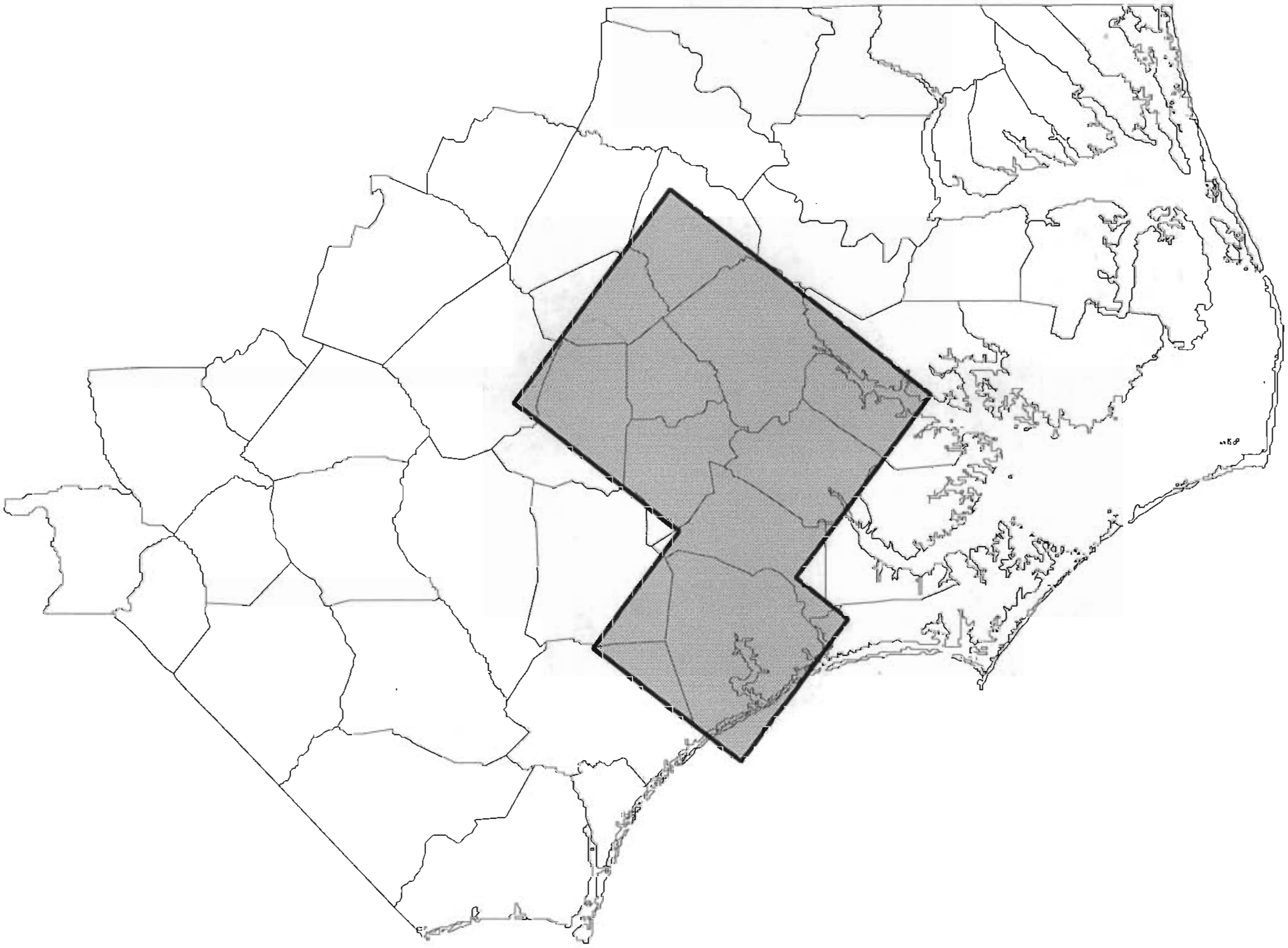
INTERIM REPORT

CENTRAL COASTAL PLAIN GROUND WATER MODEL



DIVISION OF WATER RESOURCES

April 1993

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North Carolina
Department of Environment, Health, and Natural Resources

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ABSTRACT

In the past three years, the Division of Water Resources (DWR) investigated the possibility of using a ground water flow model to help local governments in the Central Coastal Plain (CCP) region of North Carolina manage their ground water use. Efforts were directed towards testing the United States Geological Survey (USGS) ground water model of the CCP developed in the late 1980s as an outgrowth of Regional Aquifer Systems Analysis work. DWR staff checked the calibration of the model by comparing actual water levels with computed water levels in the three major Cretaceous aged aquifers -- Upper Cape Fear, Black Creek, and Peedee. Model calibration during 1986-1990 time period was comparable to USGS calibration data prior to 1987 published in the USGS CCP model report. A few areas showed large discrepancies and require model recalibration for more accurate water level estimations.

Results of model runs from 1987 to 2010 show the cumulative effect of ground water pumping from the many users in the CCP area. Large cones of depression have formed and will continue to grow in depth and scope due to withdrawals in the Black Creek and Upper Cape Fear aquifers. Aquifer damage may result from lowering water levels below the top of these aquifers (de-watering) and should be avoided. Largest drawdowns occur beneath Kinston, Onslow County-Jacksonville, New Bern, and Farmville systems. The model is very capable of providing valuable information about the combined effects of all CCP water systems, however, several limitations in the model will require increased efforts by DWR and local entities to update the water use and hydrogeological data bases. An improved model can be the foundation for management of the CCP ground water resources.

TABLE OF CONTENTS

INTERIM REPORT
CENTRAL COASTAL PLAIN GROUND WATER MODEL

Introduction

The Central Coastal Plain region of North Carolina includes all or portions of 16 counties as illustrated on figure 1. This area has shown marked ground water level drops since the mid-1900s as ground water use has increased dramatically. The rapid lowering of ground water levels is particularly obvious in the Cretaceous[1] aged aquifers known as the Upper Cape Fear, the Black Creek, and the Peedee. The Central Coastal Plain (hereafter CCP) region includes the area of largest drawdown of ground water levels and highest population or water use growth.

The United States Geological Survey's (USGS) Regional Aquifer Systems Analysis (RASA) work began in 1978 (Winner and Coble, 1989; Giese, Eimers, and Coble, 1991). The RASA study analyzed the aquifer framework and ground water flow in the eastern coastal plain of the United States from New Jersey southward through Georgia. However, it was decided in the mid-1980s among the USGS and their cost-sharing partners that a more detailed analysis was required for the CCP because of the significant ground water use and disturbing drop in water levels.

A group of municipalities, private water systems, and county governments, the North Carolina Department of Environment, Health, and Natural Resources (EHNR), and the USGS developed a cooperative agreement which funded the CCP study. The CCP study evolved from the RASA work and involved defining the hydrogeological framework of the aquifers, recording historical withdrawals (until 1986) from the ground water system, and modeling the ground water flow through that system. The Cretaceous aquifers in the CCP were of special concern because they are extensively used for public water supplies. A complete description of the USGS model and their modeling results is found in Eimers, Lyke, and Brockman, 1990. The references at the end of this report list the major USGS reports associated with the CCP project.

Responsibility for the ground water model operation transferred to EHNR, Division of Water Resources (DWR) in April 1990, after the USGS published their results. This report summarizes the initial efforts by DWR to use the Central Coastal Plain hydrogeological framework and an application of the ground water model developed by the North Carolina District of the USGS. The modeling results, analysis, and conclusions contained herein are the products of DWR efforts.

CCP Model Runs

Model Run Preparation

DWR has undertaken the responsibility of running the CCP model to help local governments and other water users manage the ground water resources of the area. DWR advertised the availability of the model in April 1990 as a tool to examine the effects of different rates of ground water withdrawal on the aquifer system and received responses from the following cooperators:

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[1] Cretaceous is a period in the geologic time scale which refers to sediments deposited between about 144 and 66 million years before present.

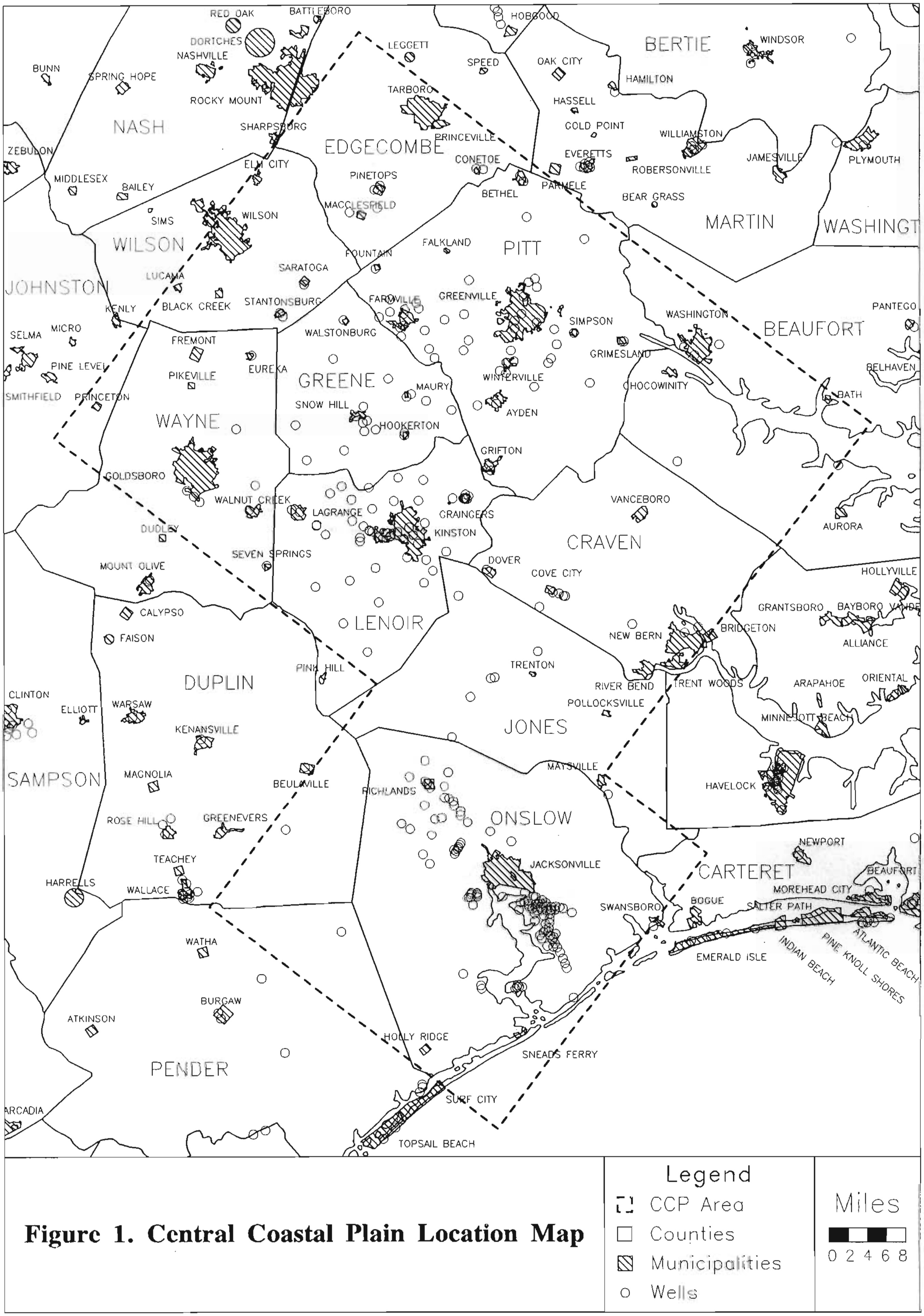


Figure 1. Central Coastal Plain Location Map

Kinston, Jacksonville, New Bern, Onslow County, and Farmville. On the whole, the cooperators understood the capabilities of the model, but some exhibited misconceptions about expected results from model runs. Between the initial requests for model runs in June 1990 from Kinston and the latest from Farmville in February 1992, DWR gained a better comprehension of the ground water flow model.

The model uses a computer program developed by the USGS in the 1980s (McDonald and Harbaugh, 1988) which is commonly called MODFLOW. DWR personnel received training in the use of MODFLOW and learned valuable tips for running the CCP model from USGS hydrologists and modelers.

