What are the Experts Saying About Effects of Climate Change on Rainfall and Streamflow in the Southeast?

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This document is a review of what three expert panels have observed about potential consequence of global climate change on water resources of the southeastern United States. Possibly the most important and predictable water related impacts of climate change on the Southeast is rising sea level. This review is focused on the less well understood impacts on rainfall and streamflow on which much of our water supplies for urban areas, industry, agriculture, ecosystems, and energy production are dependent. An assessment of these impacts might be more useful if they could be scaled to politically-defined areas such as the State of North Carolina, but the spatial resolutions of currently available models of global change on which the predictions are based are not that small.

There is now a class of more than 30 general circulation models (GCM's) that simulate global changes in response to increased emissions of so-called greenhouse gases. Some involve the coupling of atmospheric and climate process and are referred to as AGCM's or ACGCM's. Others specifically incorporate atmospheric-oceanic interactions and are referred to as AOCGM's. In all cases, models of climate change are based on simultaneous simulation of heat and moisture balances over successive time intervals over a large number of regions defined by spatial grids cells. Even to cover the earth with fairly large regions requires a very large number of grid cells. Some efforts have been made to use predicted regional changes in temperature and precipitation to estimate effects on streamflows, soil moisture and groundwater in smaller river basins and aquifers. Such efforts may reflect differences of topography, soils, geology, and land uses within a region, but estimated impacts are still heavily dependent on predicted changes in climate at the regional scale.

Three primary documents are included in this review. The first and most recent is a 2007 report of Working Group I "The Physical Science Basis" for the 2007 report on climate change by the Intergovernmental Panel on Climate Change (IPCC). IPCC was established by the World Meteorological Organization and the United Nations Environmental Program. Its charge is "… to assess scientific, technical and socio-economic information relevant for the understanding of climate change, its potential impacts and options for adaptation and mitigation." The report of Working Group I will be incorporated in IPCC's Fourth Assessment Report "Climate Change 2007". That report describes the range of predicted precipitation patterns from 21 different GCM's.

A second document reviewed here, edited by Rosenberg and Edmonds (2005), was produced by the Joint Global Change Research Institute of Pacific Northwest National Laboratory (PNNL). That report covered two models selected to show the widest range of projections of future climates over the continental United States. Results of those models are then downscaled and interpolated to conform to boundaries of 18 water resource regions as delineated by the United States Water Resources Council. Changes in temperature and precipitation for those regions are then routed through a watershed model to estimate effects on water streamflow.

The third document referenced in this report is one prepared by the Water Sector Assessment Team (WSAT) of the National Assessment Synthesis Team (NAST). NAST is an advisory committee chartered under the Federal Advisory Committee Act. Its report was prepared for the U.S. Global Change Research Program and delivered to the President and Congress in November 2000 for their consideration. That effort used results of two other general circulation models. Despite stated reservations about the accuracy and spatial resolution of available models, they reported projected changes in precipitation for six broadly defined regions that cover the coterminous United States, one of which is the Southeast. The Southeast Regional Assessment Team, a component of NAST, used results of the WAST assessment to examine effects of predicted temperature and precipitation changes on selected hydrologic units (HU's or watersheds) to examine spatial variations of impacts within the Southeast and variations between wet (December-May) and dry seasons (June-November) in the region.

Working Group I 2007

The 2007 report of IPCC's Working Group I includes area-averaged temperature and precipitation changes from a coordinated set of 21 climate model simulations. Baseline mean temperature and precipitation responses were averaged for each model over all available realizations of the 1980 to 1999 period for each region of the models. Similar means for each model were computed for projected levels over the 2080 to 2099 period using a consistent set of projected greenhouse gas emissions. Changes over 2080-2099 from baseline conditions in the 1980-1999 period were computed as percentages of baselines. Results for the 21 models were ranked, and the minimum, maximum, median (50%), and 25 and 75% quartile values among the 21 models were shown for each region.

