

**CLIMATE CHANGE ASSESSMENT FOR URBAN WATER
RESOURCES AVAILABILITY**

A Senior Scholars Thesis

by

RAMIRO MARTINEZ

Submitted to the Office of Undergraduate Research
Texas A&M University
in partial fulfillment of the requirements for the designation as

UNDERGRADUATE RESEARCH SCHOLAR

April 2011

Major: Civil Engineering

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Approved by:

Research Advisor:
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ABSTRACT

Climate Change Assessment for Urban Water Resources Availability. (April 2011)

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In the past two decades, scientific evidence has predicted a significant change in the earth's climatic atmosphere. Although there are many studies that demonstrate changes in the atmospheric temperatures, there are few studies that show how climate change will influence in the availability of local water resource systems. Water resources are especially vulnerable to dramatic changes in temperature and precipitation, and significant impacts may be experienced by both human and ecosystems. The objective of this study is to develop a methodology to investigate the impacts of climate change on water resources. This is accomplished through coupling General Circulation Models (GCMs) with a hydrologic model and simulating hydrologic runoff for projected rainfall scenarios. Without an understanding of the potential climate change and the consequences for the timing and volumes of streamflows, current water management practices may not be robust enough to address the challenges and adapt to climate changes. This study demonstrates a methodology for exploring future water supply scenarios to advise water management and policy development. The modeling

methodology is demonstrated for an illustrative case study for the municipality of Arlington, TX.

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I would also like to give special thanks to my family, my friends, and especially my girlfriend in supporting me throughout this whole research experience. They were there to pick me up late at night when everyone else was asleep.

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NOMENCLATURE

| | |
|------|---|
| GCM | General Circulation Model |
| GIS | Geographic Information System |
| IPCC | Intergovernmental Panel on Climate Change |
| NACC | National Assessment of Climate Change |
| SWAT | Soil and Water Assessment Tool |
| TRWD | Tarrant Regional Water District |
| WMO | World Meteorological Organization |

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CHAPTER I

INTRODUCTION

Scientific studies in recent years have predicted an imminent and significant change in the earth's climatic atmosphere. The Intergovernmental Panel on Climate Change (IPCC) has noticeably depicted that temperatures and sea levels will continue to rise even if green-house gas emissions are kept at levels emitted in 2000 (IPCC 2000).

Although there are many studies that make this evident, there are fewer studies that show how these changes will impact local water resource systems. Without a better understanding of the consequences of climate change, managers of water resources systems may not be able to generate reasonable strategies to manage the available water supply and adapt to changing climate conditions. In addition, further development of urban areas, accompanied by a significant amount of population growth and construction development, alters the hydrologic flows and increases demands for water, which may compound the consequences of climate change. There is an indispensable need to identify the impacts that climate change will have on urban water resources in order to avoid water shortages in the future.

Within the past two decades, numerous scientists have directed their studies to

This thesis follows the style of *Journal of Water Resources Planning and Management*.

investigate the specific impacts that the changing climate has on our water resources. The Intergovernmental Panel on Climate Change (IPCC) was jointly established by the World Meteorological Organization (WMO) and the United Nations in 1988 to assess scientific information related to climate change issues and, based on their findings, to formulate and propose response strategies. Although there is not a complete consensus in the scientific community whether global warming is caused by human greenhouse emissions, changes in climate, including precipitation and rainfall patterns, are imminent. The increased concentrations of greenhouse gases in the atmosphere, such as carbon dioxide and methane, have increased temperature on Earth in the last century (Houghton et al. 1997). Literature shows that the Earth's temperature has increased by 0.3 to 0.6 ° C over the last 100 years, and predictions indicate that the temperature may increase from 1 to 3.5 ° C by 2100 (Lane and Kirshen 1999).