The modeled area is subdivided vertically into ten layers corresponding to the number of aquifers, and horizontally into 102 columns and 120 rows (figure 2). Thus, the model contains 122,400 grid cells (10 layers by 120 rows by 102 columns). About 30% of these cells are inactive because they lie outside the lateral limits of a particular aquifer or they are outside the no-flow boundaries delimited by the 10,000 mg/l chloride concentration of ground water. The density of cells is highest in the CCP area for better resolution, and decreases toward the boundaries of the model grid. Within the CCP area cell size averages 0.98 square miles with smallest cells covering 0.77 square miles. Outside the CCP area cell size reaches a maximum of 56.25 square miles. The model estimates a ground water level in each grid cell at certain time steps by calculating the flow of ground water through the cells. The ground water level in a cell is a function of a change in the amount of stored ground water, which is equal to the difference between the amount of ground water flow into the cell from neighboring cells and through recharge, and the amount of ground water flow out of each cell by wells and from discharge to neighboring cells.

DWR gathered additional water use data from many of the larger ground water users in the Central Coastal Plain region to estimate the withdrawal of ground water between 1986 and 1991. Detailed information for most of the water systems in the area was gained from Water Supply System Report for 1989 questionnaires previously completed and returned to DWR and through additional data requests by DWR to specific communities and industries.

Three model runs were completed in July and August of 1992 using water use data collected by DWR in 1990, 1991, and early 1992. Each of these runs required time-consuming efforts (typically 2 to 3 weeks) to create the input data file, transfer it via modem to the USGS computer system, run the model (3-5 day run-time), transfer the necessary output data back to DWR computers via modem, and analyze the output. In January of 1993 DWR moved the model to a computer within the Division to allow more efficient runs.

Model Calibration

In order to test the accuracy of the CCP model, actual water levels must be compared to computed values. Levels from seven EHNR research station wells were chosen for this process and are illustrated on figure 3. These research stations were picked because of their distinct geographic positions (figures 13-15) and the aquifer each sampled. It should be noted that yearly average water levels for these monitoring wells are charted against calculated water levels from the center of the model cell encompassing the well location. If the research station well lies near the perimeter of the cell, then some differences between the two levels may exist.

In general, computed water levels track actual variation in water levels between 1986 and 1990 as

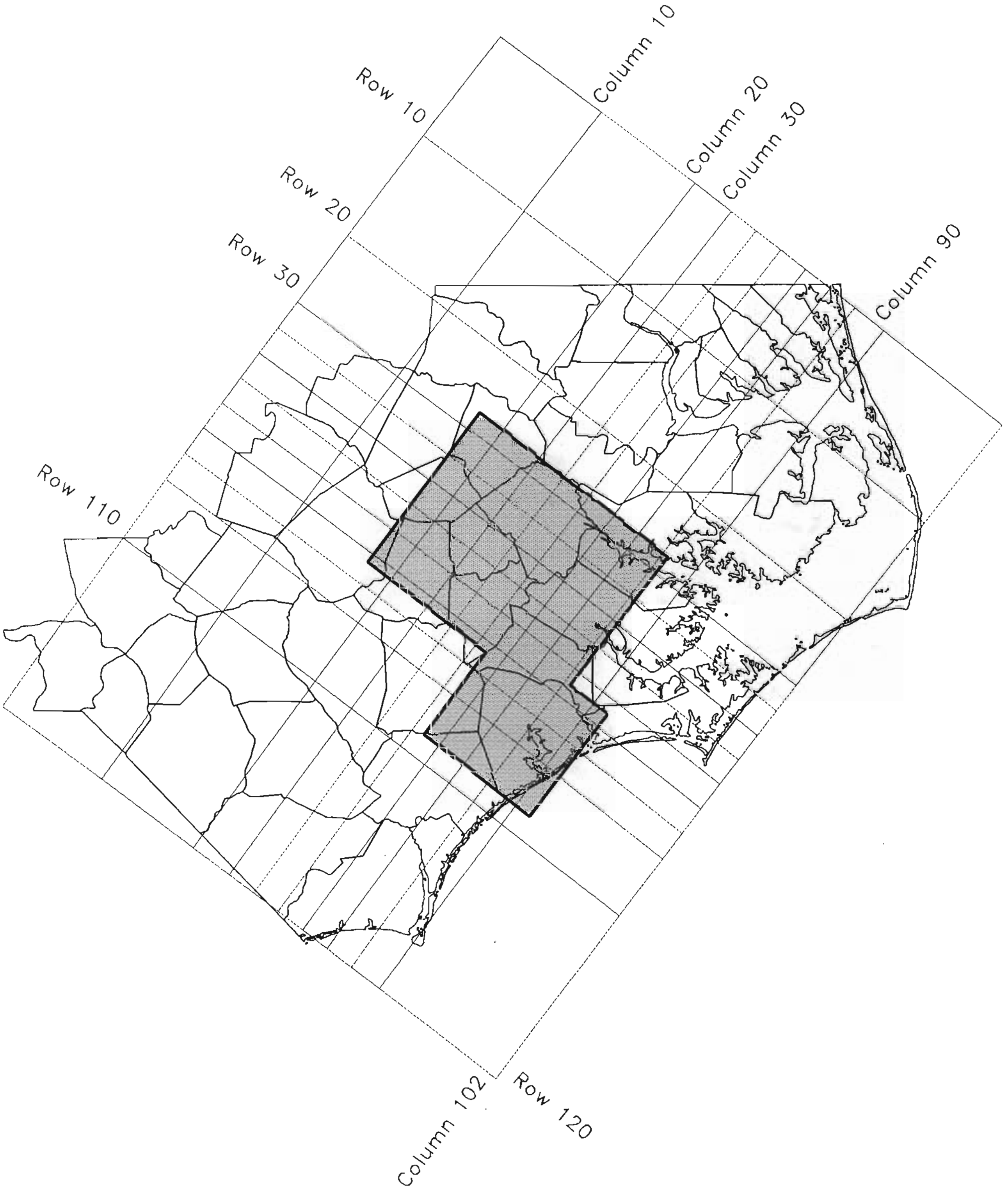
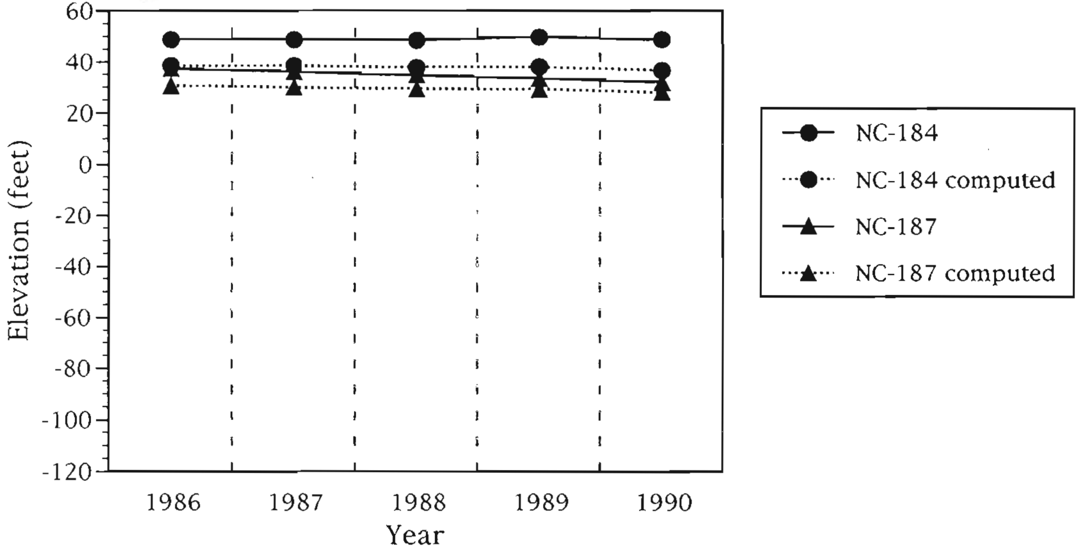


Figure 2. Central Coastal Plain Model Area

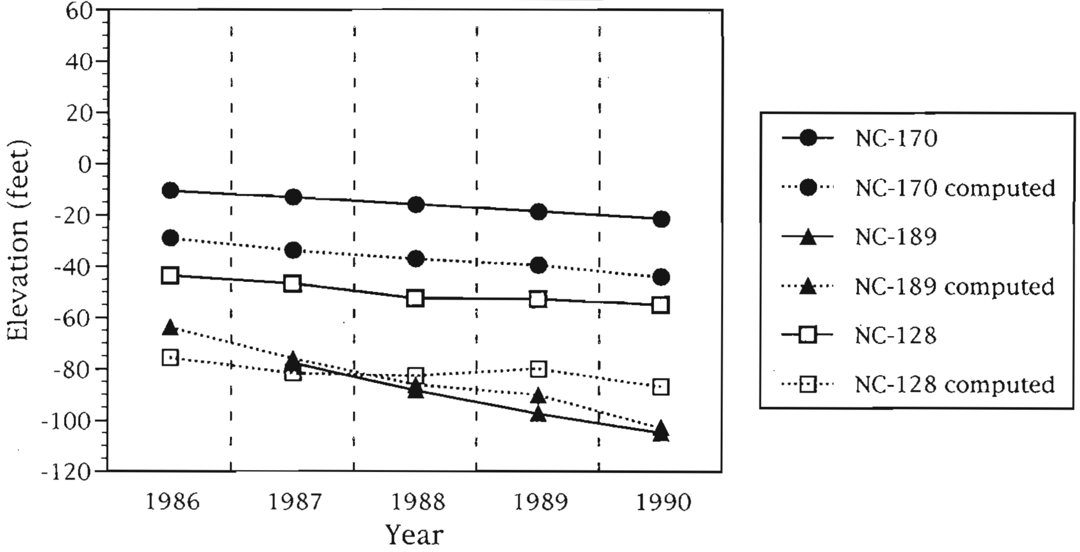
Every Tenth Row and Column of Grid

Figure 3. Yearly Average Ground Water Elevation
Actual versus Computed

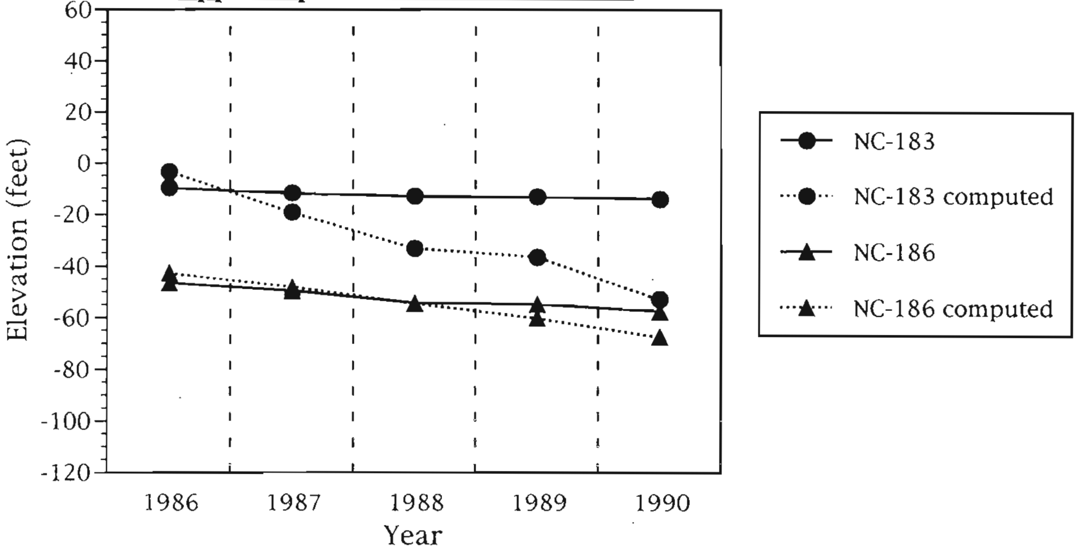
Peedee Research Stations



Black Creek Research Stations



Upper Cape Fear Research Stations



well as was described in the USGS model report for water levels prior to 1987 (Eimers, Lyke, and Brockman, 1990). In most cases, the computed level follows the proper trend, but at a lower elevation. The differential ranges from about 5 to 35 feet. The largest deviations occur in the more heavily pumped aquifers -- the Black Creek and Upper Cape Fear aquifers. The two most significant comparisons occur with NC-128 and NC-183.

The Black Creek research station near Kinston (NC-128) shows significantly higher water levels than the computed values for that model cell. In this case, as well as with NC-183, model parameters need to be adjusted to produce levels in line with the actual conditions. Research station NC-183, which lies northeast of Farmville, gives water level information vastly different than the model estimates. In fact, the levels are diverging. Limited water level data from Farmville seems to follow the research station trend. Both of these cases NC-183, and NC-128 suggest that recalibration in these areas is necessary prior to estimating where and when water levels might drop below the top of the aquifer and cause aquifer de-watering.

