data would allow park management to make more informed resource management policy.

The following list provides a set of recommended priorities for infrastructure improvements:

- Parks with greatest need for additional groundwater monitoring resources:
    - CAHA: Cape Hatteras National Seashore
    - CALO: Cape Lookout National Seashore
    - CANA: Canaveral National Seashore
    - CONG: Congaree National Park
    - CUIS: Cumberland Island National Seashore
- Parks with lesser need for additional groundwater monitoring resources
    - Parks with adequate existing programs
        - FOFR: Fort Frederica National Monument
        - FOMA: Fort Matanzas National Monument
        - FOPU: Fort Pulaski National Monument
        - MOCR: Moores Creek National Battlefield
        - OCMU: Ocmulgee National Monument
        - TIMU: Timucuan Ecological and Historic Preserve
    - Piedmont and Blue Ridge Aquifers
        - CHAT: Chattahoochee River National Recreation Area
        - HOBE: Horseshoe Bend National Military Park
        - KEMO: Kennesaw Mountain National Battlefield Park
    - Parks with minimal groundwater impacts
        - CASA: Castillo de San Marcos National Monument
        - CHPI: Charles Pinckney National Historic Site
        - FOCA: Fort Caroline National Memorial
        - FORA: Fort Raleigh National Historic Site
        - FOSU: Fort Sumter National Monument
        - WRBR: Wright Brothers National Memorial

At a minimum, one monitoring well should be installed at each park unit in each of the dominant aquifers (e.g., water table, surficial, Floridan, Coastal Plain, etc.). While well data exists for wells that are on (or near) park property, many wells on park property are not currently monitored. Because well completion data for many of these are lacking, an evaluation of the suitability of each well should be determined and used to decide whether they may provide useful information about groundwater conditions. If lacking, well completion data can be obtained using downhole videography. These wells should be routinely monitored (e.g., weekly,

bimonthly, or monthly) for evaluating short-term, seasonal, and long-term fluctuations. Cumulative rainfall, river and/or tidal stages, and other hydrologic information should also be collected in the vicinity of the observation wells.

Five parks, identified above, have the highest priority for groundwater monitoring. It is recommended that one or more existing wells, where available, be instrumented with dataloggers and pressure transducers (along with ancillary equipment such as precipitation gages, power supplies, etc.) in each of these parks. Amongst the five parks, priority should be given to those with qualified staff who are familiar with environmental monitoring, as well as the availability of monitoring facilities (e.g., existing wells).

CAHA: Cape Hatteras National Seashore

Four existing wells are currently available for monitoring:

- K2E7, Surficial aquifer, screened interval = 5-10 ft, water level at 4.3 ft
- K2E4, Yorktown aquifer, screened interval = 124-134 ft, water level at 10 ft
- K2E3, Yorktown aquifer, screened interval = 184 ft, water level at 8 ft
- K2E2, Yorktown aquifer, screened interval = 204-214 ft, water level at 4.9 ft

These wells belong to the North Carolina Department of Environment and Natural Resources (NCDENR), and could be equipped with recording water level sensor. Yet NCDENR may install recording sensors in the near future, and waiting for them to install the system may be preferred. Monitoring the shallow water levels in these wells could be conducted using capacitance-type gages, which provide excellent accuracy and precision.

CALO: Cape Lookout National Seashore

Only one well is known to exist at this park (at the Hunt Club Site), and the screened interval and aquifer are unknown. A downhole survey to determine the screened zone, well depth, and depth to water should be performed to determine whether this well is suitable for monitoring. If the screened zone is confirmed in the principal confined aquifer, then this well could be instrumented for automated water level recordings. Because the depth to water is unknown, either a capacitance-type (for water levels less than approximately less than 20 feet), or pressure transducers (for water levels deeper than 20 feet) should be used.

CANA: Canaveral National Seashore

Multiple, shallow wells are located at the southern end of the park, adjacent to the Kennedy Space Center. Yet these wells are not likely to be suitable for determining long-term trends associated with regional water removals from the underlying confined aquifer. A more effective strategy would be to install a cluster of wells, with each well monitoring a different stratigraphic unit at the park. Again, because the depth to water is unknown, either a capacitance-type or pressure transducers should be used depending upon observed water levels.

CONG: Congaree National Park

Twelve existing monitoring wells are located at the park, which had been monitored by the U.S. Geological Survey. Cluster analysis of the responses of these wells to streamflow changes indicates that not all of these wells require monitoring - subsets of wells respond similarly, and only a single indicator well is needed for each group that responds similarly (Conrads et al.,

2008a). Capacitance-type water-level measurement devices should be suitable for this system. In addition to these shallow monitoring wells, at least one monitoring well should be installed to monitor deeper aquifers at the site.

CUIS: Cumberland Island National Seashore

Six existing wells are located at the park, which are occasionally monitored by the U.S. Geological Survey:

- KBMP 2, Surficial Aquifer, Well depth = 23 ft, water level = 5 ft
- KBMP 5, Surficial Aquifer, Well depth = 44 ft, water level = 5 ft
- KBMP 3, Surficial Aquifer, Well depth = 94 ft, water level = 5 ft
- 34E001, Upper Floridan Aquifer, Well depth = 645 ft, Water depth = artesian
- 34E002, Upper Floridan Aquifer, Well depth = 600 ft, Water depth = artesian
- 34E003, Upper Floridan Aquifer, Well depth = 730 ft, Water depth = artesian

These wells should be installed with automated water monitoring equipment to obtain baseline datasets for long-term water level changes due to regional groundwater development. Capacitance-type water-level measurement devices should be suitable for the surficial system, while pressure transducers will likely be required for the artesian system.

General Recommendations

As noted in the analysis section provided earlier, existing groundwater monitoring at many parks makes inference of landscape level disturbances problematic. Given a long-term (e.g., ten year) record of groundwater-level observations, better control on the impacts of external (off-park) surface and groundwater resource management could be evaluated. The effects of ecosystem and habitat alteration due to increases and/or decreases in surficial watertable aquifer changes (i.e., CONG), as well as depressurization and subsidence from confined (artesian) aquifer utilization (i.e., CAHA, CALO, CANA, and CUIS), could be identified. Lacking these baseline datasets, however, only limited inferences can be made regarding external resource management.

Groundwater monitoring using dataloggers and pressure transducers at other, lower priority parks should be undertaken as funding and staff resources permit. Also, existing wells can be monitored using sounders if existing wells are present and qualified staff is available.

Efforts to partner with local communities, non-governmental organizations, and state and federal agencies to develop regional groundwater monitoring programs should be encouraged. Many SECN park units raised concerns about groundwater quality and the risk of contamination, so that partnership efforts should also be encouraged to develop regional groundwater quality monitoring programs.

Another concern is that many of the SECN units contain wells that are inactive (i.e., not currently in use). These wells should either be capped or permanently plugged. Open wells provide a pathway for groundwater contamination. Also, flowing wells (observed at CUIS) are an unnatural alteration of the hydrologic system, and can affect natural flow regimes. Efforts should be made to identify inactive wells, and to correctly cap or permanently plug them to eliminate adverse groundwater impacts. If flowing wells are capped, then a digital pressure gage

should be installed so that hydraulic head readings can be monitored. If non-flowing wells are capped, then access should be provided for periodic monitoring.

And finally, because most park units express a concern about groundwater contamination, a Resource Conservation and Recovery Act (RCRA) facility investigation (Phase 1) should be considered where subsurface contamination is known or suspected (U.S. Environmental Protection Agency, 1986; 1989). The purpose of the investigation is to determine the nature and extent of releases of hazardous wastes or hazardous constituents from regulated units, solid waste management units, and other source areas at the facility, and to gather all necessary data to support the environmental assessment. The investigation includes the collection of site-specific impacts of contamination from the site. This survey would be used in conjunction with interviews with current and former employees to provide information about the locations and types of potential contamination.

Literature Cited

Alber, M., J. Flory, and K. Payne. 2005. Assessment of coastal water resources and watershed conditions at Cumberland Island National Seashore, Georgia. U.S. National Park Service, Technical Report NPS/NRWRD/NRTR-2005/332, Fort Collins CO.

Anderson, S. M., C. Katin, and W. R. Wise. 2005 Assessment of coastal water resources and watershed conditions at Timucuan Ecological and Historic Preserve (Florida). Department of Environmental Engineering Sciences, University of Florida, Technical Report NPS/NRWRD/NRTR-2005/340, Gainesville, FL.

Barlow, P. M. 2003. Ground water in freshwater-saltwater environments of the Atlantic Coast. U.S. Geological Survey, Circular 1262.

Campbell, B. G., F. H. Chapelle, J. E. Landmeyer, and M. D. Petkewich. 1996. Geology, hydrogeology, and potential of intrinsic bioremediation at the National Park Service Dockside II Site and adjacent areas, Charleston, South Carolina, 1993-1994. U.S. Geological Survey, Water-Resources Investigations Report 96-4170.

Campbell, B. G., K. J. Conlon, J. E. Mirecki, D. L. Parkhurst, and M. D. Petkewich. 2004. Hydrologic and geochemical evaluation of aquifer storage recovery in the Santee Limestone/Black Mingo Aquifer, Charleston, South Carolina, 1998-2002. U.S. Geological Survey, Scientific Investigations Report 2004-5046.

Clarke, J. S., and R. E. Krause. 2001. Use of ground-water flow models for simulation of water-management scenarios in the coastal area of Georgia and adjacent parts of South Carolina. Proceedings of the 2001 Georgia Water Resources Conference, held March 26-27, 2001, at the University of Georgia, K. J. Hatcher (ed.), Institute of Ecology, The University of Georgia, Athens GA, p. 627-630.

Conrads, P. A., T. D. Feaster, and E. A. Roehl Jr. 2007. Separating anthropogenic influences on hydrology using data mining techniques - A case study of the Congaree National Park, South Carolina. Water Environment Federation Technical Exhibition Conference 2007, San Diego CA.

Conrads, P. A., T. D. Feaster, and L. G. Harrelson. 2008a. The effects of surface-water flow in the Congaree River on the ground-water hydrology of the Congaree National Park floodplain, South Carolina. U.S. Geological Survey, Scientific Investigations Report 2008-5170.

Conrads, P. A., T. D. Feaster, L. G. Harrelson, and E. A. Roehl Jr. 2008b. Using data-mining techniques to analyze the hydrologic effects of the Saluda River Dam. 2008 Research Symposium, Congaree National Park, February 26-28, 2008, Columbia SC.

Drost, B. W. 2005. Quality-assurance plan for ground-water activities. U.S. Geological Survey, Washington Water Science Center, Open-File Report 2005-1126, 27 p.