These increases in temperatures cause a considerable impact on water resources around the world, as climate change affects the amount of precipitation and, consequently, streamflow. Over time potential evapotranspiration increases, and as a result, smaller volumes of water will reach surface water bodies. The precipitation regime is expected to change, significantly increasing the severity of drought in some areas and increasing the frequency and magnitude of storms in other regions. The first U.S. National Assessment of Climate Change (NACC) noted that while the global average precipitation will increase, the regional impacts are unknown and difficult to predict

(Mimikou et al., 2000). This calls for a method which can be applied for water resources systems in different regions around the world.

Climate change predictions are created by General Circulation Models (GCMs), designed to represent the main physic processes of the atmosphere and oceans. Many climatic institutes around the world have developed GCMs to study future climate conditions, generating times series of future temperature, precipitation, evaporation and other climatic data. Common water availability studies use hydrologic models that transform meteorological data, such as precipitation, to stream flows. Coupling GCM variables with hydrologic models is a powerful methodology to study the impact of climate change on a watershed. Muttiah and Wurbs (2002) have applied this methodology to model the impacts of climate change on water supply reliabilities of the San Jacinto River Basin in Texas.

Large metropolitan areas may suffer a great risk of water shortages in the future due to climate change. In many regions of the US, urban water systems are already stressed due to the rapid increase of water demands caused by population growth. One of these regions is the Dallas-Fort Worth area, which in 2009 had a population of approximately 6.5 million inhabitants. The cities of Fort Worth and Arlington are supplied by the Tarrant Regional Water District (TRWD), which is one of the largest raw water suppliers in Texas. The TRWD system is composed of a set of reservoirs, channels and pipelines. One important reservoir in this system is Lake Arlington, which provides

water for a majority of the city of Arlington through two water treatment plants. Lake Arlington has a storage capacity of approximately 45,000 acre-feet and receives water drained from a watershed of 143 square miles and from inter-basins transfers, which are pumped into Lake Arlington from a distant reservoir, Cedar Creek Lake.

This study aims to assess the impact of climate change on the water resources availability for the city of Arlington and to provide information and guidance that could be used for the development of future water management plans. The objective of the research is to use projected time series of temperature and precipitation as generated by GCMs to generate forecasted streamflow time series, providing data for assessing the consequences of climate change on water availability. The modeling framework is constructed by coupling multiple GCMs and a hydrological model of Lake Arlington.

CHAPTER II

METHODOLOGY

The methodology of the present study consists of simulating a watershed using a hydrologic model with rainfall and temperature estimates generated by GCMs to obtain future streamflow time-series and assess water availability. Throughout the world, a multitude of climate models have been produced to simulate the earth's atmosphere. The present study is focusing on four particular GCMs. By incorporating multiple climate models, the over/underestimation of a certain model can balance out the overall hydrology. This consequently will create a range and mean of possible future hydrologic patterns.

Four GCMs were selected: CSIRO-Mk3.0, IPSL-CM4, INCAR-CCSM3, and UKMO-HadGCM3. The original projections are from the World Climate Research Programme's (WCRP's) Coupled Model Intercomparison Project phase 3 (CMIP3) multi-model dataset, which was referenced in the Intergovernmental Panel on Climate Change Fourth Assessment Report (Maurer et al., 2007). Downscaled scenarios are available at "Bias Corrected and Downscaled WCRP CMIP3 Climate Projections" (<http://gdo-dcp.ucllnl.org/>). These models generate monthly rainfall and temperature estimates for 1950 to 2099. The values provided are averaged based on the set regional boundaries.

The Soil and Water Assessment Tool (SWAT) is used to generate streamflow time-series. SWAT is a daily time step watershed hydrologic model that uses as inputs precipitation, maximum and minimum temperatures (Arnold et al., 1993). SWAT also require as inputs land use information, elevation and soil maps, used to divide the watershed in catchments and hydrologic response units (HRUs). The data necessary for the hydrologic modeling was generated using the software ArcGIS (ESRI 2010), and the hydrologic calculations were executed using the extension ArcSWAT.