As shown in Figure 1, the Southeast lies between latitudes 25^0N and 40^0N and between longitudes 75^0W and 95^0W. Two grid cells in the Working Group I report cover that area. One, referred to as ENA, covers a grid bounded on the west and east by 85^0W and 50^0W, respectively, and on the south and north by 25^0N and 50^0N, respectively. The second, referred to as CNA, covers an area bounded on the west and east by 103^0W 85^0W, respectively, and on the south and north by 30^0N and 50^0N, respectively. Predicted changes in precipitation for the two areas from 21 GCM's are given in Table 1. Results from the 21 models were rank-ordered, and the minimum, maximum, 25^{th}, 50, and 75^{th} percentiles of those results are reported.

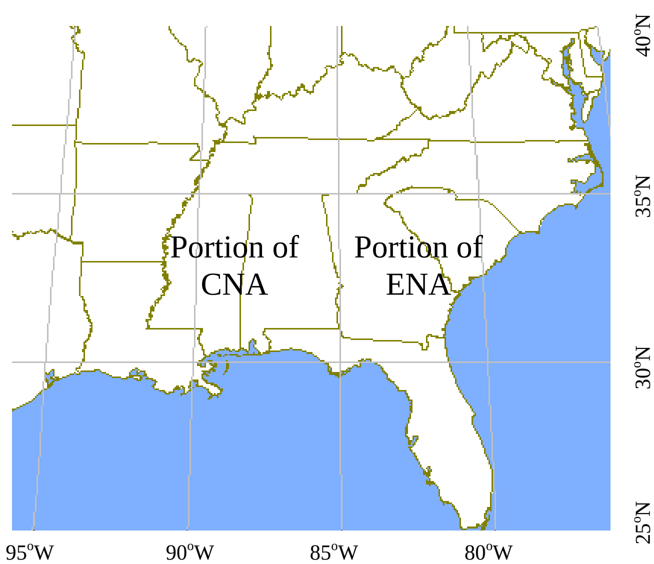

Figure 1. IPCC Working Group I CAN and ENA Regions

It is clear from Table 1 that in the CNA region, predictions for the 21 models are about equally weighted between wetter and drier climates ranging from –16 to +15 percent changes on an annual basis. Seasonal predictions are also about equally weighted between wetter and drier climates. For Region ENA the predictions are more heavily skewed toward a wetter climate, but some models are showing little to no change in precipitation.

Table 1. Statistics of Percent Change in Precipitation for for 21 Climate Models as Computed by Working Group I of IPCC

ENA Region

Period	Min	25%	50%	75%	Max
Annual	-3	5	7	10	15
Dec-Feb	2	9	11	19	28
Mar-May	-4	7	12	16	23
June-Aug	-17	-3	1	6	13
Sept-Nov	-9	5	7	10	15

CAN Region

Period	Min	25%	50%	75%	Max
Annual	-16	-3	3	7	15
Dec-Feb	-18	0	5	8	14
Mar-May	-17	2	7	12	17
June-Aug	-31	-15	-3	4	20
Sept-Nov	-17	-4	4	11	24

The range of outcomes from the various models reviewed by the Working Group suggest that predicting even the direction of change in precipitation in the Southeast is subject to considerable uncertainty. Predictions for the period June-August are especially subject to large uncertainties.

It is noteworthy what the Working Group had to say about changes in precipitation in other parts of North America, namely that "Annual mean precipitation is very likely to increase in Canada and the northeast USA, and likely to decrease in the southwest USA." The mixed outcomes of predictions for the Southeast led the Working Group to remain silent about this region.