Dzurik, A. A. 2002. Water resources planning. Rowman & Littlefield Publishers, Inc. 384 pp.

Edward E. Clarke Engineers-Scientists, Inc. 1987. KSC subsurface hydrology and groundwater survey, Volume 4, The Areawide Program. P.O. Box 21167 KSC Headquarters Building, Kennedy Space Center Florida 32815, KSC-DF-3081

Feaster, T. D., P. A. Conrads, and L. G. Harrelson. 2008. Using peak flow data to assess changes in the magnitude and frequency of floods in the Congaree River, South Carolina. 2008 Research Symposium, Congaree National Park, February 26-28, 2008, Columbia SC.

Freeman, L.A., M. C. Carpenter, D. O. Rosenberry, J. P. Rousseau, and R. Unger. 2002. Use of submersible pressure transducers in water-resources investigations. U.S. Geological Survey, Techniques of Water-Resources Investigations Book 8 (Chapter A3).

Garber, M. S., and F. C. Koopman. 1978. Methods of measuring water levels in deep wells. U.S. Geological Survey, Techniques of Water-Resources Investigations Book 8 (Chapter A1), 23 p.

Harrelson, L. G., and J. M. Fine. 2006. Selected well data used in determining ground-water availability in the North and South Carolina Atlantic Coastal Plain Aquifer Systems: U.S. Geological Survey, Open- File Report 2006-1298, 81 p.

Heath, R. H. 1987. Basic ground-water hydrology. U.S. Geological Survey, Water-Supply Paper 2220, 81 p.

Johnston, R. H., and P. W. Bush. 1988. Summary of the hydrology of the Floridan Aquifer System in Florida and parts of Georgia, South Carolina, and Alabama. U.S. Geological Survey, Professional Paper 1403-A, 24 p.

Koterba, M. T., F. D. Wilde, and W. W. Lapham. 1995. Ground-water data-collection protocols and procedures for the National Water-Quality Assessment Program. U.S. Geological Survey, Open File Report 95-399.

Kunkle, S., and D. Vana-Miller. 2000. Water resources management plan: Chattahoochee River National Recreation Area. Department of Earth Resources, Colorado State University, U.S. National Park Service, Chattahoochee River National Recreation Area, GA.

Lane, R. C. 2007. Guidelines for coding and entering ground-water data into the ground-water site inventory database Version 4.6. U.S. Geological Survey, Washington Water Science Center, Open-File Report 2006-1371, 104 p.

Lapham, W. W., F. D. Wilde, and M. T. Koterba. 1995. Ground-water data-collection protocols and procedures for the National Water-Quality Assessment Program: Selection, installation, and documentation of wells, and collection of related data. U.S. Geological Survey, Open-File Report 95-398, 69 p.

Lautier, J. C. 2001. Hydrogeologic framework and ground water conditions in the North Carolina Central Coastal Plain. North Carolina Department of Environment and Natural Resources, Division of Water Resources.

Leeth, D. C., M. F. Peck, and J. A. Painter. 2007. Ground-water conditions and studies in Georgia, 2004-2005. U.S. Geologic Survey, Scientific Investigations Report 2007-5017.

Mallin, M. A., V. L. Johnson, and M. R. McIver. 2004. Assessment of coastal water resources and watershed conditions at Cape Lookout National Seashore, North Carolina. U.S. National Park Service, Technical Report NPS/NRWRD/NRTR-2004/322, Fort Collins CO.

Mallin, M. A., M. R. McIver, and V. L. Johnson. 2006. Assessment of coastal water resources and watershed conditions at Cape Hatteras National Seashore, North Carolina. U.S. National Park Service, Technical Report NPS/NRWRD/NRTR-2006/351, Fort Collins CO.

Matz, M., and D. Tucker. 1998. Baseline water quality data inventory and analysis - Congaree Swamp National Monument. U.S. National Park Service, Technical Report NPS/NRWRD/NRTR-98/1481998, Fort Collins CO.

McCobb, T. D., and P. K. Weiskel. 2002. Long-term hydrologic monitoring protocol for coastal ecosystems. U.S. Geological Survey, Open-File Report 02-497, Northborough MA.

McFarlin, C., and M. Alber. 2005. Assessment of coastal water resources and watershed conditions at Fort Pulaski National Monument, Georgia. U.S. National Park Service, Technical Report NPS/NRWRD/NRTR- 2005/345, Fort Collins CO.

Mehta, A. J., and C. P. Jones. 1977. Matanzas Inlet glossary of inlets. Report #5, Coastal and Oceanographic Engineering Laboratory, University of Florida, Gainesville FL.

Meyer, F. W. 1989. Hydrogeology, Ground-water movement, and subsurface storage in the Floridan Aquifer System in Southern Florida. U.S. Geological Survey, Professional Paper 1403-G.

Miller, J. A. 1986. Hydrogeologic framework of the Floridan Aquifer System in Florida and in parts of Georgia, Alabama, and South Carolina. U.S. Geological Survey, Professional Paper 1403-B.

Miller, J. A. 1990. Ground water atlas of the United States - Alabama, Florida, Georgia, and South Carolina. U.S. Geological Survey, Hydrologic Atlas 730-G.

Minter, J., and D. Tucker. 1996. Baseline water quality data inventory and analysis - Canaveral National Seashore. U.S. National Park Service, Technical Report NPS/NRWRD/NRTR-96/85, Fort Collins CO.

National Park Service. 1995. Baseline water quality data inventory and analysis, Cape Lookout National Seashore. U.S. National Park Service, Technical Report NPS/ NRWRD/NRTR-95/63, Fort Collins CO.

National Park Service. 1997a. Baseline water quality data inventory and analysis Cumberland Island National Seashore. U.S. National Park Service, Technical Report NPS/NRWRD/NRTR-97/104, Fort Collins CO.

National Park Service. 1997b. Baseline water quality data inventory and analysis, Horseshoe Bend National Military Park. U.S. National Park Service, Technical Report NPS/NRWRD/NRTR-97/142, Fort Collins CO.

National Park Service. 1997c. Baseline water quality data inventory and analysis, Moores Creek National Battlefield. U.S. National Park Service, Technical Report NPS/ NRWRD/NRTR-97/120, Fort Collins CO.

National Park Service. 1998a. Baseline water quality data inventory and analysis, Fort Frederica National Monument. U.S. National Park Service, Technical Report NPS/NRWRD/NRTR-98/155, Fort Collins CO.

National Park Service. 1998b. Baseline water quality data inventory and analysis, Fort Matanzas National Monument. U.S. National Park Service, Technical Report NPS/ NRWRD/NRTR-98/171, Fort Collins CO.

National Park Service. 1998c. Baseline water quality data inventory and analysis, Castillo de San Marcos National Monument. U.S. National Park Service, Technical Report NPS/ NRWRD/NRTR-98/168, Fort Collins CO.

National Park Service. 1999. Baseline water quality data inventory and analysis, Fort Pulaski National Monument. U.S. National Park Service, Technical Report NPS/NRWRD/NRTR-99/250, Fort Collins CO.

National Park Service. 2000. Baseline water quality data inventory and analysis, Timucuan Ecological and Historic Preserve. U.S. National Park Service, Technical Report NPS/NRWRD/NRTR-2000/278, Fort Collins, CO

National Park Service. 2001a. Baseline water quality data inventory and analysis, Ocmulgee National Monument. U.S. National Park Service, Technical Report NPS/ NRWRD/NRTR-2001/288, Fort Collins CO.

National Park Service. 2001b. Baseline water quality data inventory and analysis, Fort Sumter National Monument. U.S. National Park Service, Technical Report NPS/ NRWRD/NRTR-2001/283, Fort Collins CO.

National Park Service. 2004a. Appendix 6 - Maps of Southeast Coast Network Parks. U.S. National Park Service, Southeast Coast Network, Atlanta GA.

National Park Service. 2004b. Appendix 8 - Water resources of Southeast Coast Network. U.S. National Park Service, Southeast Coast Network, Atlanta GA.

National Park Service. 2005. Rehabilitation of the River Trail. U.S. National Park Service, Environmental Assessment, Internal Document.

Patterson, G. G., G. K. Speiran, and B. H. Whetstone. 1985. Hydrology and its effects on distribution of vegetation in Congaree Swamp National Monument, South Carolina. U.S. Geological Survey, Water-Resources Investigations Report 85-4256.

Perkins, D. W., H. Sosinski, K. Cherwin, and T. F. Zettner. 2005. Southern Plains Network vital signs monitoring plan: Phase I. U.S. National Park Service, Southern Plains Network, Johnson City TX, 79 p.

Perkins, D. W., H. Sosinski, K. Cherwin, and T. F. Zettner. 2006. Southern Plains Network vital signs monitoring plan: Phase II, U.S. National Park Service, Southern Plains Network, Johnson City TX, 71 p.

Phelps, G. G. 1990. Geology, hydrology, and water quality of the surficial aquifer system in Volusia County, Florida. U.S. Geological Survey, Water Resources Investigations Report 90-4069. Tallahassee, Florida.

Priest, S., and J. S. Clarke. 2005. Potential effects of groundwater development in Eastern Camden County, Georgia, on groundwater resources of Cumberland Island National Seashore. 2005 Georgia Water Resources Conference, April 25-27, 2005, Athens GA.

Roman, C. T., and N. E. Barrett. 1999. Conceptual framework for the development of long-term monitoring protocols at Cape Cod National Seashore. U.S. Geological Survey, Patuxent Wildlife Research Center, University of Rhode Island, 59 p.

Schmalzer, P. A., and G. R. Hinkle. 1990. Geology, geohydrology and soils of Kennedy Space Center: A Review. NASA Technical Memorandum 103813.

Schmalzer, P. A., M. A. Hensley, M. Mota, C. R. Hall, and C. A. Dunlevy. 2000. Soil, groundwater, surface water, and sediments of Kennedy Space Center, Florida: Background chemical and physical characteristics. NASA Environmental Program Office, NASA/Technical Memorandum-2000-208583, Kennedy Space Center FL.

Shelley, D. C., T. A. Thom, M. French, and B. Dolphin. 2008. Piezometers as tools for floodplain hydrology monitoring, research, and education programs at Congaree National Park, abstract for Floodplain Ecosystem Symposium: Integrating Science into the Restoration and Management of Floodplain Ecosystems of the Southeast, March 4-6, 2008, Little Rock, AR.

Stephenson, L. W., and C. Palmer. 1914. A deep well at Charleston, South Carolina, with a report on the mineralogy of the water. U.S. Geological Survey, Professional Paper 90-H.

Stockert, J. W. 1985. History of the public water, septic, and drainage systems at Moores Creek National Battlefield. U.S. National Park Service, Internal Report.