Model Results

The three DWR model runs estimated ground water levels for the Cretaceous aquifers in the CCP region. Results are presented for the Peedee, Black Creek, and Upper Cape Fear aquifers. The first run used a two percent growth in water use per year, the second incorporated a linear trend to estimate future water use, and the third assumed no increased water withdrawals beyond latest water use figures (latest use ranged from 1986 to 1991 values). Each model run estimated ground water levels until the year 2010 in five-year increments, or stress periods. The average volume pumped per grid cell for each five-year stress period was used in the computations. Rates of ground water use by the CCP cooperators are listed in Appendix A (water use by the 140 other users represented in the model are not included in this appendix). Values for each model run are tabulated by year and by stress period.

The two-percent growth simulation results are illustrated on the attached figures 6-8 and 10-12. This growth rate most accurately reflected total water use growth in the CCP between 1986 and 1991. Results from the second run using linear growth were discarded because of errors. This method of linear extrapolation of ground water withdrawals proved to be inaccurate because of gaps in water use records for individual wells. Although water systems can usually report total use by well field accurately, the data for individual wells is frequently not available. Thus, this missing data often skewed the calculated future water use.

One method of viewing results from model runs is to use cross-sections through an area of interest. Two cross-section lines (A-A´ and B-B´) were chosen for analysis and are shown along with well locations in figure 4. On figures 5 and 9, the Cretaceous aquifers of interest and their corresponding confining units are illustrated for each of these cross-sections. These are known as confined aquifers because ground water flows easily through the sand-rich, aquifer material, but flow into less permeable, clay-rich, confining material above and below the aquifer is hampered. Unconfined aquifers lack the upper confining material. Land surface and aquifer levels are drawn based on data from selected wells located near the cross-section lines. The 250 mg/l chloride concentration, delineating the boundary between freshwater and saltwater, is also shown in figures 5 and 9. This interface is based on RASA work (Winner and Coble, 1989). Chloride concentrations increase down dip towards 10,000 mg/l and eventually seawater concentrations (about 19,000 mg/l). The 10,000 mg/l concentration interface is not shown.

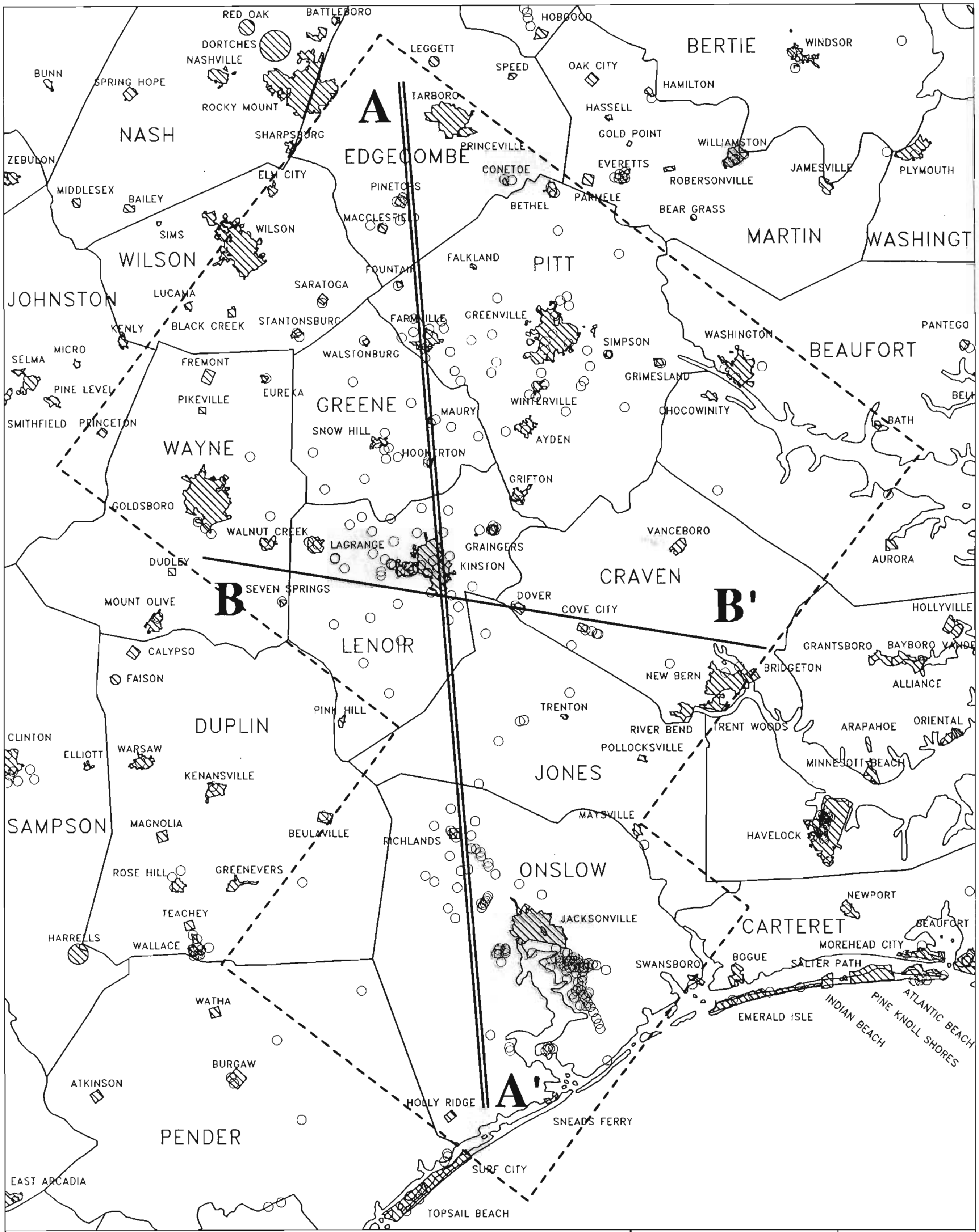


Figure 4. Central Coastal Plain Cross-Sections and Well Locations

Legend

- ⌜⌟ CCP Area
- ☐ Counties
- ▨ Municipalities
- ═ Cross-section A-A'
- — Cross-section B-B'
- ○ Wells

Miles

0 2 4 6 8

Figure 5. CCP Cretaceous Aquifers

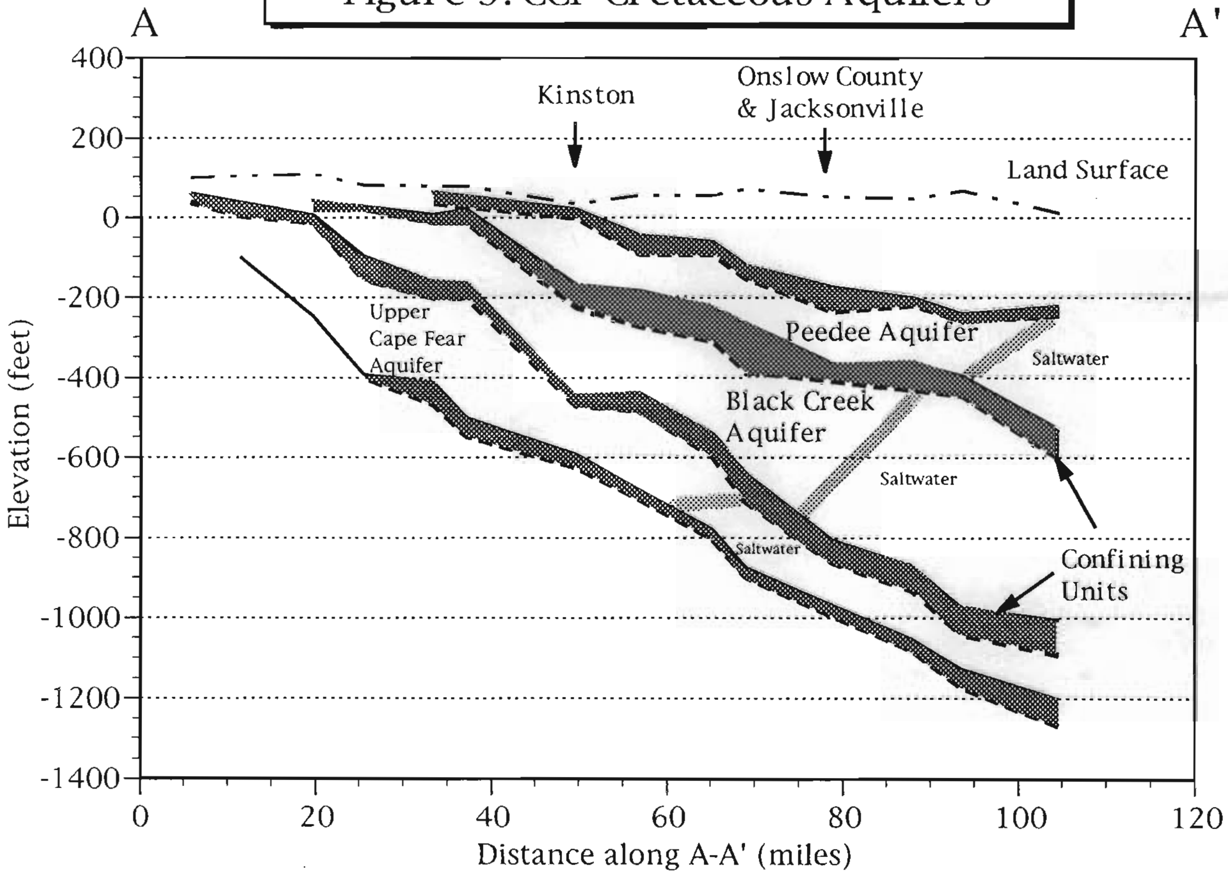
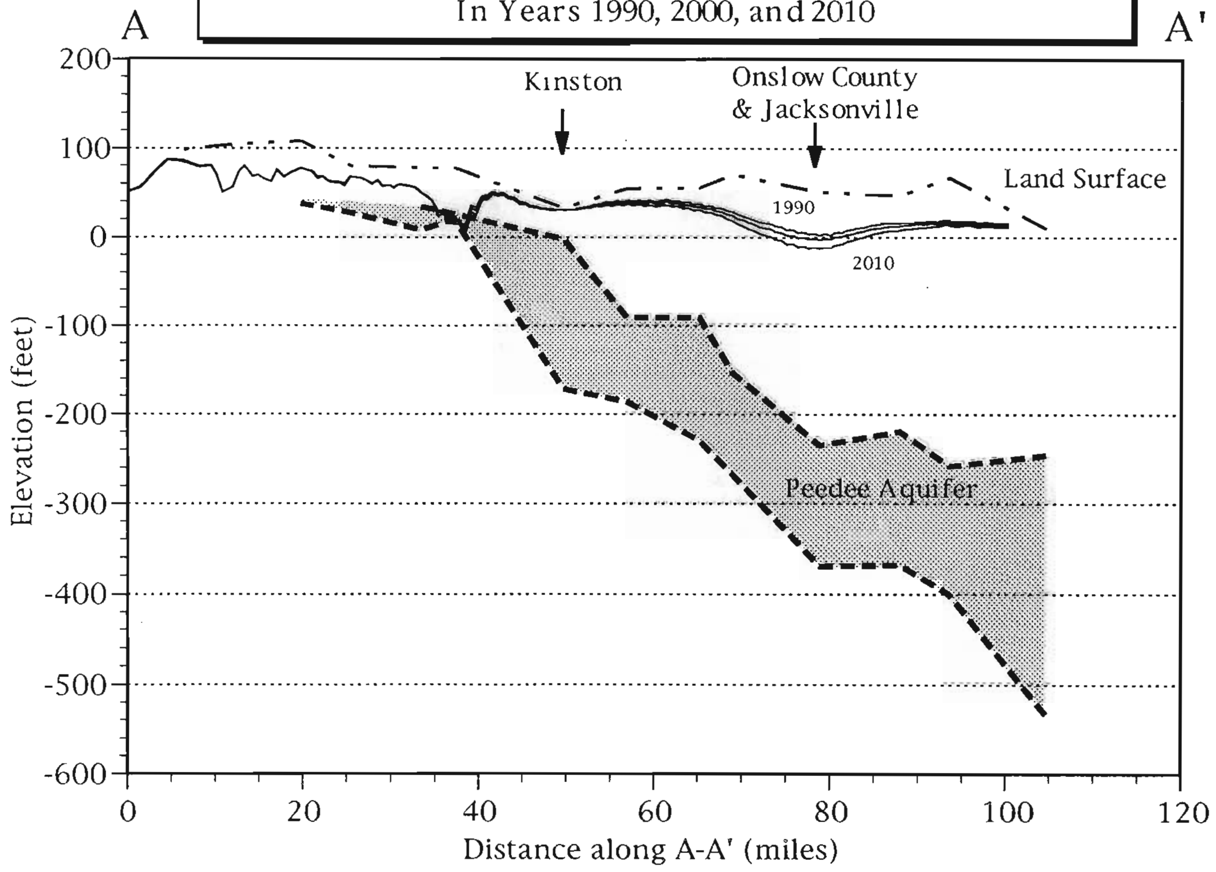


Figure 6. Peedee Water Levels with 2% Growth

In Years 1990, 2000, and 2010



Figures 6-8 display, along cross-section A-A´, water levels for the Peedee, Black Creek, and Upper Cape Fear Aquifers in the simulated years 1990, 2000, and 2010. These cross-sections indicate the rate of growth of the cone of depression from 1990 to 2010. Near Kinston for the Black Creek aquifer and Farmville for the Upper Cape Fear aquifer, it is apparent that ground water withdrawals increasing at two percent per year may cause water levels to drop below the top of the aquifer and begin to de-water the aquifer. Although, the Onslow County-Jacksonville area does not appear to be in danger of aquifer de-watering, they may experience saltwater intrusion.