The Pacific Northwest National Laboratory Report

The second set of results reviewed in this document is reported by Rosenberg and Edwards (2005). They selected a model from the Australian Bureau of Meteorology Research Center (BMRC) to represent the warmer-drier end of the climate change spectrum and a model developed by the University of Illinois Urbana-Champaign (UIUC) to represent the less warm-wetter end of the spectrum. A variation on the UIUC model that accounted for sulfate concentrations in the atmosphere was also used, but it added little to the purpose of this discussion. Baseline estimates of climate were derived from a historic climate data series covering the period 1960 to 1969. Projected changes in regional climates were made under two levels of global temperature increases and two global levels of carbon dioxide. That is four scenarios for each of the two models. Global temperature increases were set at 1°C and 2.5 °C; global carbon dioxide levels were set at 365 parts per million by volume (ppmv) and 560 ppmv. Results of the two models were down-scaled to predict temperature and precipitation changes for each of 18 water resource regions in the coterminous United States.

Average daily temperature changes for each season for the South Atlantic-Gulf water resource region for each of the two global temperature scenarios are given in Table 2. Corresponding changes in precipitation are also shown in Table 2.

Table 2. Changes in Temperature and Precipitation for the South Atlantic-Gulf Region As Predicted by Two GCM's for Selected Global Temperature Increases

	1°C Global Increase				2.5°C Global Increase			
Model	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall
	Temperature Change, °C							
BMRC	1.14	1.21	1.21	1.05	2.87	3.03	3.03	2.64
UIUC	0.66	0.83	0.95	1.04	1.64	2.09	2.37	2.58
	Precipitation Change, percent							
BMRC	-10	-6	-18	-4	-25	-15	-45	-11
UIUC	0	-14	7	28	0	-35	18	71

Thomson, et al. (2005) used outcomes of these scenarios to predict changes in water yield for each of the 18 major water resource regions. Water yield is defined as the sum of surface runoff, lateral flow from the soil profile, and groundwater flow from shallow aquifers. The Southeastern U.S. is covered in the most part by three of those regions, namely the South Atlantic-Gulf, Tennessee, and Lower Mississippi. Water yield was estimated using the Hydrologic Unit Model of the United States (HUMUS), a GIS-based model that provides inputs to the Soil and Water Assessment Tool (SWAT), a hydrologic model that accounts for precipitation inputs, surface runoff, evapotranspiration and the flux and storage of water in soils and groundwater aquifers. Predicted temperatures and precipitation for each of four scenarios were used to drive the SWAT model. Results of those simulations are shown in Table 3.

Table 3. Changes in Water Yield from Baseline Conditions for Southeastern Water Resource Regions for Each of Four Scenarios Using Precipitation and Temperatures as Predicted by the BMRC and UIUC Models

	South Atlantic-Gulf		Tennessee		Lower Mississippi	
Scenario	BMRC	UIUC	BMRC	UIUC	BMRC	UIUC
+1°C/365 ppmv CO_2	-5.9	1.8	-5.1	3.5	-9.1	3.4
+1°C/560 ppmv CO_2	-2.8	4.9	-3.1	5.3	-4.6	8.0
+2.5°C/365 ppmv CO_2	-15.0	4.3	-13.6	3.3	-22.6	13.6
+2.5°C/560 ppmv CO_2	-12.1	7.4	-11.6	9.6	-18.2	13.7

These results represent predictions based on only two GCM's that were purposefully chosen to represent ends of the spectrum. They show again that predicting precipitation and water yield in the Southeast is subject to considerable uncertainty. Even the direction of change is subject to uncertainty, let alone the magnitude of the change in either direction.

National Assessment Synthesis Team

The third set of results covered in this report was prepared in 2000 by WAST for the National Assessment of the Consequences of the Potential Consequences of Climate Change and Variability for the U.S. Global Change Research Program. The National Assessment chose two GCM's, the Canadian Global Coupled Model (CGCM) and the British Hadley Center Coupled Model (Version 2), referred to as the HadCM2 model. Both of these models were based on business-as-usual scenarios that assumed carbon dioxide would increase at the rate of one percent each year and that sulfur emissions would double by 2100.

WAST examined potential consequences for the coterminous United States and six broadly defined geographical regions. Even though WAST expressed reservations about the accuracy and spatial resolution of currently available GCM's, they reported predicted percent changes in annual precipitation for the years 2030 and 2095. Table 4 shows the results for 2095.

