Chapter 10

Assessing and Modeling Flood Event and Climate Change in the Gulf Coast Region

Wael M. Khairy, Center for Hydrology, Soil Climatology, and Remote Sensing (HSCaRS) Alabama A&M University, Alabama

Summary

A wide variety of regional assessments of the potential water-related impacts from climate changes have been conducted over the past two decades using different methods, approaches, climate models, and assumptions. Several studies have suggested that projected changes in temperature and precipitation along with anthropogenic activities could have significant influences upon the impacts of extreme flooding events. A promising modeling approach has been developed linking the General Circulation Models (GCMs) to hydrologic models and results from this linked modeling system have been applied for flood control planning and management. A good understanding of the current conditions and future trends is critical to conducting any climate change impact assessment. The purpose of this case study is to contribute to the Gulf Coast regional assessment through credible evaluation of the potential consequences of climate change with a focus on extreme flood events. Establishment of regional hydrologic and climatic baseline conditions, climate forcing scenarios, an hydrologic simulations and analysis were conducted in this case study.

In this case study, the Canadian General Coupled Model (CGCM2, hence referred to as the Canadian model) was integrated with the Soil and Water Assessment Tool (the SWAT model) to assess the vulnerability of flood events in the Gulf Coast region to its projected changes in climate. The predictions were dependent upon the specific assumptions employed regarding future changes in climate (the Intergovernmental Panel for Climate Change, IPCC, 2000; the National Assessment Synthesis Team, NAST, 2000), as well as the particular methods and models applied in this analysis (Khairy, 2000). All other hydrologic characteristics remained constant during the study period (1938-2100). Therefore, the results extracted from this study can be considered direct impacts of the applied projected climate scenarios. To interpret these projections, it is important to bear in mind that, uncertainties regarding the character, magnitude and rate of future climate change remain. These uncertainties impose limitations on the ability of scientists to project impacts of climate change, particularly at sub-regional scale.

The hydrologic and anthropogenic activities baseline conditions, which are the actual existing conditions based on the period (1983-2000), were established for the Tangipahoa watershed in southeastern Louisiana (518,600 acres). The geographic location of Tangipahoa watershed is in the center of the Gulf Coast region. The hydrologic and topographic conditions of Tangipahoa watershed are the average (typical) among the Gulf Coast region basins. Therefore, Tangipahoa watershed was considered a good prototype for the entire Gulf Coast region. The existing hydrologic baseline conditions were established and the performance of the SWAT model was evaluated and verified. This study considered detailed time series of projected climate forcing parameters as well as hydrologic processes for the period (1938-2100).

The Canadian model projected future trends of precipitation, temperature, solar radiation, and humidity in the Gulf Coast region over the next 100 years. The Canadian model projects that the mean annual surface temperature of the Gulf Coast region will increase by 5 – 8 ^{o}C, annual precipitation will increase by 7 – 10 %, and there will be increased variability in precipitation and temperature patterns by year 2100.

Projected change in annual stream flow of the Tangipahoa River using the SWAT model and based on the Canadian model projected climate forcing scenarios indicated potential projected increases as well as decreases. Seasonal changes in surface runoff also could be substantial. The climate change scenarios suggested increased winter precipitation, which could result in increased surface runoff in the Tangipahoa River flow in winter and spring. On the other hand, the projected climate scenarios showed reductions in summer precipitation and as a result lower summer soil moisture levels could occur, which could result in significant declines in summer and autumn surface runoff. Due to the differences in scale (spatial and temporal resolutions) between the regional Canadian model and the local SWAT model, uncertainty levels in predicting stream flow and extreme flood events using the current coupled climate and hydrologic models could be introduced. This scaling problem was treated in this study by applying a disaggregation technique and introducing correction factors for the projected climate parameters before being used by the SWAT model.