Taylor, C. J., and W. A. Alley. 2002. Ground-water-level monitoring and the importance of long-term water-level data. U.S. Geological Survey, Circular 1217, 68 p.

Thornhill, J. T. 1989. Ground-water issue paper: Accuracy of depth to water Measurements. U.S. Environmental Protection Agency, EPA/540/4-89/002, 3 p.

Toth, D. J. 1990. Geohydrologic summary of the Floridan Aquifer in coastal areas of Nassau, Duval, and St. Johns Counties. St. Johns River Water Management District, Technical Publication SJ 90-S.

Tucker, D. 1994. Baseline water quality data inventory and analysis - Cape Hatteras National Seashore. U.S. National Park Service, Technical Report HPS/ NRWRD/NRTR-94/27, Fort Collins CO.

U.S. Bureau of Reclamation. 2001. Water measurement manual, a water resources technical publication. Third Edition, US Department of the Interior, Bureau of Reclamation, Water Resources Research Laboratory.

U.S. Environmental Protection Agency. 1986. RCRA groundwater monitoring technical enforcement guidance document. EPA/530/SW-86/055, 207 p.

U.S. Environmental Protection Agency. 1987. A compendium of Superfund field operations methods. EPA/540-P-87/001, 508 p.

U.S. Environmental Protection Agency. 1989. Interim final RCRA facility investigation (RFI) guidance. EPA 530/SW-89-031.

U.S. Geological Survey. 1974. Definitions of selected ground-water terms - Revisions and conceptual refinements.Water-Supply Paper 1988, 21 pages.

U.S. Geological Survey. 1980. National handbook of recommended methods for water-data acquisition: Ground water. Chapter 2, 149 p.

U.S. Geological Survey. 1984. National handbook of recommended methods for water-data acquisition: Chemical and physical quality of water and sediment. Chapter 5, 194 p.

U.S. Geological Survey. 1996. Ground-water resources of the Upper Chattahoochee River Basin in Georgia - Subarea 1 of the Apalachicola-Chattahoochee-Flint and Alabama-Coosa-Tallapoosa River Basins. Open File Report 96-363.

U.S. Geological Survey. 2002. NWISWeb: New site for the nation's water data. Fact Sheet 128-02.

U.S. Geological Survey. 2003. Principal aquifers of the 48 conterminous United States, Hawaii, Puerto Rico, and the U.S. Virgin Islands. Available online at http://www-atlas.usgs.gov/

U.S. Geological Survey. 2005. User’s manual for the National Water Information System of the U.S. Geological Survey - Ground-water site-inventory system. Open-File Report 2004-1238. Version 4.3.

U.S. Geological Survey. 2006. User’s manual for the National Water Information System of the U.S. Geological Survey - Water-quality system. Open-File Report 2006-1145,Version 4.6.

U.S. Geological Survey. 2008. National field manual for the collection of water-quality data. Techniques of Water-Resources Investigations Book 9, Section A.

Walters, L., A. Roman, J. Stiner, and D. Weeks. 2001. Water resources management plan - Canaveral National Seashore, Florida. Department of Biology, University of Central Florida, National Park Service, Orlando FL.

Wilde, F. D., and D. B. Radtke, D.B. 2006. Field measurements. U.S. Geological Survey, Techniques of Water-Resources Investigations Report 08-A6.

Winner Jr, M. D. 1978. Ground-water resources of the Cape Lookout National Seashore, North Carolina. U.S. Geological Survey, Water-Resources Investigations 78-52.

Appendix A: SECN Park Infrastructure and Programs

This appendix provides information provided by park personnel related to groundwater concerns as well as site facilities related to groundwater use and monitoring. While efforts were undertaken to verify the accuracy of this information, the locations of some reported facilities were not found due to vegetation cover or dune migration. Evaluation of reported surface-water and groundwater contamination concerns were beyond the scope of this analysis.

CAHA: Cape Hatteras National Seashore

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- Karen Sayles, Biological Science Technician

Park personnel report the following concerns:

- Barrier islands experience flooding from hurricanes and large storm events.
- Cape Hatteras has potential contamination problems due to surrounding development, saltwater intrusion due to overpumping of groundwater, bacterial contamination in seawater due to park drainage, possible abandoned underground storage tanks from previous ownership by the U.S. Navy.
- There are water supply and monitoring wells in the park that are no longer in use.

Park personnel report the following site facilities:

1. Frisco Campground on Hatteras Island
   a. An operating water plant with a chlorination system, a 2000-gallon water tank, and three water-supply wells (Figure 21).
   b. Three inactive monitoring wells installed by the North Carolina Division of Water Resources (Table 13 and Figure 22).
2. Buxton Area
   a. A water-supply well, #4 (Figure 23).
   b. A suspected abandoned underground storage tank (N35.25017 W75.54070) (Figure 24).
   c. Four inactive (since 2001) monitoring wells (Table 13).
3. Cape Point Campground
   a. An inactive monitoring well (Table 13).
   b. An inactive, inaccessible monitoring well in the marsh.
4. Pea Island National Wildlife Refuge
   a. Two 13-ft deep water-supply wells adjacent to the highway that serve the bathroom at the nature trail (Table 13 and Figure 25).
5. Bodie Island Station
   a. Two inactive water supply wells and one water tower (N35.83612 W75.57442) (Table 13 and Figure 26).
   b. Four active monitoring wells used to monitor saltwater intrusion. Installed and operated by the North Carolina Division of Water Resources (Table 13 and Figure 27).
6. Fort Raleigh (FORA) Visitor Center
   a. An operating water plant with a chlorination unit and water storage tank.
   b. Two water-supply wells (Table 13 and Figure 28).

Table 12. Wells at Cape Hatteras National Seashore (CAHA).

Well ID	Aquifer	Screened Interval, ft	Latitude	Longitude	Owner	Water Level, ft
Frisco campground (three)	NA	NA	35.23994	-75.59151	NCDENR	NA
Buxton 1	NA	50	35.25092	-75.53995	NPS	NA
Buxton 2	NA	50	35.25003	-75.54052	NPS	NA
Buxton 3	NA	50	35.25120	-75.54100	NPS	NA
Buxton 4	NA	50	35.25120	-75.54048	NPS	NA
Pea Island (two)	NA	NA	35.71627	-75.49327	NPS	NA
Cape Point campground	NA	NA	35.23768	-75.54132	NA	NA
Pea Island	Surficial	NA	35.71627	-75.49327	NPS	NA
Bodie Island water plant	NA	NA	35.83612	-75.57442	NPS	NA
K2E\4	Yorktown	124-134	35.82365	-75.56982	NCDENR	4.3
K2E3	Yorktown	184	35.82365	-75.56982	NCDENR	10
K2E2	Yorktown	204-214	35.82365	-75.56982	NCDENR	8
K2E7	Surficial	5-10	35.82365	-75.56982	NCDENR	4.88
FORA Visitor Center	NA	NA	35.93407	-75.71258	NPS	NA
FORA Visitor Center	NA	NA	35.93450	-75.71258	NPS	NA

Figure 21. CAHA - Frisco Campground, active water-supply well.

Figure 22. CAHA - Frisco Campground, inactive monitoring wells.

Figure 23. CAHA - Buxton Area, active water-supply well.

Figure 24. CAHA - Buxton Area, suspected underground storage tank.

Figure 25. CAHA - Pea Island Wildlife Refuge, active water-supply wells.

Figure 26. CAHA - Bodie Island, inactive water-supply wells.

Figure 27. CAHA - Bodie Island, active saltwater-intrusion monitoring wells.

Figure 28. FORA - Visitor Center, water-supply facility.

CALO: Cape Lookout National Seashore

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- Mike Mallin, Professor, UNC-Wilmington

Park personnel report the following concerns:

- There is groundwater contamination due to leaky underground storage tanks that contained fuel.
- Flooding from hurricanes and large storm events has caused problems.

Park personnel report the following site facilities:

1. Three public water-supply wells, all located near ferry landings. The wells were drilled approximately 300-ft deep and extend through an unconfined aquifer, a confined aquifer, and into a second, underlying confined aquifer.
2. At least four shallow wells that are less than 10-ft deep that were hand driven, by park officials, to tap surficial water for the washing of vehicles and equipment.
3. A monitoring well at the Hunt Club site.
4. A monitoring well at the former U.S. Coast Guard site near the lighthouse.

CANA: Canaveral National Seashore

Contact Information:

- 212 S. Washington Avenue, Titusville, Florida 32796
- John Stiner, Chief of Resource Management, John_Stiner@nps.gov
- Brian Dietz, Facility Manager, Brian_Dietz@nps.gov
- Candace Carter, Biological Science Technician, Candace_Carter@nps.gov

Park personnel report the following concerns:

- Groundwater quality, including saltwater intrusion from groundwater withdrawals, and contamination from nearby agricultural and industrial activity, as well as from leaking septic tanks and NASA Kennedy Space Center
- Water level declines from overpumping of shallow aquifers

Park personnel report the following site facilities:

1. Park water is from a municipal source
2. NASA has a number of shallow wells that are used for monitoring groundwater contamination in the southern part of the park near the Kennedy Space Center (Table 14).
3. Volusia County has some test wells, groundwater data, and possibly weather and tide gauge stations in the northwest portion of the park.
4. The Florida Institute of Technology has conducted groundwater studies.

Table 13. Monitoring well locations at Canaveral National Seashore (CANA).

Well ID	Aquifer	Screened Interval, ft	Latitude	Longitude	Owner	Water Level, ft
DS-1D	Surficial	49.9	28.78581	-80.7964	NASA	NA
DS-1I	Surficial	35.1	28.78582	-80.7964	NASA	NA
DS-2D	Surficial	49.9	28.62754	-80.6545	NASA	NA
DS-2I	Surficial	35.1	28.62752	-80.6545	NASA	NA
DS-4D	Surficial	49.9	28.49300	-80.6677	NASA	NA
DS-4I	Surficial	35.1	28.49301	-80.6677	NASA	NA
DS-5I	Surficial	35.1	28.50777	-80.6651	NASA	NA
DUNE-1I	Surficial	35.1	28.88543	-80.7948	NASA	NA
DUNE-1D	Surficial	49.9	28.88542	-80.7948	NASA	NA
DUNE-2D	Surficial	49.9	28.65636	-80.6329	NASA	NA
DUNE-2I	Surficial	35.1	28.65638	-80.6330	NASA	NA
DUNE-5I	Surficial	35.1	28.59558	-80.5833	NASA	NA
DUNE-6I	Surficial	35.1	28.57447	-80.5769	NASA	NA
DUNE-6D	Surficial	49.9	28.57445	-80.5769	NASA	NA
MARSH-1D	Surficial	49.9	28.82374	-80.8470	NASA	NA
MARSH-1I	Surficial	35.1	28.82375	-80.8470	NASA	NA
MARSH-3I	Surficial	35.1	28.67759	-80.7714	NASA	NA
MARSH-4I	Surficial	35.1	28.66382	-80.6395	NASA	NA
MARSH-5D	Surficial	49.9	28.58781	-80.6602	NASA	NA
MARSH-5I	Surficial	35.1	28.62469	-80.7285	NASA	NA
WEST-1I	Surficial	35.1	28.65769	-80.7153	NASA	NA
WEST-1D	Surficial	49.9	28.56266	-80.7007	NASA	NA
WEST-3D	Surficial	49.9	28.54063	-80.6747	NASA	NA
WEST-3I	Surficial	35.1	28.54064	-80.6748	NASA	NA
WEST-4D	Surficial	49.9	28.48588	-80.6925	NASA	NA
WEST-4I	Surficial	35.1	28.48589	-80.6925	NASA	NA
WEST-5I	Surficial	35.1	28.62262	-80.7065	NASA	NA

CASA: Castillo de San Marcos National Monument

Managed by Fort Matanzas National Monument (FOMA); information about this park can be found in the FOMA section of this report.