De-watering may cause irreparable damage to the aquifer. Ground water is contained in the pore spaces of the aquifer material and helps support the structure of the aquifer. As ground water is drained from the aquifer, the aquifer material may compact, reducing the volume of the pore space. If water is allowed to fill the aquifer again through reduction of pumping, less water can be stored in the aquifer if pore spaces have collapsed. So, de-watering of the aquifer may cause loss in storage capacity. Also, the compaction of aquifer material may result in subsidence of the land surface.

Figures 10-12, illustrating cross-section B-B´, show similar trends to the previous figures. Ground water levels are lowered dramatically near Kinston and Cove City in both the Black Creek and Upper Cape Fear aquifers. Peedee aquifer water levels show little deviation from 1990 values.

In general, the cross-sections indicate that drawdown in water levels is significant over a large region. Withdrawals from many municipal and industrial supply wells contribute to the depressed water levels. The model shows clearly the cumulative effect of the many withdrawal sites in the CCP area. This continued drawdown will require pumps be dropped to lower levels and/or new wells be drilled as has happened in the past for many CCP communities and industries. The drawdowns illustrated in these cross-sections dramatize the finite water resources available.

Figures 13-15 show the extent of drawdown between the years 1990 and 2010 in map format. Both the Black Creek and Upper Cape Fear aquifers show regions of high drawdown. In the Black Creek aquifer, drawdown is largest in the area between Onslow County-Jacksonville and Kinston. The Upper Cape Fear aquifer also shows widespread drawdown, with peak drawdown zones near Kinston and Farmville-Greenville. The Peedee aquifer shows only small drawdown effects over this time span assuming two-percent growth. The minor zones of drawdown occur near Onslow County-Jacksonville and Aurora. The drawdown near Aurora is due to pumping of the Castle Hayne aquifer (an aquifer above the Peedee) at Texas Gulf, Inc.

The third simulation incorporating no growth in water withdrawals was run to determine if ground water levels would reach equilibrium at 1986 to 1991 (depending on data from system) withdrawal rates. According to the model, if pumping is sustained at these rates, ground water levels in the Cretaceous aquifers would stop falling and reach a balanced condition by about 2010. Further model runs were not performed that might estimate the maximum rates of withdrawal these aquifers could handle.

Future of CCP Model

In its present state, the model is capable of estimating the cumulative effect on the water levels in the Cretaceous aquifers due to ground water withdrawals. The computer model can also be used to judge the relative merits of locating a well in one place or another (which location enlarges the cone of depression least). However, the model has a resolution of, at best, 0.8 mile because of the size

Figure 7. Black Creek Water Levels with 2% Growth
In Years 1990, 2000, and 2010

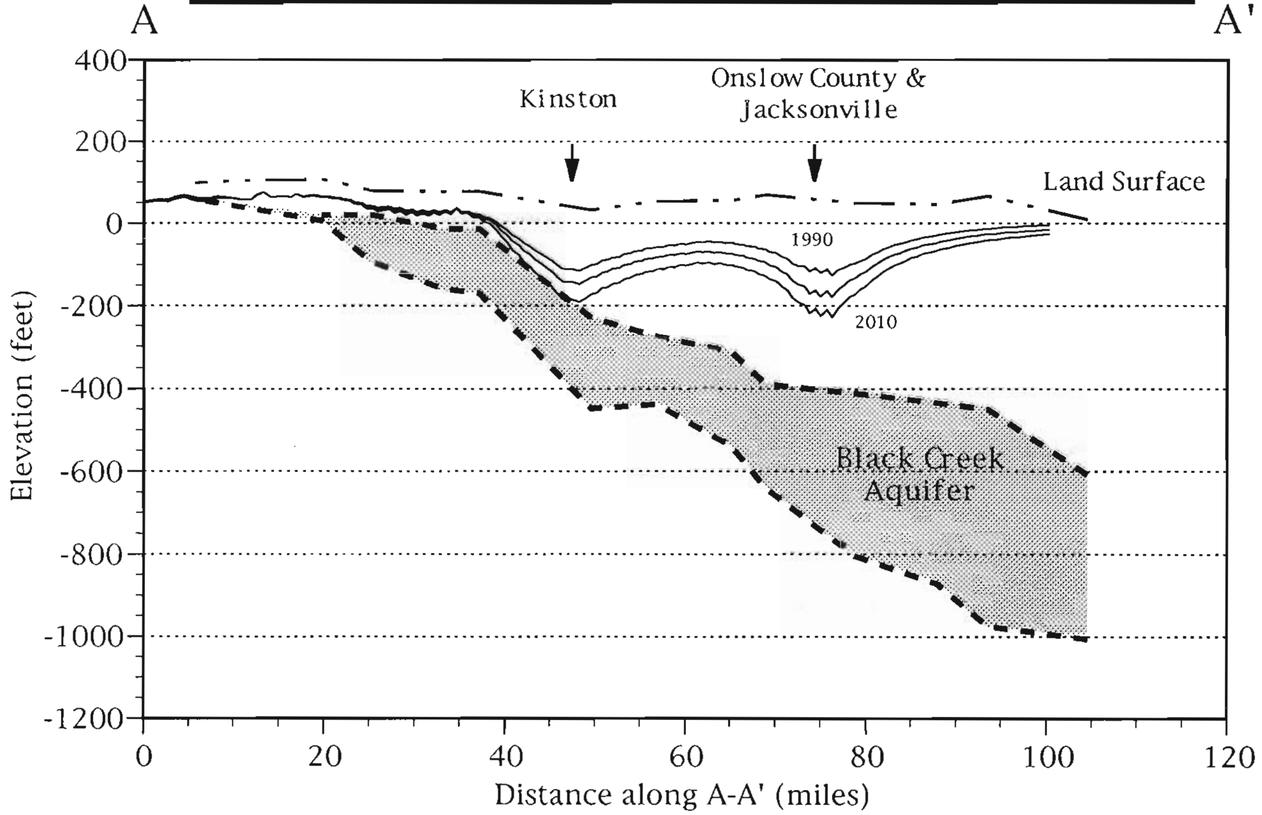


Figure 8. Upper Cape Fear Water Levels with 2% Growth
In Years 1990, 2000, and 2010