The annual average stream flow trend that was estimated within this study for the period 1938 – 2100 using the SWAT model indicated significant increase in the Tangipahoa River projected discharges over the next 100 years. Using the SWAT model, the Tangipahoa River annual average discharge recorded 892 cfs, 1,319 cfs, and 1,286 cfs during the periods 1938 – 1999, 2000 – 2049, and

2050 – 2100, respectively. This trend suggests that stream flow of the Tangipahoa River could be decreased during the second half of this century, but still the flood hazard will remain since the average annual discharge is expected to exceed the current records by about 44%. Based on the Tangipahoa watershed assumption as a good prototype for the Gulf Coast region, flood hazard possibility in the Gulf Coast region during the next 100 years is suggested to be high, because the projected increase in annual average stream flows are suggested at 48% and 44% during the periods 2000 – 2049 and 2050 – 2100, respectively. The projected peak flow during the next 100 years is suggested almost double the current records. These results, which suggest a high possibility of stream flow rise and increased flood risk over the Gulf Coast region in the next 100 years, strongly agree with previous reported findings about expected increase in temperature, precipitation, and stream flow in the Gulf Coast region (NAST report, 2000; Watson et al., 1997; IPCC report, 2000).

Should the Canadian projections of temperature rise of 5 – 8 ^{o}C and precipitation increase of 7 – 10% in the Gulf Coast region in the next 100 years occur then they could have a major influence on the economics of the region. Human settlements and infrastructure are especially vulnerable to extreme flood events, and the socioeconomic impacts could be significant if the frequency and intensity of extreme flood events were to increase over the next 100 years. The human and economic impacts from significantly large floods are difficult to measure. In addition, any extreme flood events have the potential to impact recreational activities, wetlands productivity, the fish and poultry industries, and agriculture especially in Louisiana, Mississippi, and Alabama, where these activities are centered.

10.1 Introduction

Over the past few hundred years, evidence clearly indicates that human activities have started to change the balance. Originally, plant respiration and decomposition of organic matter released more than 10 times the CO_2 released by human activities; but these releases have generally been in balance during the centuries leading up to the industrial revolution. That situation caused the rapidly usage of fossil fuels in industry. The fossil fuels were formed many millions of years ago from the fossil remains of plants and animals in the geological formation of the earth. They produce carbon dioxide, which can be absorbed by terrestrial vegetation and the oceans, and added to the atmospheric carbon levels. Since the beginning of the industrial revolution, atmospheric concentrations of carbon dioxide have increased nearly 30%, methane concentrations have more than doubled, and nitrous oxide concentrations have risen by about 15%. Deforestation and the spread of intensive agriculture initiated a growth in emissions of CO_2, in the mid-18th century (Houghton, 1995). Starting in the 19th century and accelerating in the 20th century, combustion of coal, oil, and natural gas has led to additional emissions (Andres et al., 2000). These increases have enhanced the heat-trapping capability of the earth's atmosphere. Combustion of fossil fuels is currently a significant source of emissions to the atmosphere (IPCC, 2000).

The earth's climate is predicted to change because human activities are altering the chemical composition of the atmosphere through the buildup of greenhouse gases (primarily carbon dioxide, methane, and nitrous oxide). Carbon dioxide alters the radiative balance and tends to warm the atmosphere. The heat-trapping property of these gases is still undisputed clearly. Although uncertainty exists about exactly how earth's climate responds to these gases, global temperatures are rising. Estimating future emissions is difficult, because it depends on demographic, economic, technological, policy, and institutional developments. Several emissions scenarios have been developed based on differing projections of these underlying factors. For example, by 2100, in the absence of emissions control policies, carbon dioxide concentrations are projected to be 30-150% higher than today's levels (Ning and Abdollahi, 1999; Harvey, 2000; Mitchell et al., 2000). Sulfate aerosols, a common air pollutant, cool the atmosphere by reflecting light back into space; however, sulfates are short-lived in the atmosphere and vary regionally. Aerosols, which have an opposite effect on the atmosphere's radiative balance tends to cool the atmosphere. Aerosols can have important conse-quences for continental-scale patterns of climate change (Watson et al, 1997).