The selected watershed is the area that drains to Lake Arlington in Tarrant County, Texas. Lake Arlington reservoir is part of the Tarrant Regional Water District (TRWD), which supplies water for the City of Arlington. Figure 1 shows the subcatchments and boundary for the Lake Arlington watershed.



Figure 1. Hydrological model of the drainage area flowing into Lake Arlington.

Lake Arlington has an total reservoir capacity of 49.6 million cubic meters, which inundates an area of 7.79 square kilometers at conservation pool elevation (167.64 meters above mean sea level) (TWDB 2008). The main tributary of Lake Arlington is Village Creek, which drains an area of 370.4 square kilometers. The Lake Arlington watershed model contains historical meteorological data of maximum and minimum temperatures and average precipitation from 1947-2009, which was compiled from six nearby weather stations. The model has divided the river basin into 95 catchments and 3653 HRUs.

Although the GCMs provide the required input values, they are generated in monthly time steps and need to be disaggregated in daily time steps. The temporal disaggregation was performed using a simplified approach, which computes the average rainfall and temperature of each month of the year. The daily rainfall and temperature used in the model are calculated as the product of the historical daily rainfall and temperature by the ratio of the monthly predicted rainfall and temperature to the average rainfall and temperature for that month. Figures 2 and 3 demonstrate the predicted values for temperature and precipitation from the GCMs. Figure 2 demonstrates that the predicted values of precipitation do not change dramatically over the next 70 years. In Figure 3, however, a noticeable difference in temperature can be seen when comparing the year 2010 and 2080. Three out of the four GCMs predicted a change of about 2°C, and can cause an increase in the rate of evapotranspiration causing the streamflow to diminish.

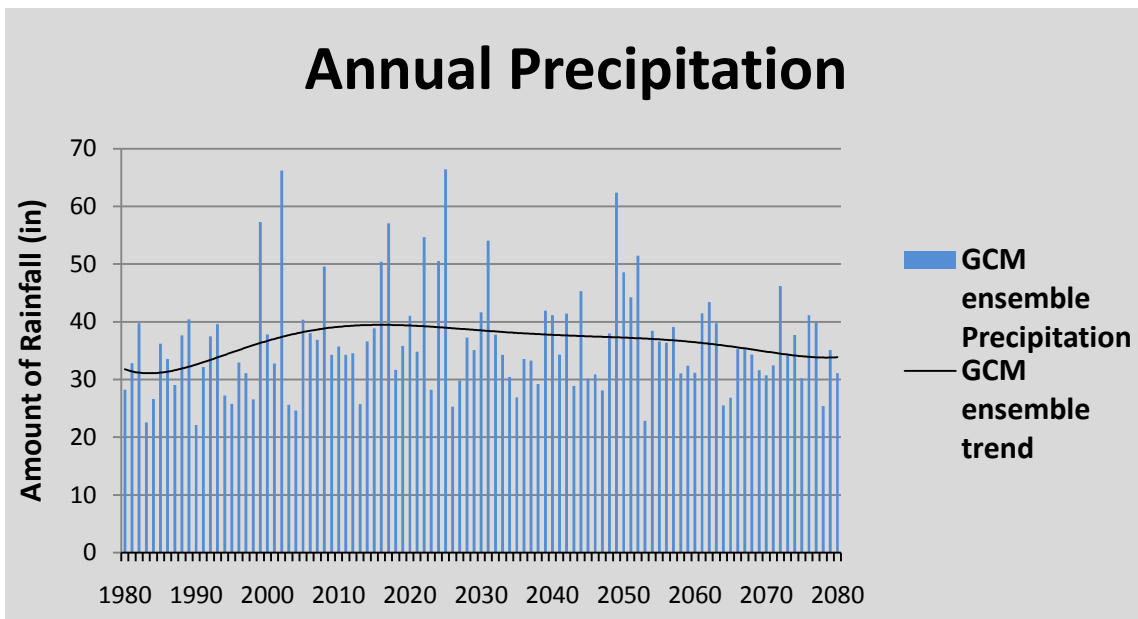


Figure 2. Annual precipitation. An ensemble using four GCMs to predict rainfall in future years.