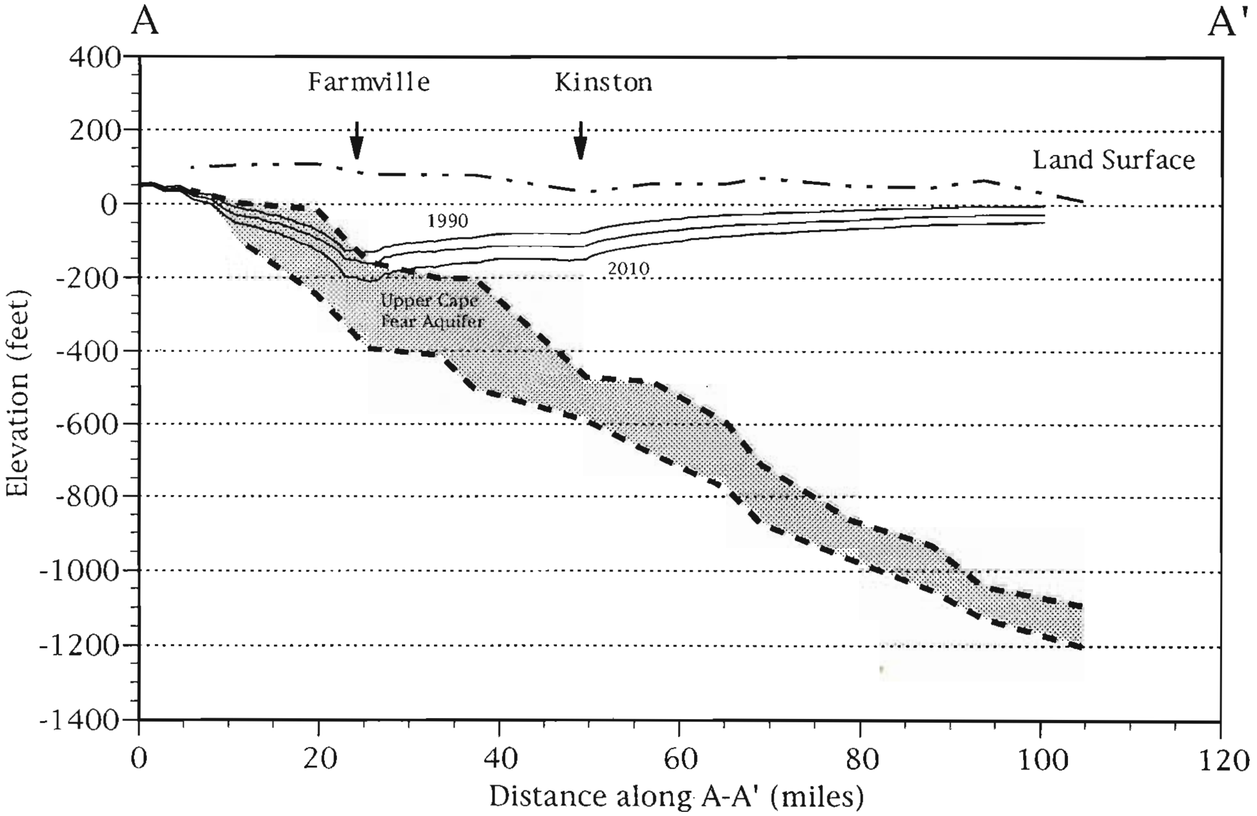


Figure 9. CCP Cretaceous Aquifers

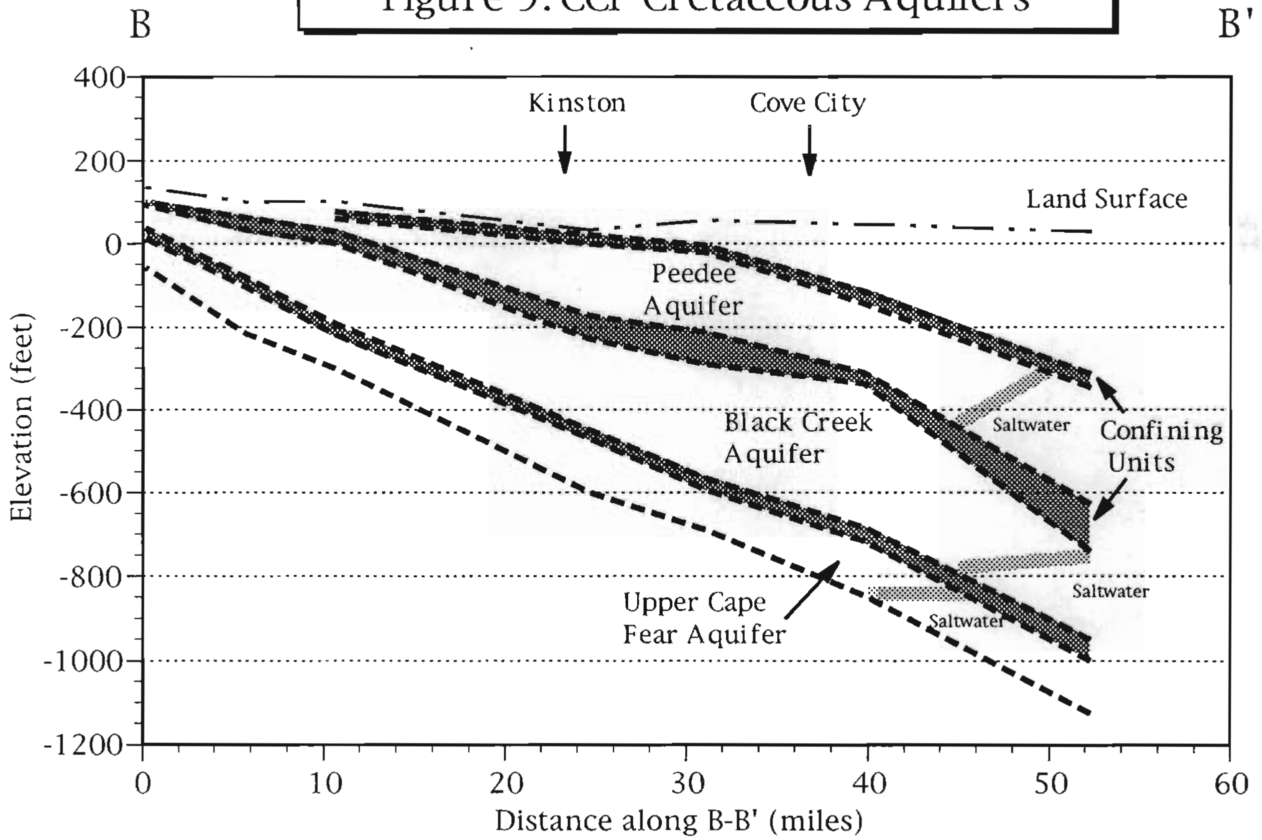


Figure 10. Peedee Water Levels with 2% Growth

In Years 1990, 2000, and 2010

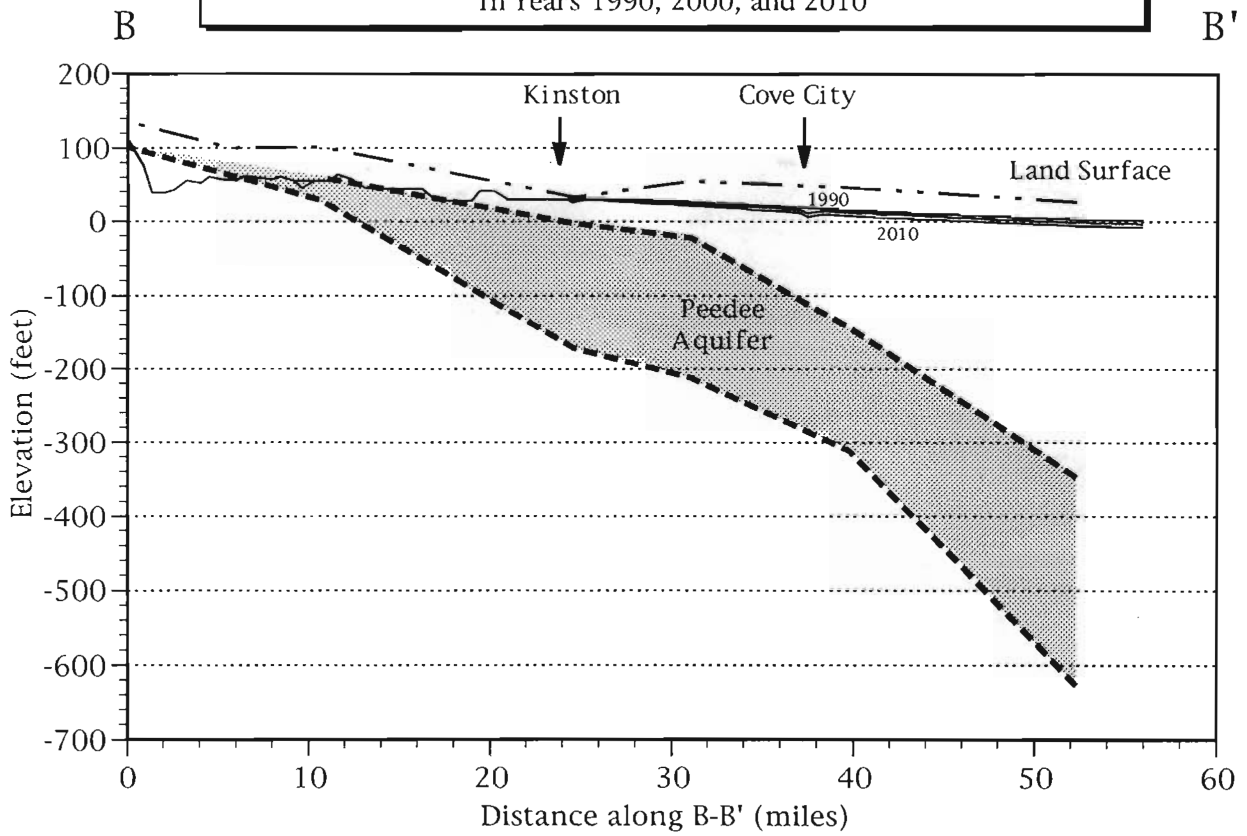


Figure 11. Black Creek Water Levels with 2% Growth

In Years 1990, 2000, and 2010

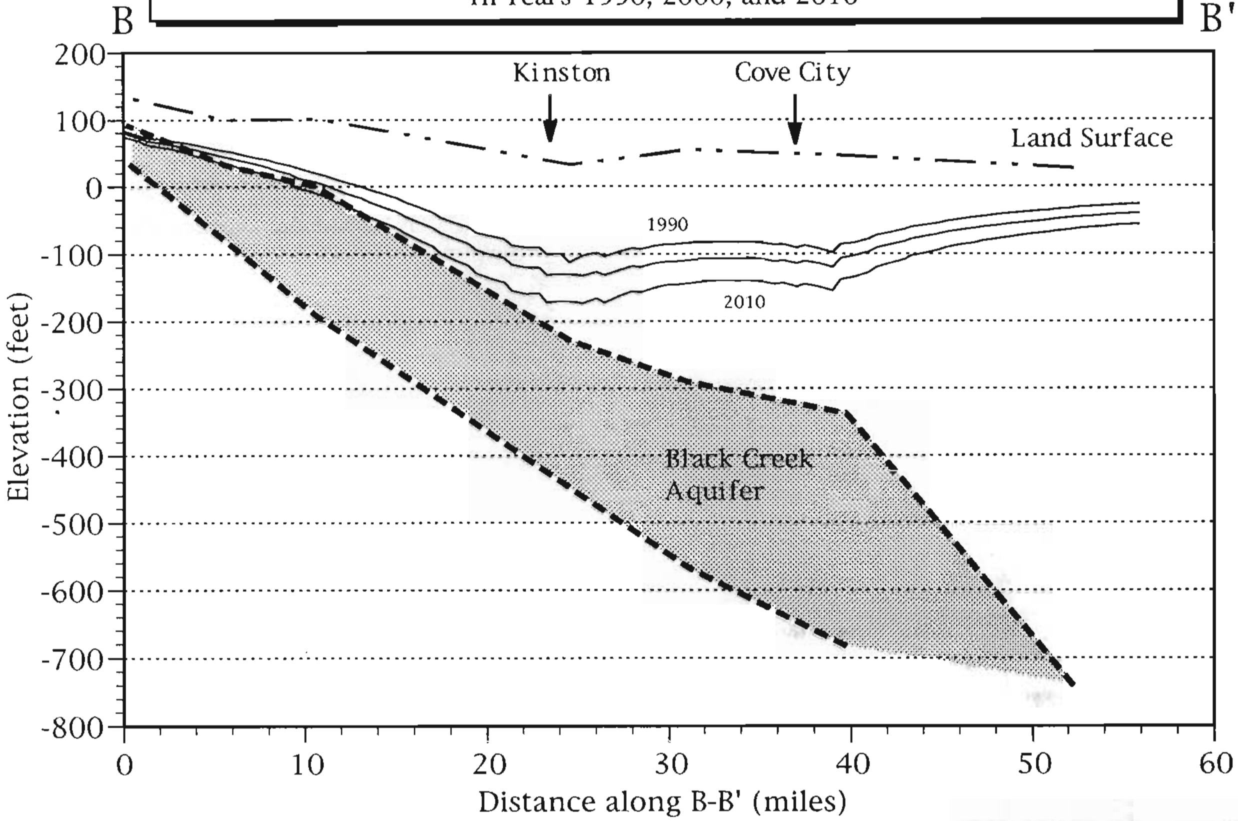
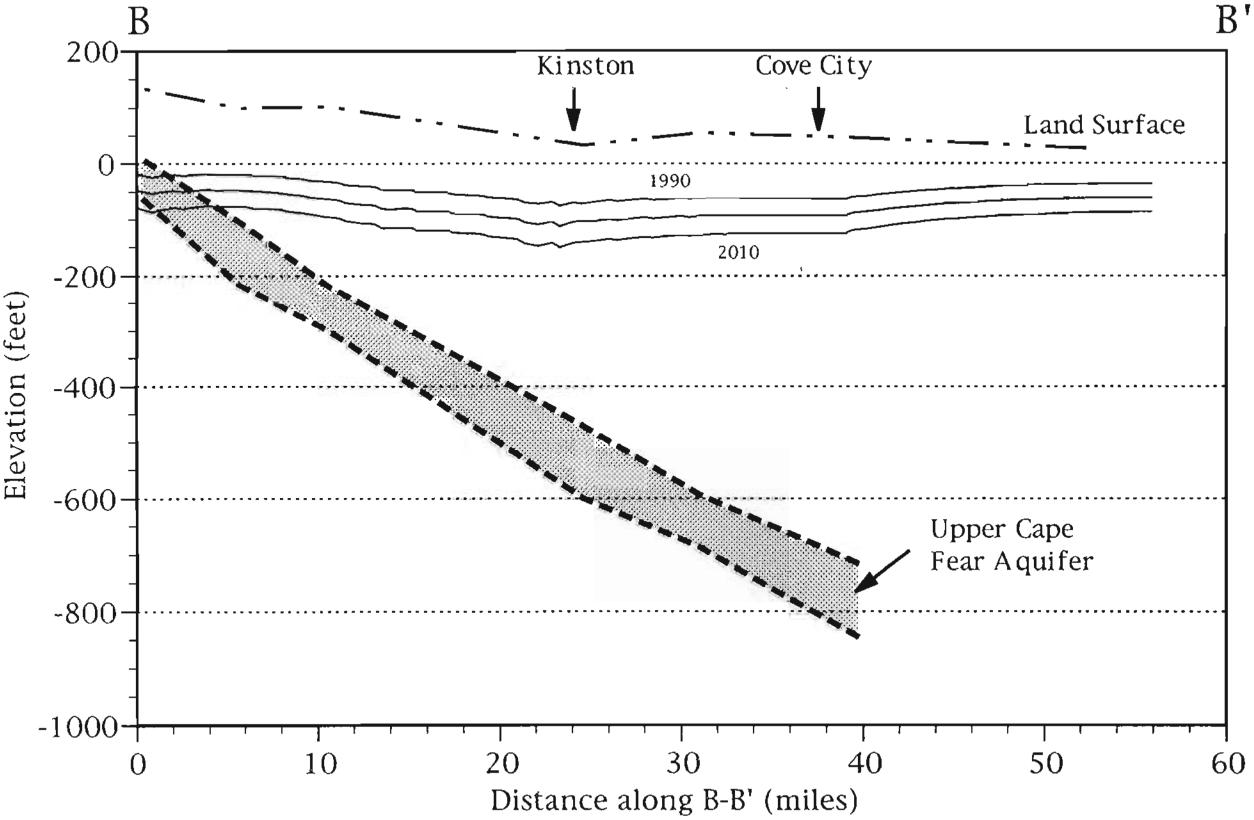