There has been an increase in the global atmospheric content of carbon dioxide by about 9% since the mid-1970 (Weber et al., 1993). Carbon dioxide allows incoming short-wavelength energy to reach the earth from the sun, but impedes the return radiation from the earth as longer wavelengths. This has led to a temperature increase of 1^{o}C and the heating of the ocean as well as the melting of land-based glaciers have led to an increase in sea level of 10 cm over the last century (Nakicenovic et al, 2000). It is predicted that there will be a further rise of 1.5 to 4.5ºC and sea level is predicted to rise 50 cm by 2050, and 1m by 2100 (Moore III, 1999). Global mean surface temperatures have increased 0.2 – 0.6ºC since the late 19th century. The 20th century's 10 warmest years all occurred in the last 15 years of the century. Of these, 1998 was the warmest year on record. The snow cover in the Northern Hemisphere and floating ice in the Arctic Ocean had decreased. Globally, the sea level has risen 4 – 10 inches over the past century (Leatherman et al., 2000).

Worldwide precipitation over land has increased by about 1%. The frequency of extreme rainfall events has increased throughout much of the United States. Over the US, precipitation has increased by 5-10% on average (Watson et al, 1997). Evaporation will increase as the climate warms, which will increase average global precipitation. Soil moisture is likely to decline in many regions, and intense rainstorms are likely to become more frequent. Calculations of climate change for specific areas are much less reliable than global ones, and it is unclear whether regional climate will become more variable. Global climate change could also change the frequency and severity of inland flooding, particularly along rivers.

General Circulation Models (GCMs) suggest that some regions of the United States may have more rainfall in the future during the wet season, which could increase river and lake levels. One of these areas the Gulf Coast region (The National Assessment Synthesis Team report, 2000). The most flood-prone communities of the United States are at least partly protected by levees and reservoir flood-storage capacity. Large sections of the upper Mississippi/Missouri River basins experienced major flooding during the summer of 1993. The Mississippi/Missouri River floods of 1993 illustrated that the protection systems are designed to prevent the relatively frequent, moderately destructive floods (up to 100-yr occurrence floods), those with at least a 1% chance of occurring in any given year. However, these systems are overwhelmed and almost completely ineffective against the rare flood that is more devastating than the flood the system was designed to handle (e.g., 500-yr floods).

10.2 Methods of Study

The approach followed in this study consists of five stages: 1) establishing the hydrologic conditions and verifying the model used for estimated flood events; 2) projecting the climate change in the period (2000 – 2100); 3) estimating the expected flood events based on the projected climate change and the already established hydrologic model; 4) assessing the implications of climate change and anthropogenic activities; and then 5) discussing the control of floods.

10.2.1 The Study Area Description

This study was limited to the Tangipahoa River watershed within the Gulf Coast region. The geographic location of Tangipahoa watershed is in the central part of the Gulf Coast region. The hydrologic and topographic conditions of Tangipahoa watershed can be considered the average (typical) among the Gulf Coast region basins. Therefore, Tangipahoa watershed can be considered a fairly good prototype for the whole region. Assumption of generalizing the findings of this case study to be relevant for the entire Gulf Coast region was specified in this study. This assumption might not be accurate enough in the coastal areas near to the Gulf Coast where significant climate variability may occur in some months during the year. Chapter 9 of this book "Assessing the Potential Climate Change Impacts on Salinity in Northern Gulf of Mexico" stated that there are large differences in the various estuaries of the Gulf Coast region with various amounts of freshwater inputs. Even so, this study can give overall indication about the impact of climate change on extreme flood events in the entire Gulf Coast region.

The Tangipahoa River Watershed

Tangipahoa River watershed, in southeastern Louisiana (LA) has a total area of 518,600 acres (about 1,900 km^2). The northern portion of Tangipahoa watershed extends into Pike County in Mississippi (MS). Tangipahoa Parish, which includes the majority of Tangipahoa watershed, is 536,148 acres, of which 22,228 acres are lakes, bayous, and rivers (USDA and SCS, 1990). Tangipahoa Parish is bordered on the north by Amite and Pike Counties; on the south by Lake Pontchartrain, Lake Maurepas, and St. John the Baptist Parish; on the east by St. Tammany and Washington Parishes; and on the west by Livingston and St. Helena Parishes as shown in Figures 1 and 3. According to the 1980 census, Tangipahoa Parish population was 80,698. About 65% of the Parish population is in rural areas.