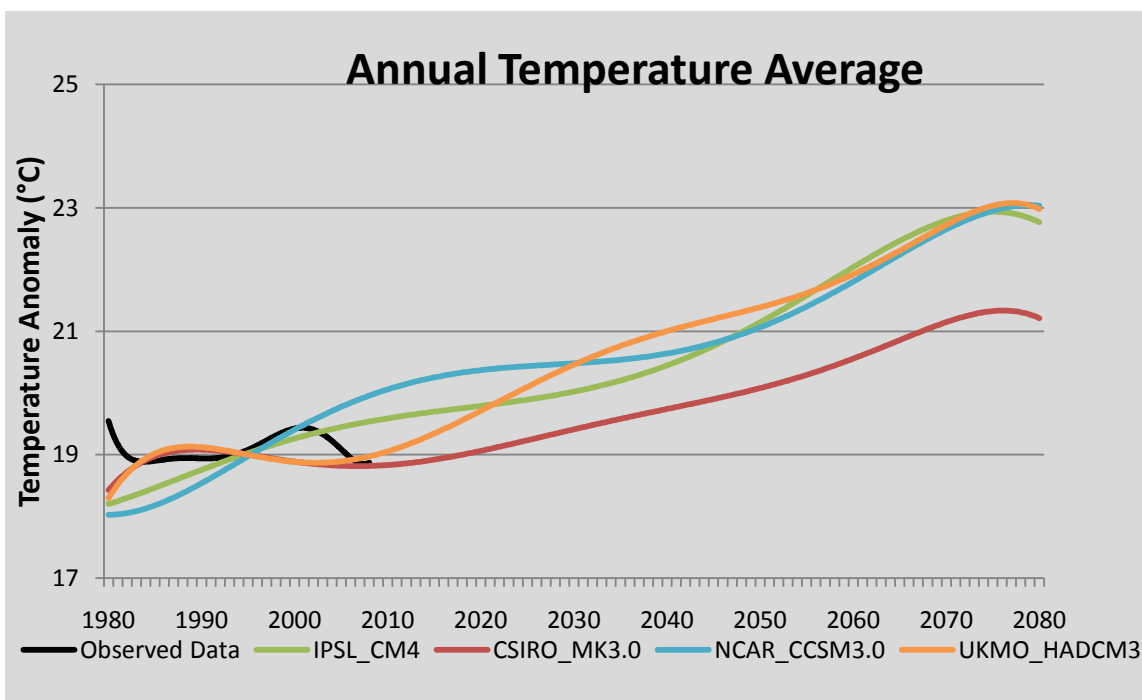


Figure 3. The annual temperature average predicted by four different General Circulation Models compared to the observed data.

The SWAT model was used to generate five scenarios of streamflow of 50 years (from 2010 to 2060). The first scenario assumes that past historical data (1950 to 2000) will reproduce future hydrologic conditions. The other four scenarios are generated using the selected GCMs. The generated time series of stream flow allow us to create flow duration curves which indicates the average probability in time that flow discharges are equaled or exceeded, and is typically used to assess water availability.

CHAPTER III

RESULTS

The availability of sixteen GCMs was a great contribution to this study. The use of multiple General Circulation Models provided a broader assessment to view how the future climate changes will impact the water resources, but some of these climate models were withdrawn due to the extremity of values present in the model. These models generate values on a global scale, so in some cases the areas in the model being studied may produce irregular values so that the rest of the model generates more likely values. These various climate models were simulated individually and then banded together to create a mean ensemble to minimize the degree of uncertainty and generate scenarios of the future streamflow. The combined output of the ensemble modeling is referred to as the GCM ensemble. The individual GCM scenarios and ensemble were then compared to the historic ensemble. The historic ensemble consists of a 70-year period of observed flow based on observed set data being repeated in the year 2010.