CHAT: Chattahoochee River National Recreation Area

Contact Information:

- 1978 Island Ford Parkway Atlanta, GA 30350
- Alex Reynolds, Biological Science Technician, 678.538.1326
- Chris Hughes, Resource Management, Chris_Hughes@nps.gov
- Elliott Jones, USGS, lejones@usgs.gov

Park personnel report the following concerns:

- The park is situated along the Chattahoochee River (Figure 29), but within heavily populated areas of Atlanta, GA. Localized development adjacent to the park consists of significant areas of impervious surfaces and a lack of stormwater control facilities from adjacent properties.
- Surface water quality concerns include sedimentation, alteration in water temperature, flooding and sewer spills that occur in the South Unit, contamination from sewer and gas lines, historical agriculture and pesticides in Sope Creek, high bacteria levels during summer rains (monitored by Bacteria Alert Program), and heavy metals contamination from a former U.S. Air Force base;
- Lack of flooding due to Buford Dam; impact on species and soil nutrients
- Increased river velocity and adverse biota affects
- Inactive wells.

Park personnel report the following site facilities:

1. The water supply for the park is obtained from municipal sources. There are no onsite water-supply wells.
2. There are between one and five historic wells from previous ownership of park land. These inactive wells have not been capped or sealed.
3. The USGS has river gauges that are generally located outside of the park property.
4. There are several springs encapsulated by spring box heads, from a previous lodge on park property (Figure 30).
5. Two monitoring wells in the Johnson Ferry portion of the park, N33° 56.305', W84° 24.792' (Figure 31). The wells were installed by CH2M-Hill as a part of an ongoing wetland restoration project (UTM N3758654.39 E739404.472, Figure 32). Eventually, a boardwalk for visitors will be constructed at the completion of the wetland restoration. Phil Sacco of CH2M-Hill indicates (personal communication, 9/15/2008) that the wetland restoration is still in the design phase.
6. There is a monitoring well field located just outside of park property at Sugar Hill. The monitoring wells were emplaced regarding a land application of treated wastewater project on property adjacent to the park. The Georgia Environmental Protection Division (EPD) has a permit describing the project.

Figure 29. CHAT - Visitor Center, view of Chattahoochee River.

Figure 30. CHAT - Visitor Center, spring box head.

Figure 31. CHAT - Johnson Ferry, monitoring wells.

Figure 32. CHAT - Johnson Ferry South. (Aerial photograph showing monitoring well locations.)

CHPI: Charles Pinckney National Historic Site

Managed by Fort Sumter National Monument (FOSU); information about this park can be found in the FOSU section of this report.

CONG: Congaree National Park

Contact Information:

- 100 National Park Rd., Hopkins, SC 29061
- Bill Hulslander, Resource Program Manager, Bill_Hulslander@nps.gov
- David Shelley, Education Coordinator, david_shelley@nps.gov
- Bruce Campbell, USGS Hydrogeologist, bcampbel@usgs.gov
- Larry Harrelson, USGS
- Paul Conrads, USGS Hydrologist

Park personnel report the following concerns:

- Park is located in a floodplain, so flooding is an issue. The effect of altered surface-water hydrology and their effects on groundwater hydrology from upstream dams is the major concern.
- Droughts and increased water demand.
- Superfund site is located approximately five miles to the northwest of the site
- Encroaching development and industry
- Water quality: septic fields on park, upstream industry, highway treatment residue, agricultural runoff
- Inactive wells
- Climate change
- Hurricanes
- Proposed landfills
- Proposed changes to floodplain ordinances

Site facilities include:

1. There is a weather station in the uplands of the park that is monitored by WIMS.
2. There are two USGS surface water gauges at the park.
3. All park water is well and septic and is monitored by DHEC.
4. Larry Harrelson at the USGS is working on an extensive study utilizing five pre-existing monitoring wells and seven monitoring wells that he installed for the study. Data is forthcoming in a publication. Well information (coordinates, depth, elevation, etc.) is provided in Table 15.
5. Known inactive well sites (Dawson’s Cabin, Field at Wise Lake), and others are possible on new park lands (e.g., Bates Fork).

Table 14. USGS well data for Congaree National Park (CONG). TOZ is top of open zone. BOZ is bottom of open zone. T is aquifer transmissivity.

USGS ID	Latitude (NAD83)	Longitude (NAD83)	Elevation (NGVD88)	Depth (ft)	TOZ (ft)	TBZ (ft)	T (ft^2/d)
RIC-341	33.82514	-80.86203	101.98	18.3	8	13	7
RIC-342	33.81236	-80.86147	105.09	28	23	28	21
RIC-343	33.80986	-80.86536	105.94	30	25	30.0	
RIC-345	33.82514	-80.81925	115.24	22.2	18	22.2	
RIC-346	33.81653	-80.82731	99.25	23.5	13.5	23.5	
RIC-699	33.77047	-80.78458	99.11	14.5	9.5	14.5	
RIC-700	33.76333	-80.67528	86.37	13	8	13.0	
RIC-701	33.80939	-80.86636	107.65	14.8	9.8	14.8	
RIC-702	33.81464	-80.78744	95.95	13	8	13.0	
RIC-703	33.79775	-80.71186	88.65	12	2	12.0	
RIC-704	33.77114	-80.78500	99.63	14	9	14.0	
RIC-705	33.79475	-80.78158	93.84	14.5	9.5	14.5	

CUIS: Cumberland Island National Seashore

Contact Information:

- 113 St. Marys St., PO Box 806, St Marys, GA 31558
- John Fry, Chief of Resource Management, John_Fry@nps.gov
- Welby Stayton, USGS, wstayton@usgs.gov
- Elliott Jones, USGS, lejones@usgs.gov

Park personnel report the following concerns:

- Saltwater intrusion in nearby Brunswick, GA, due to aquifer withdrawals. Nearby industry, i.e., paper mills, are also pumping which causes concerns about local drawdown in the Floridan Aquifer.
- Inactive artesian wells in disrepair that need capping. Since the closure of the paper mill in Saint Marys and the subsequent rebound of the cone of depression caused by the high yield well, many wells that were not known have started to flow freely and in great volume.
- Lack of funding for monitoring.

Park personnel report the following site facilities:

1. Six U.S. Geological Survey monitoring wells (Table 16).
2. Eight active wells are used to supply park facilities (Table 17 and Figures 33-40). Most water is pumped from the (deeper) Floridan aquifer, but supplies at backcountry campsites are taken from (mid-level) Hawthorne aquifer.
3. There are twelve inactive wells (Table 17 and Figures 41-52).
4. An unknown number of private wells are located on the island.
5. There are several monitoring wells in the vicinity of Dungeness Ruins and Willow Pond.
6. There is a Climate Reference Network weather station
7. All park wastewater is discharged to septic fields

Table 15. USGS well data for Cumberland Island National Seashore (CUIS).

USGS Well ID	Aquifer	Screened Interval, ft	Latitude	Longitude	Water Level, ft
304646081280901 (34E003)	Upper Floridan Aquifer	730	30.77944	-81.46917	Artesian
304522081281301 (34E001)	Upper Floridan Aquifer	645	30.75611	-81.47028	Artesian
305122081275601 (34E002)	Upper Floridan Aquifer	600	30.85611	-81.46528	Artesian
34D009 (KBMP 3; Site 1)	Surficial Aquifer	94	30.72000	-81.46722	5
34D011 (KBMP 5; Site 2)	Surficial Aquifer	44	30.71972	-81.45139	5
34D008 (KBMP 2; Site 1)	Surficial Aquifer	23	30.72000	-81.46722	NA

Table 16. NPS Water Supply Wells at Cumberland Island National Seashore (CUIS).

Well Name	Status	Latitude	Longitude
Nightingale	Active	30.78639	-81.45444
Stafford Campground Area	Active	30.80778	-81.45056
Stafford Silos	Active	30.82778	-81.45917
Brickhill Bluff Campsite	Active	30.89444	-81.44389
North Cabin	Active	30.92167	-81.43528
South Cabin	Active	30.78639	-81.45444
Davis House	Active	30.78639	-81.46361
Stafford Beach House	Active	30.81167	-81.44889
Dungeness	Inactive	30.74806	-81.47056
Dungeness Garden	Active	30.74806	-81.47167
White Cottage	Inactive	30.75167	-81.47306
Willow Pond	Inactive	30.82333	-81.45056
River Trail	Active	30.84194	-81.46417
Plum Orchard - Hunt Camp	Active	30.85639	-81.46500
Plum Orchard	Active	30.85639	-81.46500
Plum Orchard East	Inactive	30.85639	-81.46444
Burbank Point	Inactive	30.92333	-81.43472
Alberty House	Inactive	30.92333	-81.43472
Duck House South	Inactive	30.84528	-81.42889
Lake Retta North	Inactive	30.83806	-81.43222

Figure 33. CUIS – Nightingale, water-supply well and storage tank.

Figure 34. CUIS - Stafford Campground Area, water-supply well.

Figure 35. CUIS – River Trail, water-supply well (fire).

Figure 36. CUIS - Brickhill Bluff Campsite, water-supply well.

Figure 37. CUIS - North Cabin, water-supply well.

Figure 38. CUIS - South Cabin, water-supply well (NPS residential).

Figure 39. CUIS - Davis House, water-supply well (NPS residential).

Figure 40. CUIS - Stafford Beach House, water-supply well (NPS residential).

Figure 41. CUIS - Dungeness, flowing well (inactive).

Figure 42. CUIS - Dungeness Garden, water-supply well (fire).