Figure 12. Upper Cape Fear Water Levels with 2% Growth

In Years 1990, 2000, and 2010



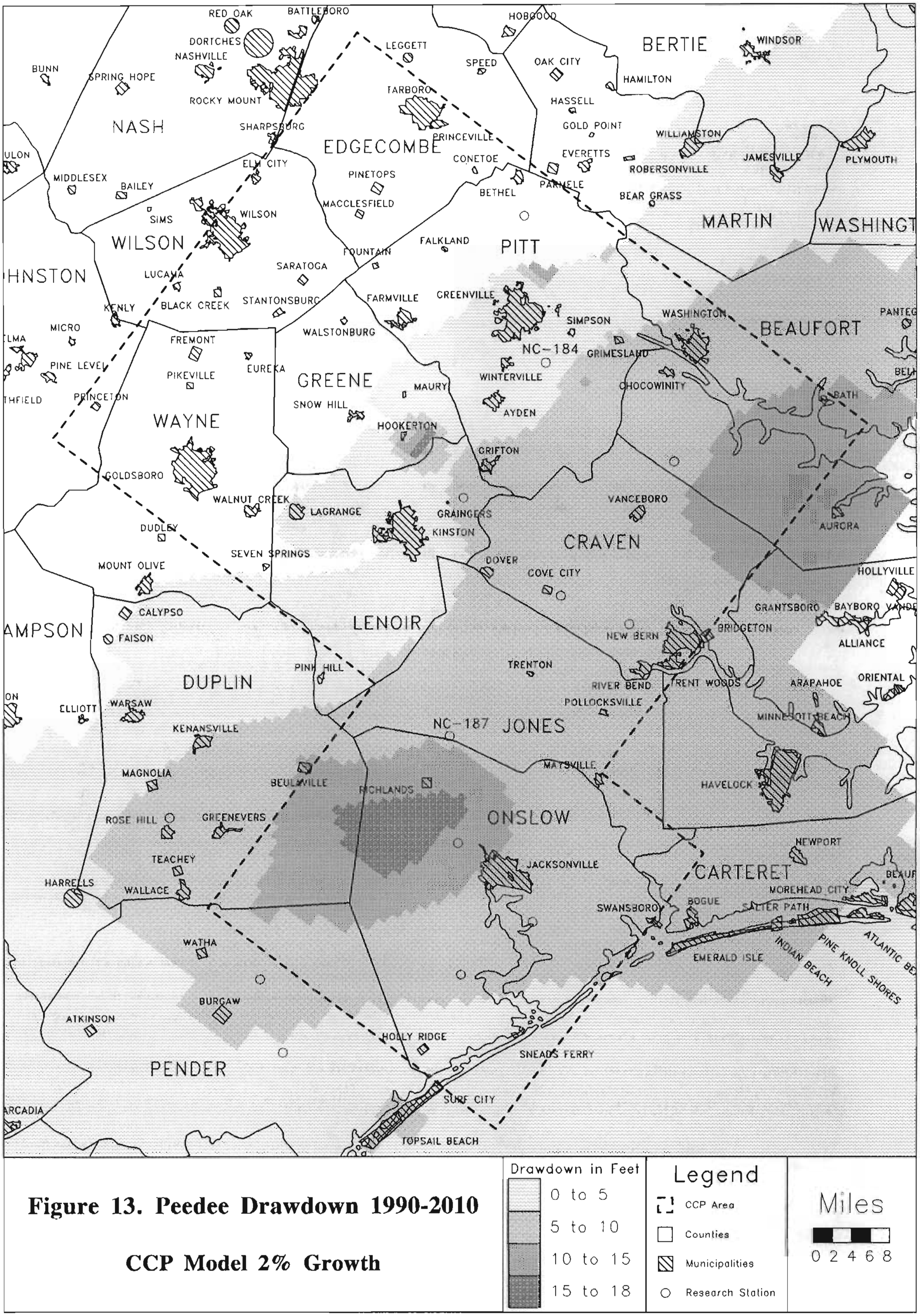


Figure 13. Peedee Drawdown 1990-2010

CCP Model 2% Growth

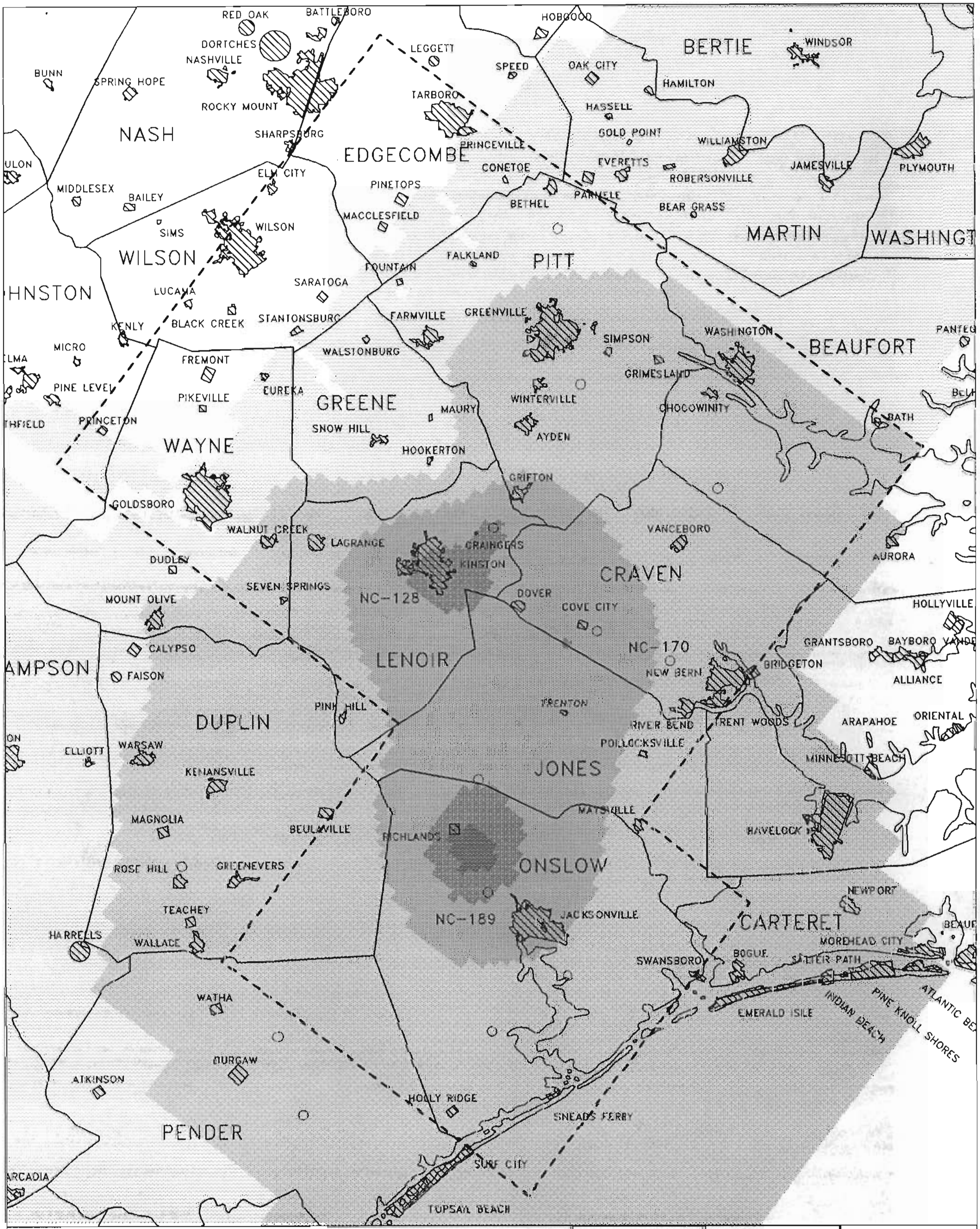


Figure 14. Black Creek Drawdown 1990-2010

CCP Model 2% Growth

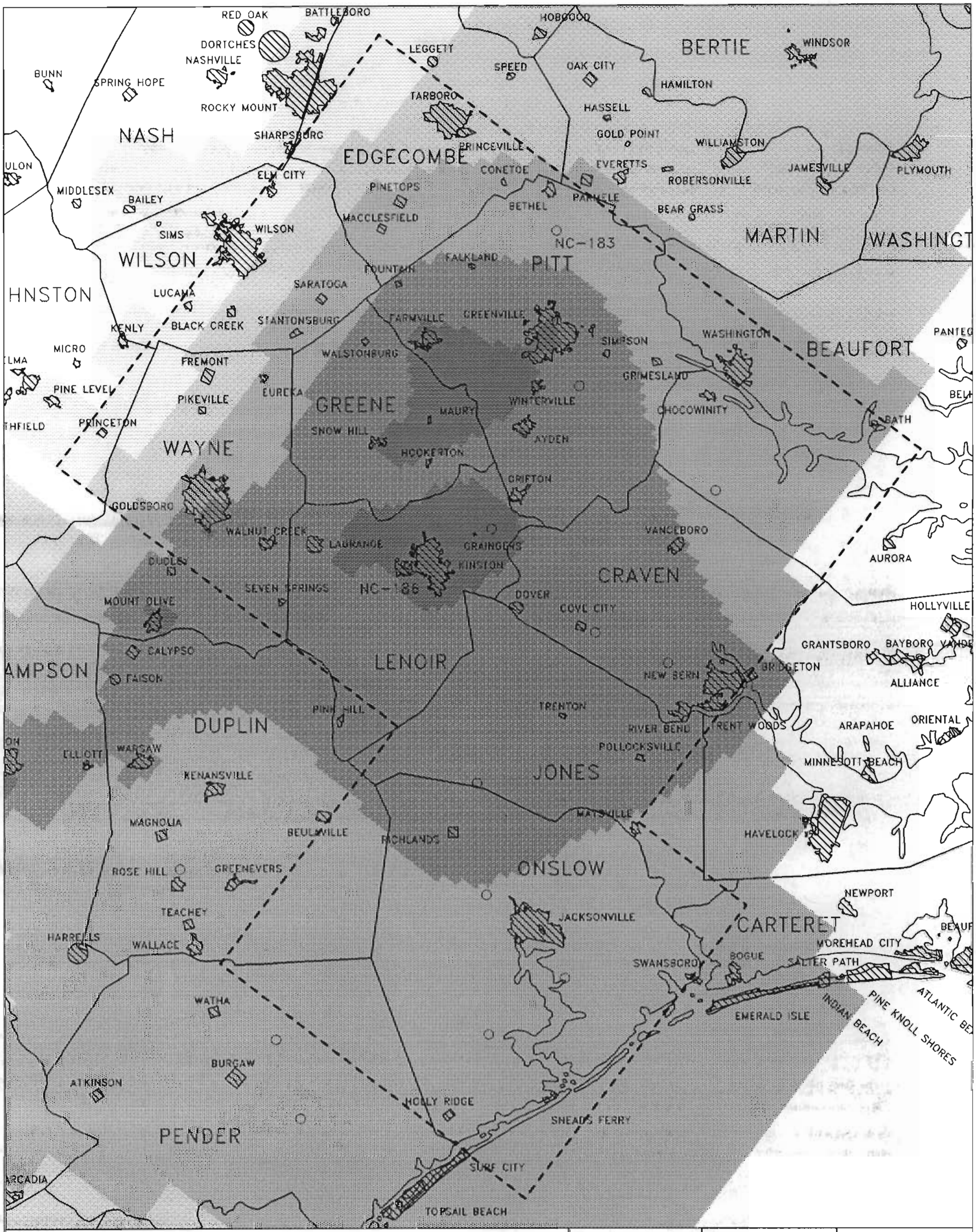


Figure 15. Upper Cape Fear Drawdown 1990-2010

CCP Model 2% Growth

of individual grid cells. Although some cooperators hoped, it is not possible for the model to project well yield or to determine precisely the best depth, spacing, or specific location for a new well.

The previous drawdown maps and cross-sections illustrate several limitations to the model. Major limitations are described below. They are ordered from least to most difficult to overcome.

Model Limitations

1. The model simulates ground water flow through the aquifers without complete information about each aquifer's physical extent. This simplification greatly eases the job of developing the input data sets. Input data defines the modeled area as having ten aquifers, and assigns the relative position of each aquifer with reference to the other aquifers; the model defines layer 1 as being above layer 2, etc. However, the depths and thicknesses of each aquifer are not required. When actual physical boundaries to the aquifers are then compared to model results, as in the previous cross-sections, the hydrogeological parameters used to define ground water flow in a particular aquifer are shown to be in error. This situation is illustrated in figure 8 and corroborated by monitoring well levels from NC-183 (figure 3). According to the simulation, de-watering of the Upper Cape Fear aquifer has been occurring near Farmville since 1990; the water level in the Upper Cape Fear aquifer is below the top of the aquifer. This is known not to be the case. The solution to this limitation is to use more of the aquifer framework information when developing model runs and recalibrate the model in problem areas.

2. The use of a no-flow boundary at the 10,000 mg/l chloride concentration is another simplification of the aquifer system. The USGS used 10,000 mg/l chloride because no ground water users in the CCP area pump near this boundary (Eimers, Lyke, and Brockman, 1990). In the drawdown maps the eastern edge of the modeled area is this no-flow boundary. However, across that interface in several areas (and in all three aquifers) the model shows a difference in head, or as in the drawdown maps, a positive drawdown. If this is truly the case, then the no-flow boundary is not appropriately located; the boundary should be moved eastward away from the stresses to the aquifer system. Because this model boundary is too close to areas of heavy pumping, the model calculates the drawdown as greater than it really is. This exaggeration of drawdown will get larger as the stresses on the aquifer increase.