Table 4. Percent Changes in Annual Mean Precipitation for the Canadian and Hadley Climate Models for 2095

	CGCM	HadCM2
Northwest	31	13
Southwest/California/Rockies	67	27
Great Plains	13	16
Great Lakes/Midwest	20	27
Southeast	-13	22
Northeast	0	24
United States	17	23

Annual average precipitation projections by HadCM2 show the Southeast becoming wetter, a 22 percent increase by 2095. By contrast CGCM shows the Southeast becoming drier, a 13 percent reduction by 2095. Only in the Southeast was there a difference in the direction of change of precipitation in 2095. While there are substantial differences in absolute values of change between the two models for some of the regions, only in the Southeast did one model predict a drier future and the other a wetter future.

The Southeast Regional Assessment Team (2002), a component of the National Assessment, used a combination of HadCM2 projections and SWAT to investigate potential spatial variations within the Southeast and variations between seasons. Temperature and precipitation projections for future conditions were based on HadCM2. Those results were used to drive SWAT to estimate changes in streamflow for selected hydrologic units (HUs) that were chosen to represent a range of watersheds in the Southeast. Only directions of change in streamflow (wetter, drier, or no change) were reported. Results for the decade of the 2090's are shown in Figure 2.

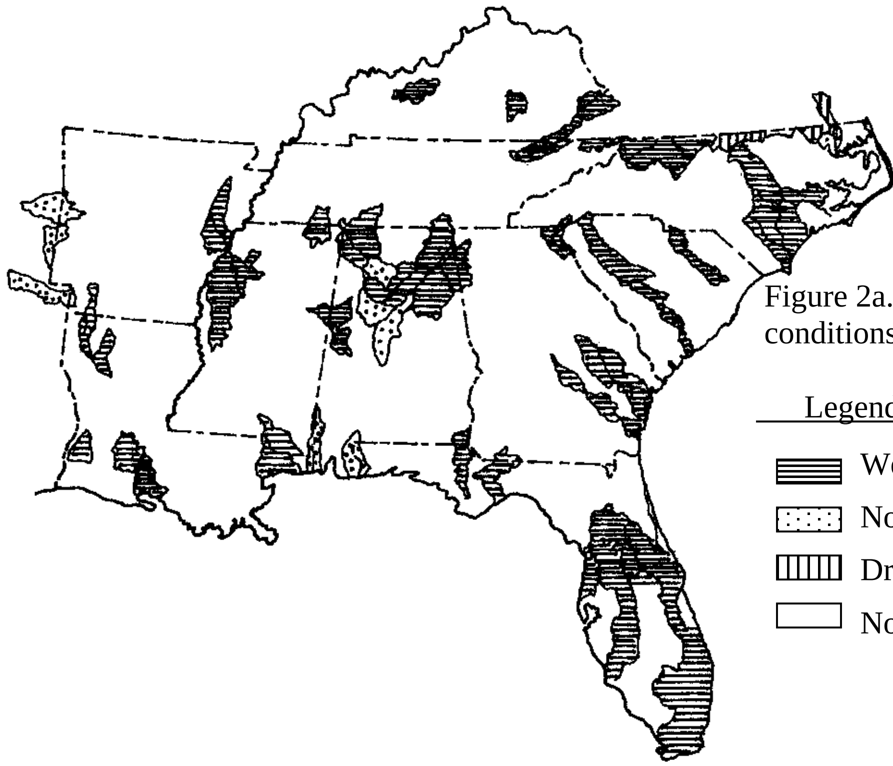

Figure 2a. Future streamflow conditions for the 2090s dry season

Legend

- Wetter
- No Change
- Drier
- Not modeled

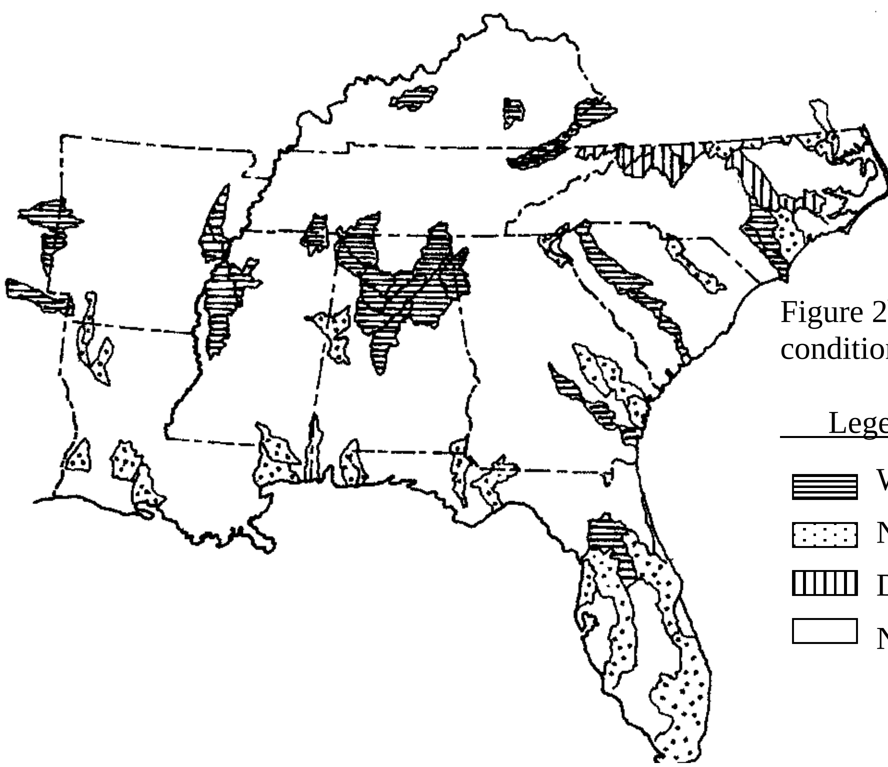

Figure 2b. Future streamflow conditions for the 2090s wet season

Legend

- Wetter
- No Change
- Drier
- Not modeled

Figure 2a shows changes for the dry season and Figure 2b shows changes for the wet season. There is only slight spatial variation in the direction of change during the dry season. Most of the area is shown as getting wetter. Only a few HUs in the northeastern portion of North Carolina were projected to be drier during the dry season. Figure 2b shows much more spatial variation during the wet season. Differences in the direction of change can be noted by comparing the two figures. South Florida is shown to be wetter during the dry season with no change during the wet season. Portions of eastern North Carolina are shown to be wetter during the dry season and drier during the wet season. It should be noted that these findings are limited to the use of a single GCM. Other models could show very different results.