Figure 43. CUIS - White Cottage (Wayne's Bathtub), flowing well (inactive).

Figure 44. CUIS - Willow Pond, flowing well (inactive).

Figure 45. CUIS - Willow Pond, leak in pipe from well.

Figure 46. CUIS - Plum Orchard Hunt Club, water-supply well.

Figure 47. CUIS - Plum Orchard, water-supply well.

Figure 48. CUIS - Plum Orchard East, flowing well (inactive).

Figure 49. CUIS - Burbank Point, flowing well (inactive).

Figure 50. CUIS - Alberty House, water-supply well (inactive).

Figure 51. CUIS - Duck House South, flowing well (inactive).

Figure 52. CUIS - Lake Retta North, inactive well.

FOCA: Fort Caroline National Memorial

Managed as part of Timucuan Ecological and Historic Preserve (TIMU); information about this park can be found in the TIMU section of this report.

FOFR: Fort Frederica National Monument

Contact Information:

- 6515 Frederica Rd. St. Simons Island, GA 31522
- Denise Spear, Cultural Resource Specialist, Denise_Spear@nps.gov
- Elliott Jones, USGS, lejones@usgs.gov

Park personnel report the following concerns:

- Water quality: Glynn County has Superfund site, area has agricultural history, underground storage tank located in a buffer zone.
- Inactive wells.

Site facilities include:

1. The park has one pumping well, which supplies water for agricultural use, and hygienic purposes near the maintenance facilities (Table 18 and Figures 53-54).
2. Four inactive, uncapped wells are present, three of which were flowing during the site visit on March 12, 2007 (Table 18 and Figures 55-58).
3. There is one diesel-fuel, above-ground storage tank as well as one gasoline, above-ground storage tank located at the maintenance facility.
4. The park is on sewage system; however, there is one unused septic tank on site that is located somewhere in the wooded area.

Table 17. Wells at Fort Frederica National Monument (FOFR).

Well Location	Status	Latitude	Longitude	Comments
Visitor Center	Active	31.22107	-81.38995	
South of Visitor Center	Inactive	31.22280	-81.39228	Flowing, March 12, 2007
Southeast of Visitor Center	Inactive	31.22190	-81.39157	Flowing, March 12, 2007
Southwest of Visitor Center	Inactive	31.22042	-81.39288	Flowing, March 12, 2007
Southwest of Visitor Center	Inactive	31.21920	-81.39378	

Figure 53. FOFR - Visitor Center, exterior view of pump house.

Figure 54. FOFR - Visitor Center, interior view of pump house.

Figure 55. FOFR - Visitor Center (South), flowing inactive well.

Figure 56. FOFR - Visitor Center (Southeast), flowing inactive well.

Figure 57. FOFR - Visitor Center (Southwest), flowing inactive well.

Figure 58. FOFR - Visitor Center (Southwest), flowing inactive well.

FOMA: Fort Matanzas National Monument

Contact Information:

- 1 South Castillo Drive, St. Augustine, FL 32084
- Andrew Rich, staff, Andrew_Rich@nps.gov
- Andy O' Reilly, USGS, aoreilly@usgs.gov

Park personnel report the following concerns:

- The main water quality issue affecting the parks is concern about saltwater intrusion. The St. John's Water District has conducted some testing in this area.
- There are observations of high fecal coliform in the waterway.

Park personnel report the following site facilities:

1. The historic Spanish fort (Figure 59) on Rattlesnake Island (Figure 60) and a Visitor Center (Figure 61).
2. Fort Matanzas has one well that is monitored by St. John's County Water District, located at the Visitor Center near an inlet, N29.71565 W81.23853 (Figure 62).
3. A capped well is located near the monitoring well (Figure 63).
4. There is a 20,000 gallon water cistern located near the administrative building that is used only for fire response (Figure 64).
5. Ft. Matanzas has a double-walled above-ground storage tank for unleaded gasoline (Figure 65).
6. Castillo de San Marcos has no groundwater facilities; however there are several historic wells on the property.

Figure 59. FOMA - Rattlesnake Island, view of historic fort site.

Figure 60. FOMA - View of historic fort.

Figure 61. FOMA - Visitor Center entrance sign.

Figure 62. FOMA - Monitoring well near beach.

Figure 63. FOMA - Inactive well near entrance.

Figure 64. FOMA - Fire response cistern.

Figure 65. FOMA - Above-ground fuel storage tank.

FOPU: Fort Pulaski National Monument

Contact Information:

- P.O. Box 30757 Savannah, GA 31410
- Mike Hosti, Facility Manager, Mike_Hosti@nps.gov
- Mike Ryan, Chief Ranger, Mike_T_Ryan@nps.gov
- Brent Rothschild, Natural Resources Manager
- Elliott Jones, USGS, lejones@usgs.gov
- Welby Stayton, USGS

Park personnel report the following concerns:

- Groundwater contamination from saltwater intrusion.
- Inactive cisterns.

Park personnel report the following site facilities:

1. The park water supply is provided by a well at the Visitor Center, a well located underground within the fort courtyard, and one located at the Picnic Area (Table 19).
2. There are also seven historic cisterns; generally, they are sealed, although many appear to be in disrepair and exposed.
3. There is a 15,000 gallon underground water tank for fire suppression at the picnic area.
4. There are two USGS monitoring well fields at the Picnic Area and also near the Docks and Volunteer Housing Area (Table 19). These are used to monitor saltwater intrusion problems. Welby Stayton, USGS, has information concerning the monitoring wells.
5. There are two above-ground storage tanks, a 1500 gal gas tank and a 1000 gal diesel tank, located near volunteer housing.
6. There is a weather station at the Coast Guard Station immediately adjacent to FOPU.

Table 18. Wells at Fort Pulaski National Monument (FOPU).

Well location	Type	Owner	Latitude	Longitude
Visitor Center	Water Supply	NPS	32.02655	-80.89193
Fort Pulaski	Water Supply	NPS	32.02715	-80.89053
Picnic Area	Water Supply	NPS	32.03097	-80.90097
Picnic Area	Monitoring	USGS	32.03097	-80.90097
Docks (3)	Monitoring	USGS	32.03370	-80.90290

FORA: Fort Raleigh National Historic Site

Managed by the Cape Hatteras National Seashore (CAHA); information about this unit can be found in the CAHA section of this report.

FOSU: Fort Sumter National Monument

Contact Information:

- 1214 Middle Street, Sullivan's Island, SC 29482
- Sandy Pusey, Cultural Resources Manager, Sandy_Pusey@nps.gov
- Bruce Campbell, USGS Hydrogeologist, bcampbel@usgs.gov

Park personnel report the following concerns:

- Significant groundwater contamination at Ft. Sumter Visitor Center from a defunct coal gasification plant and U.S. Naval Base. The Visitor Center (located at the Liberty Square Visitor Education Center, by the harbor in downtown Charleston, where ferries depart for Ft. Sumter) is part of a Superfund Site. Much of the groundwater data collected in the visitor center area result from the construction of the Charleston Aquarium and a Superfund site (contamination from an old coal gasification plant) monitored by SCE&G. Historically, the area used to have trenches that drained into the harbor.
- Two underground storage tanks were removed from Ft. Sumter.
- Encroaching development near Charles Pinckney.
- Unknown and historic wells at CHPI

Park personnel report the following site facilities:

1. Ft. Sumter Visitor Center. The water supply is from offsite, municipal sources.
2. Several monitoring wells, owned by SCANA and USGS, are present (Figure 66).
3. There is also a phytoremediation project being conducted at the site using trees to absorb contaminants (Figure 67).
4. Ft. Moultrie. The geology of the area consists of dune sands near the harbor.
    a. There is a 5-25 gpm shallow well (approximately 20 feet deep) that is pumped into a cistern and used for irrigation. The water can tend to be high in iron. (Figure 68)
    b. There is also a very old well near the cistern that is not used. (Figure 69).
5. At Charles Pinckney
    a. Park facilities (Figure 70).
    b. There are some residential developments surrounding this site, which is located near an estuarine area**.**
    c. There are several inactive historic dug wells that have been filled in (Figure 71).
    d. There are several inactive wells that were recently found - presumably used for irrigation (Figure 72).

Figure 66. FOSU - Visitor Center, monitoring well (1800 ft deep) with pressure transducer.

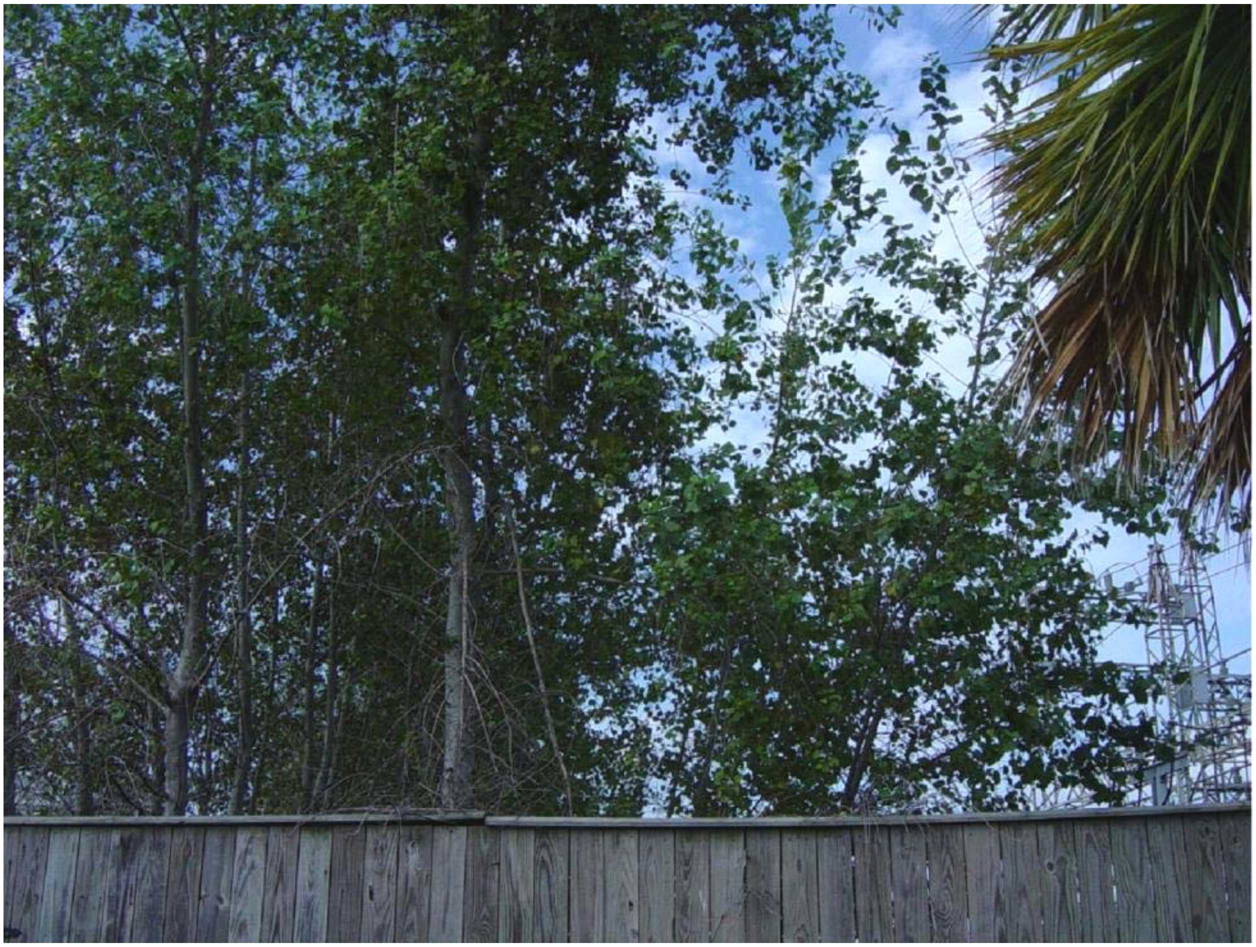

Figure 67. FOSU - Visitor Center, phytoremediation project, poplar trees.