3. The final, significant weakness of the CCP model, in its use as a management tool, occurs in its inability to simulate saltwater intrusion. It is important to be able to estimate the effects of pumping on the rate of saltwater advancement. Onslow County and Jacksonville water systems are especially susceptible to saltwater contamination of supply wells. If modeling of the saltwater flow using a different ground water flow model proves to be too difficult or costly, then wells should be monitored to track the movement of this threat.

Some of the model's limitations could be overcome with additional effort from DWR and the local cooperators to improve the data bases for hydrogeology and water use. Certainly, more industrial and agricultural ground water users should be included in the model. No-flow boundaries could be adjusted and aquifer depth and thickness defined to increase the accuracy of the model output. Additional research stations might be constructed to verify model input data. It may be possible to transfer the data sets into another ground water flow model capable of simulating both freshwater and saltwater. In this way, saltwater intrusion rates could be estimated.

Model Uses

It may be possible in the future to answer questions about saltwater intrusion and water levels expected from certain growth scenarios with confidence. However, the existing model provides valuable insights to understanding the far reaching effects of pumping from all CCP water systems. At the same time, the model shows incremental changes to depressed ground water levels associated with an individual water system. Information derived from using the model can therefore assist in managing and protecting the ground water resources of the region.

Conclusions

Ground water withdrawals from the Central Coastal Plain aquifers cannot be expanded without limits. The regulating factors include economic and hydrogeological concerns. Future costs of new well construction and pump lowering may put significant pressure on municipal or industrial budgets. The model strongly suggests that the cumulative withdrawals from these aquifers may cause drawdowns of the water levels to the point of harming the aquifer yields through de-watering. Although the possible effects of de-watering of the these aquifers as described earlier is uncertain, evidence from other areas in the United States suggests that de-watering should be avoided. The basis for achieving the most effective management lies with understanding the ground water resource and its limits, and with use of models that simulate the response of that resource to changing withdrawal patterns. Although the CCP model appears to be inaccurate in some areas, it can be improved to be a useful tool to allow proper planning of water resource development.

Recommendations

1. Ground water withdrawals should be planned to maintain the long range productivity of the CCP aquifers by avoiding aquifer de-watering.

2. Water users in the CCP region and the Division of Water Resources should cooperate to collect accurate data and to improve the model to provide a sound basis for regional ground water management and protection.

3. Water users in the CCP region should develop future water supply plans under the provisions of G.S. 143-355(l). These plans should consider available supplies from the Cretaceous aquifers, alternative water supply sources, and water conservation as means to assure adequate water supplies for future economic development.

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Appendix A. Projected Well Pumping (in MGD) by Cooperator Systems for Three Model Runs

Name	Model Run	# of wells	Yield	P1986	P1987	P1988	P1989	P1990	P1991	P1992	P1993	P1994	P1995	P1996	P1997	P1998	P1999	P2000	P2001	P2002	P2003	P2004	P2005	P2006	P2007	P2008	P2009	P2010
AYDEN																												
	Two-percent Growth	7	4.612	0.354	0.406	0.453	0.505	0.516	0.525	0.537	0.546	0.557	0.570	0.579	0.591	0.603	0.617	0.629	0.642	0.656	0.668	0.681	0.694	0.708	0.722	0.735	0.749	0.767
					Stress Period 1 (1987-1990):			0.470		Stress Period 2 (1991-1995):			0.547		Stress Period 3 (1996-2000):			0.604		Stress Period 4 (2001-2005):			0.668		Stress Period 5 (2006-2010):			0.736
	Linear Growth			0.354	0.406	0.453	0.505	0.557	0.604	0.656	0.708	0.755	0.807	0.859	0.906	0.958	1.010	1.057	1.109	1.161	1.208	1.260	1.312	1.359	1.411	1.463	1.510	1.562
					Stress Period 1 (1987-1990):			0.480		Stress Period 2 (1991-1995):			0.706		Stress Period 3 (1996-2000):			0.958		Stress Period 4 (2001-2005):			1.210		Stress Period 5 (2006-2010):			1.461
	No Growth			0.354	0.406	0.453	0.505	0.505	0.505	0.505	0.505	0.505	0.505	0.505	0.505	0.505	0.505	0.505	0.505	0.505	0.505	0.505	0.505	0.505	0.505	0.505	0.505	0.505
					Stress Period 1 (1987-1990):			0.467		Stress Period 2 (1991-1995):			0.505		Stress Period 3 (1996-2000):			0.505		Stress Period 4 (2001-2005):			0.505		Stress Period 5 (2006-2010):			0.505
FARMVILLE																												
	Two-percent Growth	13	5.017	1.641	2.196	2.198	2.405	2.286	2.029	2.071	2.112	2.154	2.199	2.240	2.285	2.331	2.377	2.426	2.473	2.523	2.573	2.626	2.677	2.732	2.785	2.841	2.897	2.956
					Stress Period 1 (1987-1990):			2.271		Stress Period 2 (1991-1995):			2.113		Stress Period 3 (1996-2000):			2.332		Stress Period 4 (2001-2005):			2.574		Stress Period 5 (2006-2010):			2.842
	Linear Growth			1.641	2.196	2.198	2.405	2.336	2.138	2.353	2.411	2.474	2.540	2.603	2.683	2.771	2.860	2.998	3.136	3.272	3.421	3.585	3.748	3.912	4.075	4.238	4.403	4.567
					Stress Period 1 (1987-1990):			2.284		Stress Period 2 (1991-1995):			2.383		Stress Period 3 (1996-2000):			2.783		Stress Period 4 (2001-2005):			3.432		Stress Period 5 (2006-2010):			4.239
	No Growth			1.641	2.196	2.198	2.405	2.278	2.011	2.011	2.011	2.011	2.011	2.011	2.011	2.011	2.011	2.011	2.011	2.011	2.011	2.011	2.011	2.011	2.011	2.011	2.011	2.011
					Stress Period 1 (1987-1990):			2.269		Stress Period 2 (1991-1995):			2.011		Stress Period 3 (1996-2000):			2.011		Stress Period 4 (2001-2005):			2.011		Stress Period 5 (2006-2010):			2.011
GREENE COUNTY																												
	Two-percent Growth	4	0.000	0.103	0.105	0.107	0.109	0.112	0.113	0.117	0.119	0.120	0.123	0.126	0.128	0.130	0.133	0.135	0.138	0.141	0.145	0.148	0.150	0.154	0.156	0.159	0.162	0.165
					Stress Period 1 (1987-1990):			0.108		Stress Period 2 (1991-1995):			0.118		Stress Period 3 (1996-2000):			0.130		Stress Period 4 (2001-2005):			0.144		Stress Period 5 (2006-2010):			0.159
	Linear Growth			0.103	0.133	0.143	0.152	0.161	0.170	0.179	0.189	0.197	0.208	0.217	0.227	0.235	0.244	0.254	0.263	0.272	0.281	0.291	0.300	0.309	0.319	0.328	0.338	0.346
					Stress Period 1 (1987-1990):			0.147		Stress Period 2 (1991-1995):			0.189		Stress Period 3 (1996-2000):			0.235		Stress Period 4 (2001-2005):			0.281		Stress Period 5 (2006-2010):			0.328
	No Growth			0.103	0.103	0.103	0.103	0.103	0.103	0.103	0.103	0.103	0.103	0.103	0.103	0.103	0.103	0.103	0.103	0.103	0.103	0.103	0.103	0.103	0.103	0.103	0.103	0.103
					Stress Period 1 (1987-1990):			0.103		Stress Period 2 (1991-1995):			0.103		Stress Period 3 (1996-2000):			0.103		Stress Period 4 (2001-2005):			0.103		Stress Period 5 (2006-2010):			0.103
GREENVILLE																												
	Two-percent Growth	17	3.492	1.800	1.943	2.089	2.233	2.276	2.322	2.369	2.418	2.465	2.515	2.564	2.617	2.668	2.721	2.775	2.831	2.891	2.945	3.006	3.067	3.129	3.190	3.256	3.318	3.386
					Stress Period 1 (1987-1990):			2.135		Stress Period 2 (1991-1995):			2.418		Stress Period 3 (1996-2000):			2.669		Stress Period 4 (2001-2005):			2.948		Stress Period 5 (2006-2010):			3.256
	Linear Growth			1.800	1.954	2.051	2.146	2.256	2.378	2.496	2.615	2.737	2.857	3.001	3.152	3.297	3.451	3.610	3.768	3.930	4.089	4.245	4.407	4.566	4.724	4.884	5.045	5.201
					Stress Period 1 (1987-1990):			2.102		Stress Period 2 (1991-1995):			2.617		Stress Period 3 (1996-2000):			3.302		Stress Period 4 (2001-2005):			4.088		Stress Period 5 (2006-2010):			4.884
	No Growth			1.800	1.929	2.062	2.191	2.191	2.191	2.191	2.191	2.191	2.191	2.191	2.191	2.191	2.191	2.191	2.191	2.191	2.191	2.191	2.191	2.191	2.191	2.191	2.191	2.191
					Stress Period 1 (1987-1990):			2.093		Stress Period 2 (1991-1995):			2.191		Stress Period 3 (1996-2000):			2.191		Stress Period 4 (2001-2005):			2.191		Stress Period 5 (2006-2010):			2.191