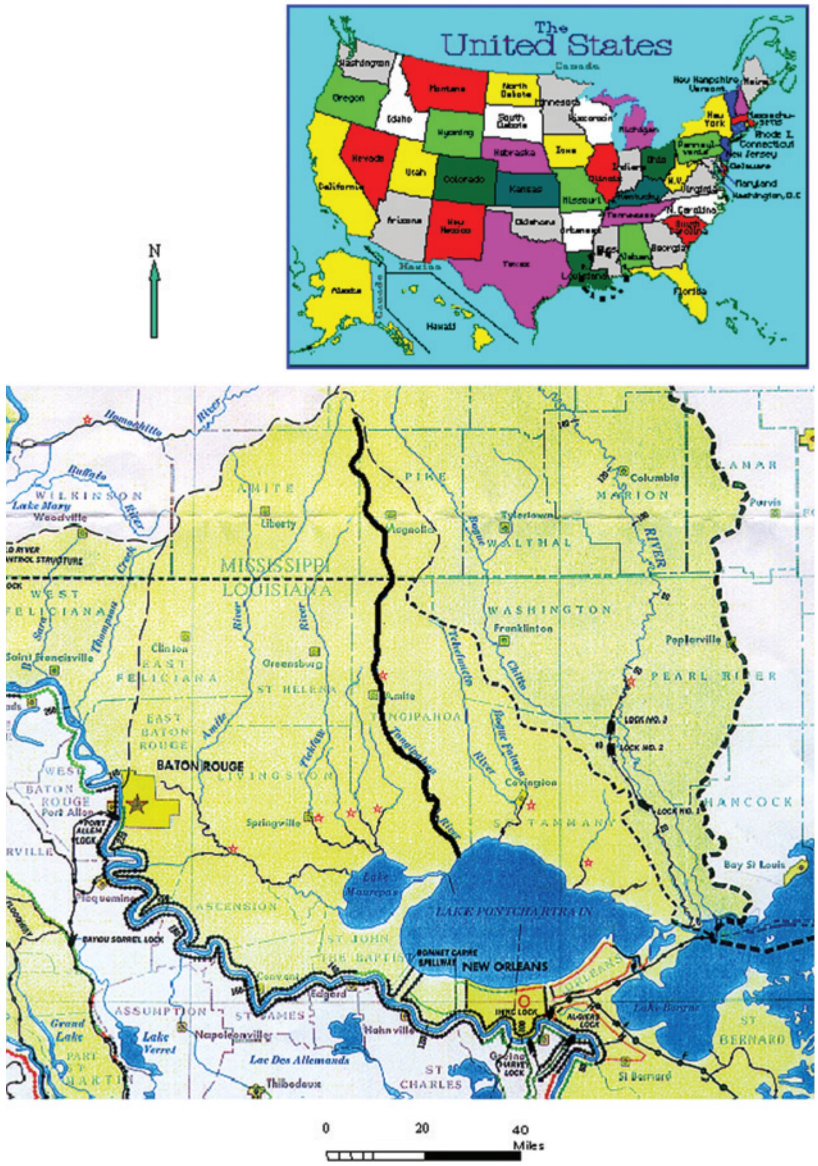


Figure 1. Lake Pontchartrain Basin, Louisiana State, USA

The Tangipahoa River is a popular recreational resource for MS and LA. In MS, the Tangipahoa River is classified as a fish and wildlife preserve; however, in the last decade the primary contact recreation activities were prohibited during the summer months due to recorded high pollution loads. In LA, the River is listed as a wild and scenic stream by the Louisiana Scenic Streams Program and is used for recreational contact. Both states have designated the Tangipahoa River as a targeted watershed in their non-point source management program reports. By this designation, the River has been identified as being potentially impaired by agricultural non-point pollution sources.

History

The name Tangipahoa is derived from the Indian village, which was located north of Lake Pontchartrain. The "Tangibao," corncob people or corn gatherers, were mentioned in accounts of French explorers dating back to 1683 (Nicholes, 1979). The Indian heritage of Tangipahoa Parish is most evident in the place names of Indian origin. Because of an increase in population and the resulting municipal needs, Tangipahoa Parish was created in 1869 from the western parts of St. Tammany and Washington Parishes and the eastern parts of Livingston and St. Helena Parishes (Lanier, 1969).