Figure 68. FOSU - Ft. Moultrie, irrigation cistern and well.

Figure 69. FOSU - Ft. Moultrie, inactive well and cistern.

Figure 70. CHPI - View of historic site.

Figure 71. CHPI - Inactive hand-dug wells.

Figure 72. CHPI - Inactive well.

HOBE: Horseshoe Bend National Military Park

Contact Information:

- 11288 Horseshoe Bend Rd. Davison, AL 36256
- Jim Cahill. Chief Ranger, Jim_Cahill@nps.gov
- Steve Vines, Maintenance
- Stephen Crowder, Staff
- Brian Atkins, USGS, jbatkins@usgs.gov

Park personnel report the following concerns:

- There is possible contamination of the Tallapoosa River due to two hydroelectric power plants that the park is situated between.
- There were above-ground fuel tanks that have been removed.
- There is significant agriculture upstream.
- There are a number of springs; a parking lot near the battlefield has runoff problems from springs.
- Agriculture and tree logging north of the park has caused some concern about nitrate and sediment transport.
- There are septic drain fields (although reasonably distanced from the river).
- There are inactive wells.

Park personnel report the following site facilities:

1. Park water, which is currently from municipal sources.
2. There is a well house adjacent to the Tallapoosa River that was used for park supply water (Table 20 and Figure 73).
3. A USGS river gauge monitoring station is located near the well house next to the Tallapoosa River bridge, N32.9788 W85.73943 (Figure 74).
4. There is an old agriculture capped well from previous property owners (Table 20 and Figure 75). The well is sealed, and is located between the picnic area and river/nature trail in what was likely a gravel quarry.
5. There is a PVC well of unknown origin adjacent to the river that is not capped (Table 20 and Figure 76).
6. Four housing units feed into a septic tank and drainage field.
7. The maintenance building also has a septic tank.
8. There are two above ground fuel storage tanks located at the maintenance building.

Table 19. Wells at Horseshoe Bend National Military Park (HOBE).

Well Location	Type	Status	Latitude	Longitude
Well House	Water Supply	Inactive	32.97932	-85.74007
Quarry	Irrigation (?)	Inactive	32.98077	-85.73133
PVC Well	NA	Inactive	32.97195	-85.73465

Figure 73. HOBE - Well house adjacent to Tallapoosa River.

Figure 74. HOBE - USGS river monitoring station.

Figure 75. HOBE - Inactive well.

Figure 76. HOBE - Inactive PVC well.

KEMO: Kennesaw Mountain National Battlefield Park

Contact Information:

- 900 Kennesaw Mountain Dr., Kennesaw, GA 30152
- Willie R. Johnson, Park Historian, Willie_R_Johnson@nps.gov
- Elliott Jones, USGS, lejones@usgs.gov

Park personnel report the following concerns:

- Several creeks enter parks from developed areas. Due to the proximity to Atlanta and the surrounding development, urban runoff and related sources of pollution have likely contaminated surface water bodies at the park - however, little monitoring has been conducted.
- Fuel tank and soil were excavated on-site.
- Sewage lines run through the park.

Park personnel report the following site facilities:

1. No groundwater facilities were found in the park.
2. Some historic house sites had wells, but they have all been filled in.
3. There are approximately 15 springs that flow during rainy periods, according to Ranger Johnson (Figure 77).

Figure 77. KEMO - Mountain spring next to trail.

MOCR: Moores Creek National Battlefield

Contact Information

- 40 Patriots Hall Dr., Currie, NC 28435
- Tyrone Brandyburg, Park Superintendent, Tyrone_Brandyburg@nps.gov
- Melinda Chapman, USGS, mjchap@usgs.gov
- Joel Wagner, NWS

Park personnel report the following concerns:

- Underground fuel storage tanks were removed adjacent to the Visitor Center, maintenance building, and administrative building during the early 1990s. The tank near the Visitor Center had a leak. During the monitoring of the site, one soil sample was 0.01 units over the regulation standard (which contaminant test is not known by the author). Neighboring property owners were notified.
- Portions of the park close during flooding from the tidal creek.
- There are neighboring hog farms and agriculture.

Park personnel report the following site facilities:

1. Park public supply water comes from one groundwater well near the administration building (Table 21).
2. There is a nearby 40,000 gal water tank that stores the pumped groundwater.
3. There are three artesian wells that are rarely used
    a. Charles Simpson well, west bank of Moores Creek; rarely used; sampled by Dr. Mallin of UNC-Wilmington (Table 21 and Figure 78).
    b. Breastworks well, unused, adjacent to earthworks (Table 21 and Figure 79).
    c. Slocumb Hill well, artesian well, unused, adjacent to savannah (Table 21 and Figure 80).
4. There are two inactive wells from previous landowners on the site that have become lost. These wells (noted in Stockert, 1985) are located in a wooded area and could not be located.
5. The savannah has 14 monitoring wells that were emplaced for the wetlands restoration project and are marked by green flags (Table 21 and Figures 81-83).
6. There are also several septic tanks on site.

Table 20. Wells at Moores Creek National Battlefield (MOCR).

Well Location	Type	Status	Latitude	Longitude
Administration Building	Water Supply	Active	34.45887	-78.10780
Charles Simpson Well	Water Supply	Occasional	34.45937	-78.11410
Breastworks Well	Water Supply	Inactive	34.45857	-78.11190
Slocumb Hill Well	Water Supply	Inactive	34.45722	-78.11082
Savannah (14)	Monitoring	Active	34.45847	-78.10977

Figure 78. MOCR - Charles Simpson well.

Figure 79. MOCR - Breastworks well.

Figure 80. MOCR - Slocumb Hill well.

Figure 81. MOCR - Standing water within the Savannah portion of the park.

Figure 82. MOCR - Freshwater creek with tidal range of 10-15 feet.

Figure 83. MOCR - Savannah Monitoring Well #14.

OCMU: Ocmulgee National Monument

Contact Information:

- 1207 Emery Highway, Macon, GA 31217
- Guy LaChine, Chief Park Ranger, Guy_LaChine@nps.gov
- Elliott Jones, USGS, lejones@usgs.gov

Park personnel report the following concerns:

- The park is heavily impacted by human activity and runoff from Macon.
- The park is next to an auto junkyard, which is next to 300 acres of wetlands as well as one of the ponds that is difficult to access.
- There is a gas station with underground storage tanks very near park.
- One stream is heavily polluted, with high erosion and high fecal count during storm events.
- A large pond has mercury pollution.
- The park has the only above ground tank in the county.
- The park had an underground tank that was removed with no evidence of contamination.
- The uplands were once cotton fields. There is considerable soil erosion. The premium topsoil has likely been washed away.
- There are several inactive wells.

Park personnel report the following site facilities:

1. There are no operating wells in the park.
2. There are two historic farm wells, which are not capped, and are covered by wooden pallets (Figure 84).
3. Water bodies at the park include the following:
    a. Ocmulgee River, Walnut Creek and associated wetlands (Figure 85).
    b. Clay Hole pond, which mildly influenced and connected to Walnut Creek (Figure 86). The pond is an oxbow of the Walnut Creek and the site of an old clay mine. This pond is alleged to have mercury contamination.
    c. Two unnamed ponds
    d. OCMU has four intermittent unnamed streams (Figures 87-88), two of which begin in the park at an outflow for the city storm sewers lines. A third begins in the park and the fourth enters the park as a stream. One ephemeral stream that flows when it rains is from a storm drain and carries litter
    e. Prehistoric ditches at an archeological site (Figure 89).
    f. There is one spring that still flows, although rarely (Figure 90), located on one of the Creek mounds (Figure 91).

Figure 84. OCMU - Historic farm well.

Figure 85. OCMU - Standing water wetland from Walnut Creek. In 2008, this wetland has gone dry.

Figure 86. OCMU - Clay Hole Pond. In 2008, this pond is half the size seen here.


Figure 87. OCMU - Ephemeral stream.

Figure 88. OCMU - Unnamed intermittent stream #1.

Figure 89. OCMU - Prehistoric ditches at archeological site.

Figure 90. OCMU - Spring located on one of the Creek mounds.

Figure 91. OCMU - Creek Indian Ceremonial Mound.

TIMU: Timucuan Ecological and Historic Preserve

Contact Information:

- 13165 Mt. Pleasant Road, Jacksonville, FL 32225
- Richard M. Bryant, Chief of Resources Stewardships, Richard_Bryant@nps.gov
- Andy O' Reilly, USGS, aoreilly@usgs.gov
- Rick Breed, St. John's River Water Management District, 386-312-2348
- Marine Estuary Reserve. 386-461-4054

Park personnel report the following concerns:

- The national park is unique in that there are several thousand residents living within the park boundaries. Being that there are residential areas, with individual wells and septic tanks, water and contaminant issues within the park can be complicated.
- Another water concern is potential saltwater intrusion on George Island that resulted from water usage from a now defunct golf course.
- Septic tanks, hundreds of residents live within park, all with septic tanks, and there is a concern related to potential groundwater contamination from failing septic systems.
- Upland areas of park have development.
- Severe saltwater intrusion in neighboring wells due to over-pumping of Floridan Aquifer.
- Water quality; Jacksonville is 10 miles upstream, high nutrient load.
- Inactive wells.