The first step employed a screening process was adopted to identify which of the sixteen GCM's should be used in the analysis. First the monthly streamflow was computed using the observed data for the year 2001. For each GCM prediction for rainfall for the year 2001, the streamflow was calculated. The percent difference across the 12 months was calculated for each GCM, and models were kept that had a difference less than 3%.

For example, in analyzing the streamflows for 2001, we found that the UKMO-HadCM3 model calculated an increase in the annual water yield of +3.25% while the rest of the GCMs estimated a decrease that same year. Four models were selected, and the 2001 GCM ensemble of these four models estimated a decrease of -1.05%. The error in one of the models (UKMO-HadCM3) causes some uncertainty if only that model is used, but using a GCM ensemble for prediction can reduce some of the errors associated with one model prediction.

A simulation was run for each of the climate models from 2000 to 2040 generating the annual streamflow coming into Lake Arlington. The gross water yield is reported in Table 1 and is the daily average flow into Lake Arlington for selected one-year period. These calculations closely compare to Wiley and Palmer's (2008) calculations used in estimating the gross water yield. There is a significant difference in predicted gross water yields between each of the four models.

All of the models predicted a change of more than 5% per decade in the gross water yield after 2000. The GCM ensemble showed a drop in water yield of about 13 MGD per decade, corresponding to a 5% drop in the water yield per decade.

Table 1. Gross Water Yield Estimates.

| Gross Water Yield Estimates for the Arlington Lake (All Values MGD) | | | | | |
|--|-------------|-------------|-------------|--------------------------------|--------------------------------------|
| Streamflow scenario | 2000 | 2020 | 2040 | Trend in MGD per decade | Relative trend per decade (%) |
| Weather Station | 17 | | | | |
| CSIRO-Mk3.0 | 36 | 42 | 20 | -3.93 | -10.95 |
| IPSL-CM4 | 17 | 14 | 8 | -2.36 | -13.86 |
| NCAR-CCSM3 | 9 | 12 | 22 | 3.22 | 34.43 |
| UKMO-HadCM3 | 21 | 26 | 16 | -1.14 | -5.48 |
| GCM ensemble | 21 | 24 | 17 | -1.05 | -5.07 |

Although a decrease in the water yield had been predicted, the amount of change produced may be unrealistic, based on historical trends. These results demonstrate the potential for water shortages, and water management for the future will need a large effort from the community to keep Lake Arlington sustainable.

The importance of this study is to be able to calculate the water yield in the future, so that water management teams can take these values and incorporate them into their water use models. This will then give them a chance to have enough water to meet the water demands and at the same time sustain the water levels in Lake Arlington.

CHAPTER IV

SUMMARY

As our population keeps growing our water demands will keep on increasing, leaving many cities with big decisions to make leaving a significant impact on future water use.

As of now many cities have made a great effort in administering water management practices which save the city and its citizens money while decreasing water use.

Although these are great effort put forth by the people there still a need for studies to be done on many water resources to keep a sustainable water supply. Without knowledge of future amounts of water, people would be at risk of water deprivation. A key variable in knowing this amount is knowing our future climate changes.

This study uses two different models, coupling GCM with hydrologic modeling, to predict the future streamflow for Lake Arlington. The general circulation models used in this study predicted a varying precipitation change in the next couple of years while also forecasting an increase in annual temperature average from 19°C to about 23°C in 2080.

These two conclusions coincide with Lane and Kirshen's (1999) declaration of an increase in average surface temperature from 1 to 3.5°C by 2100. These values were inserted into the hydrological model to calculate future streamflow values. Although there was little agreement among different GCMs, the overall ensemble of these GCMs predicted a decrease of about 5% in water yield for each of the next four decades.

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