Historic Floods

Over half of the nation's costliest weather-related disasters of the past 20 years have occurred in the Southeast (where the Gulf Coast region is located), costing the region over $85 billion in damages, mostly associated with flood and hurricanes (NAST Overview Report, 2000). The Mississippi basin, the largest river basin in the United States, forms a wedge of 1,243,000 square miles (3,220,000 sq. km.) in the center of the continent. As the Mississippi River system drains toward the Gulf of Mexico, the basin narrows, centering on the state of Louisiana. Although the basin stretches into the alpine pastures of the Rocky Mountains and the wooded valleys of the Appalachians, it covers mainly the rich grain belts of the Midwest and the Great Plains. Thirty-one states and two Canadian provinces contribute water to the Mississippi system. Figure 2, which is a false color image taken over St. Louis, Missouri on July 29, 1993 using a special NASA airborne scanner, shows the study area of St. Charles and the Missouri River. It also shows a portion of St. Louis and the Mississippi and Illinois rivers at flood stage (Baumann, 1996).

The Mississippi River system in the Gulf Coast region has experienced several major floods within the 20th century. Until the 1993 flood, the 1927 flood was considered the greatest inundation of the river. Over 700,000 people were forced to leave their homes; 246 people and 165,000 head of livestock drowned; and property damage exceeded $364 million. In 1937, heavy rains drenched the lower Mississippi, creating a lake nearly the size of Lake Superior in area. Several smaller floods in the 1940s and 1950s plagued the basin and extreme floods hit the upper basin in 1965 and 1973. Unusually high precipitation combined with soil saturation from earlier precipitation significantly contributed to the 1993 Mississippi River flood (Kunkel et al., 1994). The 1993 flood was concentrated in the upper Mississippi basin (Iowa state) and the middle and lower sections of the Missouri basin (Missouri and Ohio states). The Ohio basin, which generally accounts for about 70 percent of the total volume within the system, was not experiencing any major flooding. The discharge from the Ohio basin was being controlled during the flood period by holding water back in the numerous reservoirs on the river and its tributaries. The much larger channel and floodplain of the lower Mississippi River reduced greatly any flooding in the lower Mississippi valley. The 1993 Mississippi River flood caused wide dispersal of microorganisms and chemicals from agricultural lands and industrial sites.

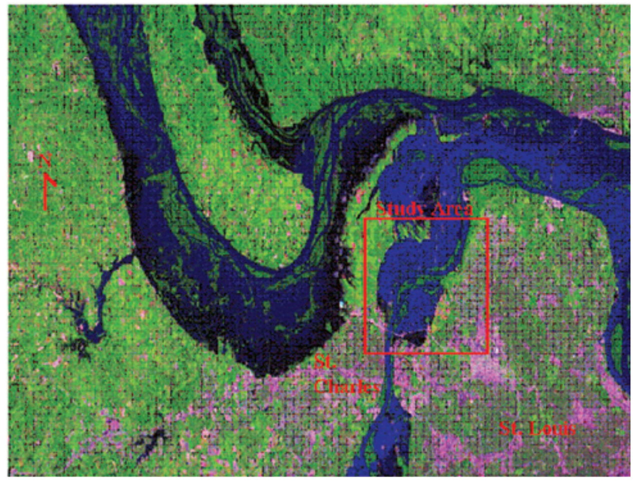


Figure 2. The Affected areas in Iowa, Missouri, and Ohio states by the 1993 Mississippi River Flood (source: Baumann Flood Analyses Report, 1996).

Within the flooded area, the 1993 flood reached record levels. On the upper Mississippi at Keokuk, Iowa, peak discharges exceeded significantly the previous record discharges in 1973 and 1851 and went well above the 100-year flood mark. At Boonville, Missouri, the 1993 peak discharge on the Missouri matched the 1844 flood and exceeded the 1951 and 1903 floods, all three of which were identified as 100-year or greater floods. The discharge could have been higher than the estimated 1844 peak discharge if it was not for a number of reservoirs within the upper and middle Missouri basin holding water back. The upper Mississippi basin does not have as large reservoirs as the Missouri. At St. Louis, where the Missouri and upper Mississippi merge, the 1993 peak discharge was above the 100-year flood mark, but below the 1844 level. Again, flood control through dams held the 1993 flood discharge level down; these dams and their large reservoirs did not exist in 1844.