Park personnel report the following site facilities [2]:

1. A water-supply well is located at headquarters in Theodore Roosevelt Area (Table 22 and Figure 92).
2. Spanish Pond well is artesian and completed in the Floridan Aquifer. The well was installed to fill the Spanish Pond in the 1960-70s. It is not used for domestic usage. It is now used by St. Johns River Water Management District (SJRWMD) as a monitoring well (Table 22 and Figure 93).
3. Ribault Column well used for irrigation and is less than 20 years old. The well is artesian but rarely flows and is only used occasionally (Table 22 and Figure 94).
4. Facilities at Fort Caroline.
    a. There are also two USGS monitoring wells located immediately adjacent to each other (Table 22 and Figure 95). One is completed in the surficial aquifer and the other in the Floridan.
    b. A third well is artesian and currently used for irrigation (Table 22).
5. Facilities at Ft. George Island.
    a. Commercial well for plantation, drilled in 1960s; artesian; Floridan; chlorinated; domestic (Table 22).

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[2] Unless indicated, all TIMU wells are completed in the Floridan aquifer.

b. Johnson Well, used for irrigation, leaking on December 20, 2006 (Table 22 and Figure 96, top).
c. Kontz well, originally domestic; now unused, but not capped; may be used for an eventual maintenance facility (Table 22 and Figure 96, bottom).
d. Ranger residence (Clark) well - domestic well for this house only (Table 22).

6. Broward House well, used for domestic purposes, 9935 Heckscher Drive (Table 22 and Figure 97).
7. Cedar Point well, at the southern tip of Black Hammock Island, was originally at an old fish camp, and is not used or capped. The well is artesian, from the Floridan Aquifer (Table 22).
8. St. John's River Water district also has monitoring wells.

Table 21. Wells at Timucuan Ecological and Historic Preserve (TIMU).

Well Location	Type	Status	Latitude	Longitude
Headquarters	Water Supply	Active	30.37007	-81.48507
Spanish Pond	Monitoring	Active	30.38232	-81.23577
Ribault Column	Irrigation	Occasional	30.38778	-81.48953
Fort Caroline, USGS (2)	Monitoring	Active	30.38380	-81.49702
Fort Caroline, artesian	Irrigation	Active	30.38335	-81.49792
St. George, Plantation	Water Supply	Active	30.43962	-81.43557
St. George, Johnson	Irrigation	Active	30.43965	-81.43535
St. George, Kontz	Water Supply	Inactive	30.43570	-81.43725
St. George, Ranger Residence	Water Supply	Active	30.40300	-81.43600
Broward House	Water Supply	Active	30.44278	-81.46205
Cedar Point	Water Supply	Inactive	30.37007	-81.48507

Figure 92. TIMU - Headquarters well at Theodore Roosevelt Area.

Figure 93. TIMU - Spanish Pond well.


Figure 94. TIMU - Ribault Column well

Figure 95. FOCA - Fort Caroline USGS monitoring wells.

Figure 96. TIMU - Ft. George Island wells. Top photograph is Johnson Well, bottom photograph is Kontz Well.

Figure 97. TIMU - Batton Island, Broward House well.

WRBR: Wright Brothers National Memorial

Managed by the Cape Hatteras National Seashore (CAHA); information about this park can be found in the CAHA section of this report.

Appendix B: Groundwater Analysis Programs

Two programs were developed by Professor John Dowd in the Geology Department of the University of Georgia to support groundwater analyses. The two programs are *GWInput* and *UpdateSW*, which are described below.

Program *GWInput*

This program is designed to automate the input of groundwater data for the SECN Park sites. When the program is started, the user must select the Park site from the drop down menu labeled **NPS ID**. After the site is chosen, the program will display the site number and four-character Park code. The information entered must be keyed to a unique well name. Each name will begin with the four-character Park code, followed by a number. If the **New Well** button is selected, a unique name will be created. Only wells with numbers less than this value can be entered manually. The ability to enter earlier values will enable the user to edit earlier entries in the database.

All of the information entered for each well will be recorded in data fields on three pages of input. If any information is not known, the field should be left blank and no information will be recorded for that field in the database. On the third page, a **save** button will cause the information to be written to a line in an *Excel* spreadsheet. If the filename exists, the data will be appended to the bottom of the file. If the filename does not exist, it will be created. Additional wells can be added to the spreadsheet before exiting the program. The **default** button allows the user to change the number of wells that have been written to the database. This is useful if the program is run on more than one computer.

Program *UpdateSW*

This program is designed to assist in the management and interpretation of groundwater data. The program updates daily or real time USGS streamflow or groundwater data by using the internet to update chosen gage sites, saving the data in an *Excel* format. The program can also be used to graph the data, and to evaluate whether temporal trends are present in the data. Groundwater data (head in feet) is used for a trend analysis for each well. The trend analysis was completed by retrieving all depth to water level data for a list of wells that were determined to be representative of the groundwater conditions in the SECN.

UpdateSW can be used to download data from the National Water Information System (NWIS) database, which is the national archive for hydrologic data (http://nwis.waterdata.usgs.gov/nwis). NWIS combines local databases with the centralized National Water Data Storage and Retrieval System (WATSTOR) database to create a single, distributed-information processing and management system (Dzurik, 2002).

Groundwater data collected is accessed from the NWIS database using:

- http://water.usgs.gov/waterwatch/
- http://ogw01.er.usgs.gov/AWLSites.asp?S=<stationid>

where <stationid> is the USGS station identification. *UpdateSW* stores data as an *Excel* file.

File Command

Read: Initially, this option will allow the user to navigate to the appropriate file. When re-starting the program, it will open the last gage list file read, containing a list of sites. The first time the program is run, the user must navigate to the input file. A list of sites to be updated must be in a text file in the following format having the site identification number first, followed by a description of the site:

02191300 BROAD RIVER ABOVE CARLTON, GA
02192000 BROAD RIVER NEAR BELL, GA

An example file, *filelist.txt*, is supplied with the program.

A mixture of surface water and groundwater sites is acceptable. The file *GageList.txt* is supplied as an example. The list can be modified with the **Add** command. It is preferable to use the **Add** option to maintain the list because an improper site number will cause uncertain results from the website. The data files will be stored in the directory that contains the list file. A sample screen showing the program operation is provided in Figure 98.

New: This option allows the user to navigate to a new text file that contains a list of site names to be maintained. The file *GageList.txt* is supplied as an example. The list can be modified with the **Add** command. It is preferable to use the **Add** option to maintain the list because an improper site number will cause uncertain results from the website. This command allows the user to navigate to a new file name and/or location.

Filenames: This form allows the user to change the filenames associated with the sites. The default name is a "G" followed by the site number. Names can be modified by typing a new name (without extension) and pressing the <enter> key. The list will be saved with the **Update** option, or discarded with the **Cancel** option. Default names can be obtained with the **Default** option. The **Filename** option allows the user to specify the filename that contains the list of names associated with the sites in the gage list.

Add: The current file list can be modified with this form, and appears in the right panel. A Master List can be loaded to the left side with the **Load** option. The real-time surface water sites for Georgia, for example, are contained in *GA_SW_UV.txt*, and real-time groundwater sites for Georgia are contained in *GA_GW_UV.txt*. Sites can be added to the operational list by dragging sites to the right. Only valid sites can be dragged. Sites can be removed by dragging sites from the operational list to the left. The Master List will not be permanently modified by this action. Upon return, if the file list is modified, the program will display the filenames form.

View: This option allows the user to inspect the last file downloaded and the full *Excel* spreadsheet. The site is selected from the list at the bottom; the daily values or real-time values are selected with the adjacent button. The *Excel* file can be modified by the following sequence: select a cell with the mouse, change the value, press the <enter> key. If the file is changed, the

user can select to save the changes when the **View** form is closed. A sample screen showing the program operation is provided in Figure 99.

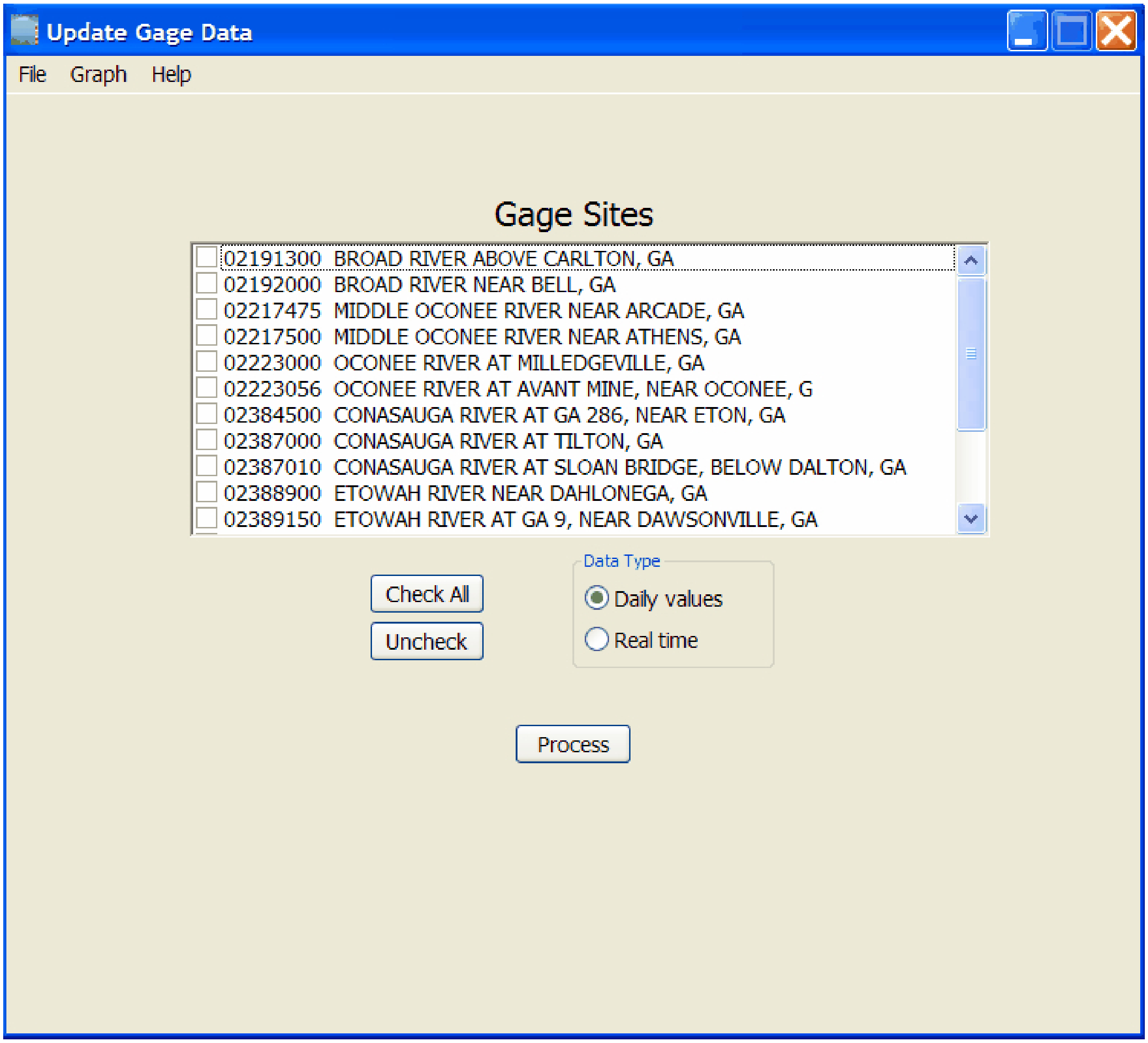

Figure 98. Program *UpdateSW* - Sample screen showing the display using the Read option.