Name	Model Run	# of wells	Yield	P1986	P1987	P1988	P1989	P1990	P1991	P1992	P1993	P1994	P1995	P1996	P1997	P1998	P1999	P2000	P2001	P2002	P2003	P2004	P2005	P2006	P2007	P2008	P2009	P2010
JACKSONVILLE																												
	Two-percent Growth	17	8.640	3.073	2.938	3.110	3.236	3.551	3.922	4.000	4.083	4.163	4.245	4.331	4.415	4.503	4.593	4.687	4.782	4.875	4.975	5.074	5.174	5.279	5.383	5.492	5.602	5.713
					Stress Period 1 (1987-1990):			3.209		Stress Period 2 (1991-1995):			4.083		Stress Period 3 (1996-2000):			4.506		Stress Period 4 (2001-2005):			4.976		Stress Period 5 (2006-2010):			5.494
	Linear Growth			3.073	2.954	3.135	3.268	3.591	3.970	3.620	3.781	3.948	4.120	4.315	4.526	4.739	4.953	5.163	5.379	5.592	5.804	6.017	6.230	6.471	6.729	6.986	7.245	7.501
					Stress Period 1 (1987-1990):			3.237		Stress Period 2 (1991-1995):			3.888		Stress Period 3 (1996-2000):			4.739		Stress Period 4 (2001-2005):			5.804		Stress Period 5 (2006-2010):			6.986
	No Growth			3.073	2.935	3.105	3.228	3.540	3.908	3.908	3.908	3.908	3.908	3.908	3.908	3.908	3.908	3.908	3.908	3.908	3.908	3.908	3.908	3.908	3.908	3.908	3.908	3.908
					Stress Period 1 (1987-1990):			3.202		Stress Period 2 (1991-1995):			3.908		Stress Period 3 (1996-2000):			3.908		Stress Period 4 (2001-2005):			3.908		Stress Period 5 (2006-2010):			3.908
JONES COUNTY																												
	Two-percent Growth	6	2.736	0.446	0.435	0.422	0.411	0.419	0.426	0.435	0.447	0.455	0.463	0.471	0.480	0.492	0.501	0.510	0.522	0.531	0.544	0.553	0.567	0.576	0.589	0.598	0.612	0.621
					Stress Period 1 (1987-1990):			0.422		Stress Period 2 (1991-1995):			0.445		Stress Period 3 (1996-2000):			0.491		Stress Period 4 (2001-2005):			0.543		Stress Period 5 (2006-2010):			0.599
	Linear Growth			0.446	0.435	0.422	0.411	0.400	0.387	0.376	0.365	0.352	0.341	0.330	0.317	0.306	0.295	0.282	0.271	0.260	0.247	0.236	0.225	0.212	0.201	0.190	0.177	0.166
					Stress Period 1 (1987-1990):			0.417		Stress Period 2 (1991-1995):			0.364		Stress Period 3 (1996-2000):			0.306		Stress Period 4 (2001-2005):			0.248		Stress Period 5 (2006-2010):			0.189
	No Growth			0.446	0.435	0.422	0.411	0.411	0.411	0.411	0.411	0.411	0.411	0.411	0.411	0.411	0.411	0.411	0.411	0.411	0.411	0.411	0.411	0.411	0.411	0.411	0.411	0.411
					Stress Period 1 (1987-1990):			0.420		Stress Period 2 (1991-1995):			0.411		Stress Period 3 (1996-2000):			0.411		Stress Period 4 (2001-2005):			0.411		Stress Period 5 (2006-2010):			0.411
KINSTON																												
	Two-percent Growth	18	14.531	4.655	5.010	4.869	4.481	4.457	4.567	4.657	4.750	4.846	4.943	5.042	5.143	5.246	5.351	5.457	5.567	5.680	5.792	5.908	6.028	6.148	6.269	6.395	6.522	6.654
					Stress Period 1 (1987-1990):			4.704		Stress Period 2 (1991-1995):			4.753		Stress Period 3 (1996-2000):			5.248		Stress Period 4 (2001-2005):			5.795		Stress Period 5 (2006-2010):			6.398
	Linear Growth			4.655	5.010	4.869	4.481	4.457	4.289	4.151	4.003	3.865	3.725	3.649	3.622	3.608	3.592	3.577	3.564	3.553	3.561	3.570	3.579	3.589	3.598	3.608	3.622	3.666
					Stress Period 1 (1987-1990):			4.704		Stress Period 2 (1991-1995):			4.007		Stress Period 3 (1996-2000):			3.610		Stress Period 4 (2001-2005):			3.565		Stress Period 5 (2006-2010):			3.617
	No Growth			4.655	5.010	4.869	4.481	4.457	4.567	4.567	4.567	4.567	4.567	4.567	4.567	4.567	4.567	4.567	4.567	4.567	4.567	4.567	4.567	4.567	4.567	4.567	4.567	4.567
					Stress Period 1 (1987-1990):			4.704		Stress Period 2 (1991-1995):			4.567		Stress Period 3 (1996-2000):			4.567		Stress Period 4 (2001-2005):			4.567		Stress Period 5 (2006-2010):			4.567
LA GRANGE																												
	Two-percent Growth	8	4.320	0.419	0.394	0.370	0.479	0.486	0.497	0.507	0.518	0.526	0.540	0.550	0.558	0.572	0.583	0.597	0.604	0.619	0.630	0.644	0.659	0.670	0.684	0.697	0.712	0.724
					Stress Period 1 (1987-1990):			0.432		Stress Period 2 (1991-1995):			0.518		Stress Period 3 (1996-2000):			0.572		Stress Period 4 (2001-2005):			0.631		Stress Period 5 (2006-2010):			0.697
	Linear Growth			0.419	0.398	0.376	0.353	0.331	0.308	0.286	0.263	0.241	0.218	0.196	0.173	0.151	0.128	0.126	0.129	0.132	0.135	0.139	0.142	0.146	0.149	0.153	0.156	0.160
					Stress Period 1 (1987-1990):			0.365		Stress Period 2 (1991-1995):			0.263		Stress Period 3 (1996-2000):			0.155		Stress Period 4 (2001-2005):			0.135		Stress Period 5 (2006-2010):			0.153
	No Growth			0.419	0.393	0.367	0.474	0.474	0.474	0.474	0.474	0.474	0.474	0.474	0.474	0.474	0.474	0.474	0.474	0.474	0.474	0.474	0.474	0.474	0.474	0.474	0.474	0.474
					Stress Period 1 (1987-1990):			0.427		Stress Period 2 (1991-1995):			0.474		Stress Period 3 (1996-2000):			0.474		Stress Period 4 (2001-2005):			0.474		Stress Period 5 (2006-2010):			0.474
NEW BERN																												
	Two-percent Growth	8	10.431	3.609	3.609	3.802	4.100	4.300	3.812	3.889	3.966	4.046	4.126	4.208	4.293	4.379	4.467	4.555	4.647	4.739	4.835	4.931	5.029	5.131	5.232	5.338	5.443	5.553
					Stress Period 1 (1987-1990):			3.953		Stress Period 2 (1991-1995):			3.968		Stress Period 3 (1996-2000):			4.380		Stress Period 4 (2001-2005):			4.836		Stress Period 5 (2006-2010):			5.339
	Linear Growth			3.609	3.609	3.802	4.100	4.300	3.812	4.214	4.312	4.410	4.507	4.606	4.703	4.801	4.899	4.996	5.095	5.193	5.290	5.389	5.486	5.585	5.683	5.780	5.879	5.976
					Stress Period 1 (1987-1990):			3.953		Stress Period 2 (1991-1995):			4.251		Stress Period 3 (1996-2000):			4.801		Stress Period 4 (2001-2005):			5.291		Stress Period 5 (2006-2010):			5.781
	No Growth			3.609	3.609	3.802	4.100	4.300	3.812	3.812	3.812	3.812	3.812	3.812	3.812	3.812	3.812	3.812	3.812	3.812	3.812	3.812	3.812	3.812	3.812	3.812	3.812	3.812
					Stress Period 1 (1987-1990):			3.953		Stress Period 2 (1991-1995):			3.812		Stress Period 3 (1996-2000):			3.812		Stress Period 4 (2001-2005):			3.812		Stress Period 5 (2006-2010):			3.812

Name	Model Run	# of wells	Yield	P1986	P1987	P1988	P1989	P1990	P1991	P1992	P1993	P1994	P1995	P1996	P1997	P1998	P1999	P2000	P2001	P2002	P2003	P2004	P2005	P2006	P2007	P2008	P2009	P2010
NORTH LENOIR																												
	Two-percent Growth	11	3.026	0.600	0.613	0.622	.0.635	0.648	0.663	0.673	0.686	0.700	0.715	0.732	0.746	0.757	0.772	0.787	0.805	0.820	0.837	0.855	0.870	0.887	0.906	0.923	0.942	0.964
					Stress Period 1 (1987-1990):			0.630		Stress Period 2 (1991-1995):			0.687		Stress Period 3 (1996-2000):			0.759		Stress Period 4 (2001-2005):			0.837		Stress Period 5 (2006-2010):			0.924
	Linear Growth			0.600	0.613	0.622	0.635	0.648	0.657	0.670	0.683	0.692	0.705	0.718	0.727	0.740	0.753	0.762	0.775	0.788	0.797	0.810	0.823	0.832	0.845	0.858	0.867	0.880
					Stress Period 1 (1987-1990):			0.630		Stress Period 2 (1991-1995):			0.681		Stress Period 3 (1996-2000):			0.740		Stress Period 4 (2001-2005):			0.799		Stress Period 5 (2006-2010):			0.856
	No Growth			0.600	0.613	0.622	0.635	0.635	0.635	0.635	0.635	0.635	0.635	0.635	0.635	0.635	0.635	0.635	0.635	0.635	0.635	0.635	0.635	0.635	0.635	0.635	0.635	0.635
					Stress Period 1 (1987-1990):			0.626		Stress Period 2 (1991-1995):			0.635		Stress Period 3 (1996-2000):			0.635		Stress Period 4 (2001-2005):			0.635		Stress Period 5 (2006-2010):			0.635
ONSLOW COUNTY																												
	Two-percent Growth	13	11.725	3.453	3.715	3.843	4.202	4.317	4.293	4.380	4.467	4.557	4.647	4.739	4.833	4.931	5.031	5.133	5.234	5.337	5.444	5.554	5.663	5.776	5.893	6.011	6.130	6.253
					Stress Period 1 (1987-1990):			4.019		Stress Period 2 (1991-1995):			4.469		Stress Period 3 (1996-2000):			4.933		Stress Period 4 (2001-2005):			5.446		Stress Period 5 (2006-2010):			6.013
	Linear Growth			3.453	3.715	3.843	4.202	4.317	4.293	4.462	4.589	4.858	5.203	5.549	5.893	6.254	6.661	7.068	7.475	7.882	8.288	8.694	9.102	9.509	9.914	10.322	10.727	11.134
					Stress Period 1 (1987-1990):			4.019		Stress Period 2 (1991-1995):			4.681		Stress Period 3 (1996-2000):			6.285		Stress Period 4 (2001-2005):			8.288		Stress Period 5 (2006-2010):			10.321
	No Growth			3.453	3.715	3.843	4.202	4.317	4.293	4.293	4.293	4.293	4.293	4.293	4.293	4.293	4.293	4.293	4.293	4.293	4.293	4.293	4.293	4.293	4.293	4.293	4.293	4.293
					Stress Period 1 (1987-1990):			4.019		Stress Period 2 (1991-1995):			4.293		Stress Period 3 (1996-2000):			4.293		Stress Period 4 (2001-2005):			4.293		Stress Period 5 (2006-2010):			4.293
PINETOPS																												
	Two-percent Growth	4	0.000	0.214	0.219	0.222	0.227	0.232	0.236	0.241	0.247	0.251	0.256	0.261	0.267	0.271	0.277	0.282	0.288	0.295	0.299	0.305	0.312	0.318	0.325	0.331	0.338	0.345
					Stress Period 1 (1987-1990):			0.225		Stress Period 2 (1991-1995):			0.246		Stress Period 3 (1996-2000):			0.272		Stress Period 4 (2001-2005):			0.300		Stress Period 5 (2006-2010):			0.331
	Linear Growth			0.214	0.197	0.204	0.210	0.216	0.221	0.227	0.233	0.239	0.246	0.251	0.257	0.263	0.270	0.275	0.281	0.287	0.293	0.299	0.305	0.312	0.318	0.322	0.328	0.335
					Stress Period 1 (1987-1990):			0.207		Stress Period 2 (1991-1995):			0.233		Stress Period 3 (1996-2000):			0.263		Stress Period 4 (2001-2005):			0.293		Stress Period 5 (2006-2010):			0.323
	No Growth			0.214	0.214	0.214	0.214	0.214	0.214	0.214	0.214	0.214	0.214	0.214	0.214	0.214	0.214	0.214	0.214	0.214	0.214	0.214	0.214	0.214	0.214	0.214	0.214	0.214
					Stress Period 1 (1987-1990):			0.214		Stress Period 2 (1991-1995):			0.214		Stress Period 3 (1996-2000):			0.214		Stress Period 4 (2001-2005):			0.214		Stress Period 5 (2006-2010):			0.214
SNOW HILL																												
	Two-percent Growth	5	2.016	1.055	0.880	0.706	0.531	0.541	0.553	0.564	0.574	0.586	0.598	0.610	0.621	0.634	0.646	0.660	0.674	0.686	0.701	0.715	0.729	0.744	0.758	0.774	0.789	0.805
					Stress Period 1 (1987-1990):			0.664		Stress Period 2 (1991-1995):			0.575		Stress Period 3 (1996-2000):			0.634		Stress Period 4 (2001-2005):			0.701		Stress Period 5 (2006-2010):			0.774
	Linear Growth			1.055	0.880	0.706	0.531	0.356	0.182	0.007	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
					Stress Period 1 (1987-1990):			0.618		Stress Period 2 (1991-1995):			0.038		Stress Period 3 (1996-2000):			0.000		Stress Period 4 (2001-2005):			0.000		Stress Period 5 (2006-2010):			0.000
	No Growth			1.055	0.880	0.706	0.531	0.531	0.531	0.531	0.531	0.531	0.531	0.531	0.531	0.531	0.531	0.531	0.531	0.531	0.531	0.531	0.531	0.531	0.531	0.531	0.531	0.531
					Stress Period 1 (1987-1990):			0.662		Stress Period 2 (1991-1995):			0.531		Stress Period 3 (1996-2000):			0.531		Stress Period 4 (2001-2005):			0.531		Stress Period 5 (2006-2010):			0.531
STANTONSBURG																												
	Two-percent Growth	2	0.000	0.123	0.126	0.128	0.131	0.133	0.136	0.139	0.141	0.144	0.147	0.150	0.153	0.156	0.160	0.163	0.166	0.169	0.172	0.176	0.179	0.182	0.187	0.190	0.194	0.198
					Stress Period 1 (1987-1990):			0.130		Stress Period 2 (1991-1995):			0.141		Stress Period 3 (1996-2000):			0.156		Stress Period 4 (2001-2005):			0.172		Stress Period 5 (2006-2010):			0.190
	Linear Growth			0.123	0.132	0.138	0.145	0.151	0.157	0.163	0.170	0.176	0.182	0.188	0.194	0.200	0.206	0.213	0.219	0.225	0.231	0.238	0.244	0.250	0.255	0.262	0.268	0.274
					Stress Period 1 (1987-1990):			0.141		Stress Period 2 (1991-1995):			0.170		Stress Period 3 (1996-2000):			0.200		Stress Period 4 (2001-2005):			0.231		Stress Period 5 (2006-2010):			0.262
	No Growth			0.123	0.123	0.123	0.123	0.123	0.123	0.123	0.123	0.123	0.123	0.123	0.123	0.123	0.123	0.123	0.123	0.123	0.123	0.123	0.123	0.123	0.123	0.123	0.123	0.123
					Stress Period 1 (1987-1990):			0.123		Stress Period 2 (1991-1995):			0.123		Stress Period 3 (1996-2000):			0.123		Stress Period 4 (2001-2005):			0.123		Stress Period 5 (2006-2010):			0.123

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