Conclusions

It is clear from the several reports covered in this brief review that predicting water resource implications in the Southeast is subject to considerable uncertainty. That general statement could be made about other regions of the United States, but, if judgments by the Working Group of IPCC are accepted, it is more applicable to the Southeast. The Working Group made relatively strong statements about changes in precipitation in other parts of the country, but the evidence about precipitation change in the Southeast is weak. Medians of the predictions from 21 general circulation models indicate that during December-May, precipitation (mostly rainfall) would increase relative to the 1980-2000 baselines. During June-August there would be little change, and during September-November there would be an increase. However, several of the models show substantial reductions in precipitation with the largest impacts being felt during the June-August time period.

Analyses by the Pacific Northwest National Laboratory used only two GCM's to show the range of potential impacts on water resources. Those two models show clearly the range of conclusions that might be drawn depending on which model is used for analysis. They would lead to very different conclusions about future patterns of precipitation and streamflow. However, because they chose to focus on the ends of a possible spectrum of predictions, there is little in that report to suggest how much confidence one might place on the results.

WAST took a similar approach to the PNNL group, using two GCM's and estimating effects of temperature and precipitation changes on streamflow. Results of that analysis are generally consistent with those of IPCC's Working Group I in the sense that there is less confidence in the direction of change in the Southeast than in other parts of the country.

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