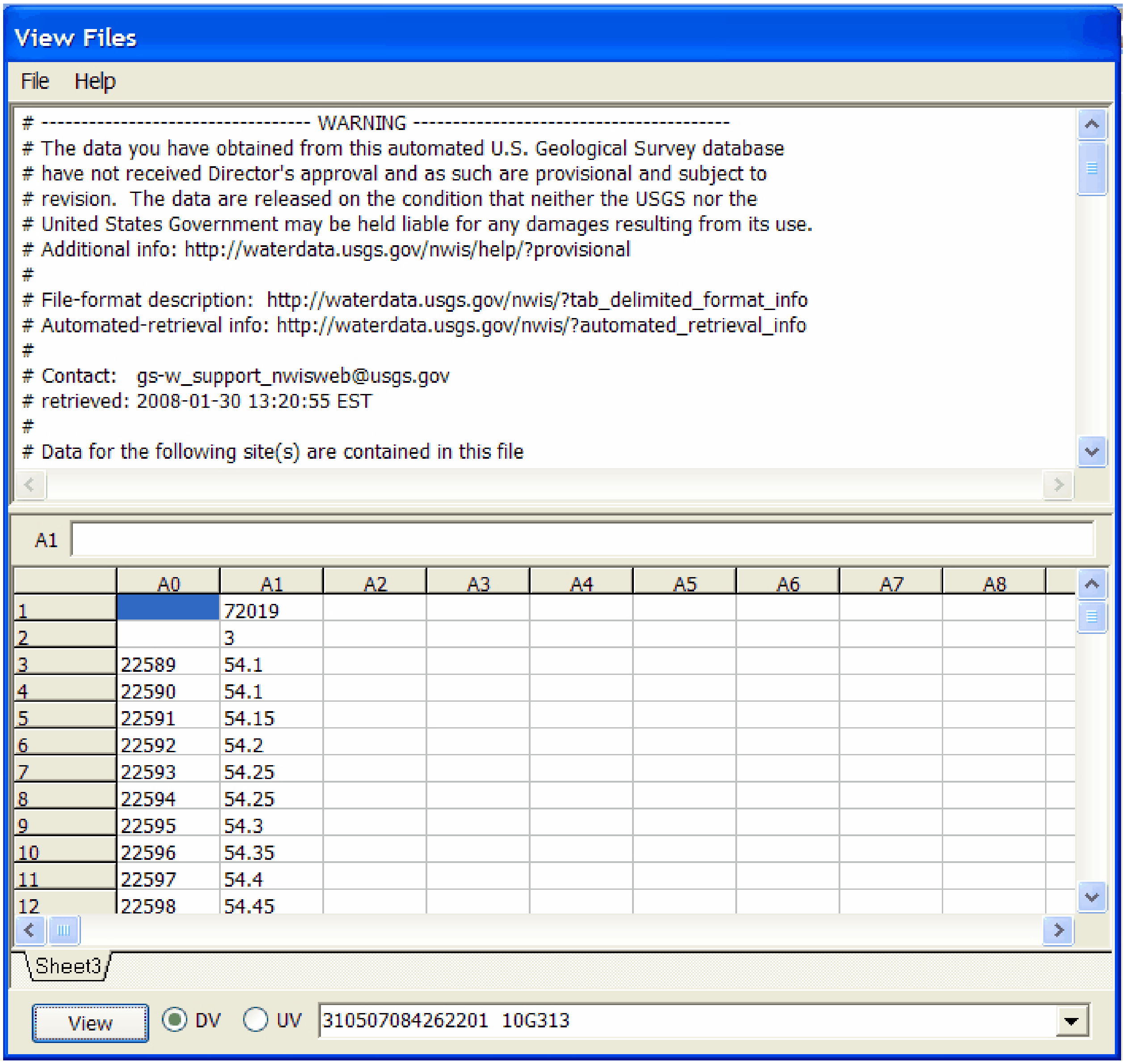

Figure 99. Program *UpdateSW* - Sample screen showing the display using the View option.

Graph Command
To view a Cartesian plot of the data, a site is selected from the drop down list box at the bottom of the Form. A button is used to select between daily and real-time values. The **Plot** button will display the selected site. If they both exist, discharge will be plotted on the left axis and gage height will be plotted on the right axis. For groundwater, depth below surface will be plotted. The **Graph > Options** menu item allows other data to be plotted. A sample screen showing the program operation is provided in Figure 100.

Options: This menu option allows the user to select any data to be plotted on the left or right axis. The list box for each axis lists all the data contained in the *Excel* file. This option also contains an edit box to change the time gap for plotting breaks in the data.

Edit: This option allows the user to manually change most aspects of the plot, including line color and axis labels. Printing can also be accomplished from this option.

Copy to Clipboard: This option is the easiest way to save a copy of the plot. If a graphics capable program is also running, selecting this option will place a copy of the graph in the clipboard. In the other program, **paste** will place the copy in the program.

Cursor: This option displays a mouse cursor, and shows the cursor position at the top of the plot. The x-axis is shown as Date/Time, and the y-axis is shown in units of either the left or right axis. The **flip** button will alternate between the two curves.

Alternate: This option allows the user to alternate the cursor between the left and right axis. Initially, the cursor points to the left y-axis.

Plot Fast: The curves are broken if there is a gap in the data (default). The magnitude of the time gap can be changed in **Options** menu option. The **Plot Fast** option will plot the data without the breaks. It is not reliable if there is a large break in the data.

Trend: For daily values of groundwater (depth below surface), the annual average depth and annual trend can be shown with the **Trend** option in the **Main** menu. The year is calculated from January 1. In order to provide a statistically significant result, the test requires a minimum number of daily observations per year, and a minimum number of years of monitoring data overall. These values can be modified on the **Options** menu.

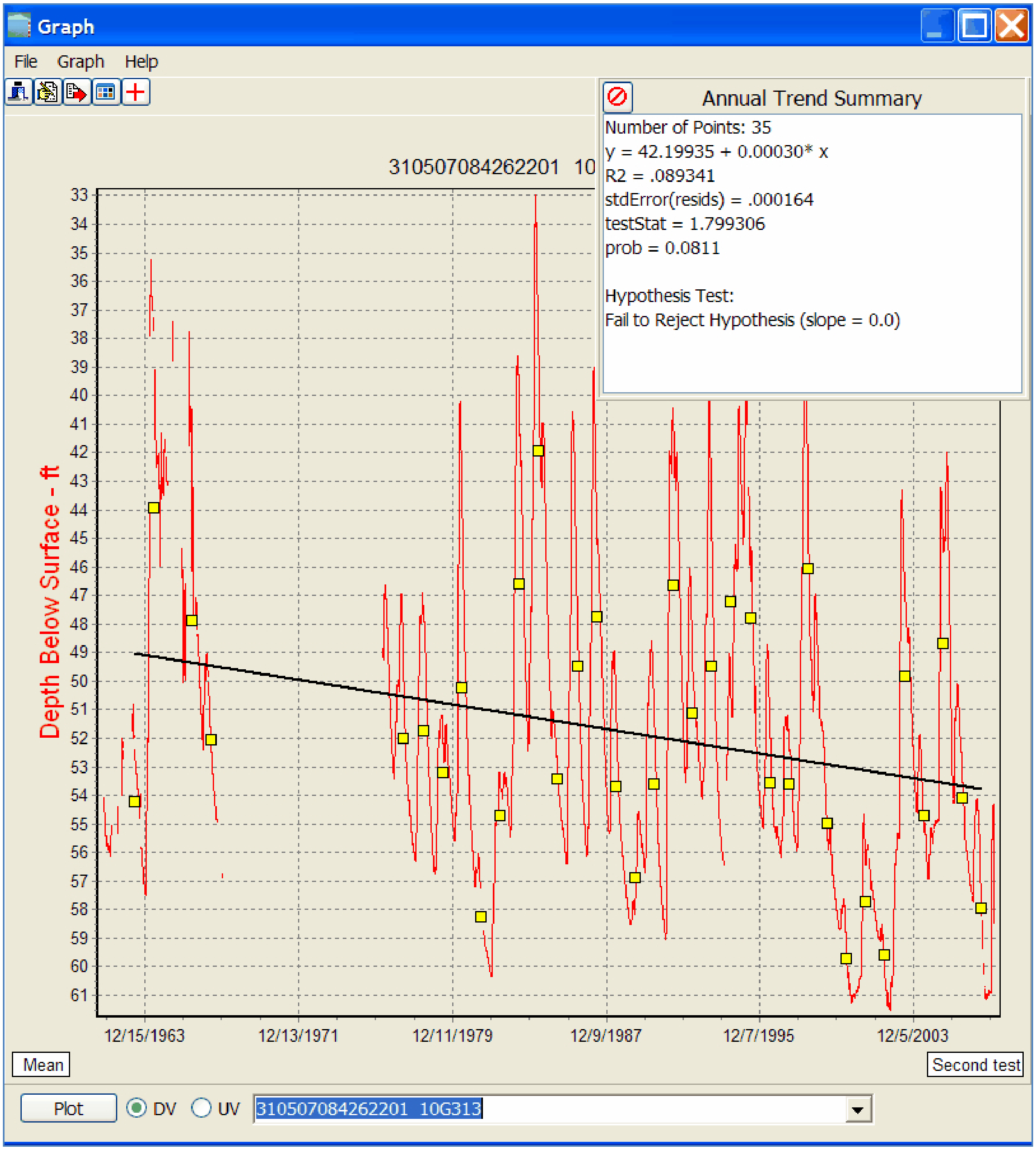

Figure 100. Program *UpdateSW* - Sample screen showing the display using the Graph option.

NPS 910/100157, Month Year

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