The 1999 North Carolina flood, resulting from Hurricane Floyd, offers a recent example of the massive dislocations and multi-billion dollar costs that often accompany such events. Dams and levees have also saved billions of dollars of investment, but these facilities, together with insurance programs, encourage development in floodplains, thereby indirectly contributing to damages (Frederick and Schwarz, 1999b). In addition, structural flood control features have high environmental costs. Climate change may affect flood frequency and amplitude, with numerous implications for maintenance and construction of infrastructure and for emergency management. Erosion and deposition rates in rivers and streams are likely to change under different precipitation regimes. The reduction in reservoir construction

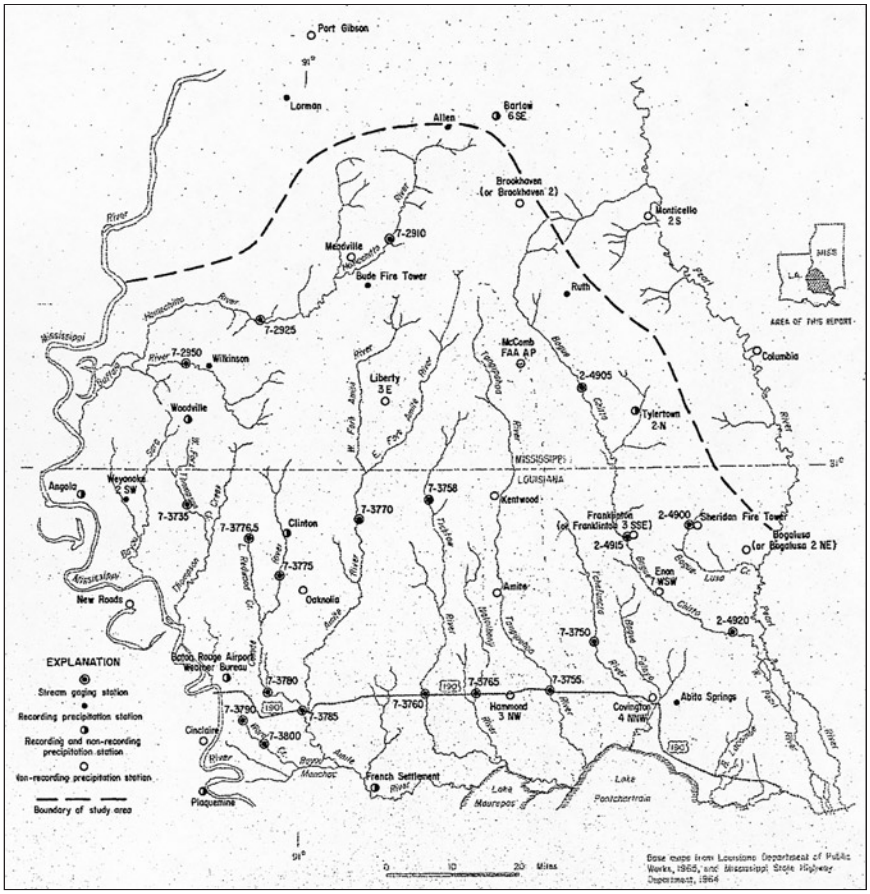


Figure 3. The Main Cities and Weather Stations in Lake Pontchartrain Basin

along with the buildup of sediment in reservoirs will affect the resilience of water supply systems and their ability to handle flood flows.

In the United States, flash floods — enormous land inundation due to extensive rainfall or hurricane events that much more above the stream system capacity, currently are the leading cause of weather-related mortality. The Gulf Coast region is subject to such extreme flood events especially during the hurricane season (late summer and fall of each year). In addition to causing deaths by drowning, flooding can lead to widespread destruction of food supplies and outbreaks of disease as a result of breakdowns in sanitation services. Flooding also may result in the release of dangerous chemicals from storage sites and waste disposal sites into floodwaters. Increased runoff from agricultural lands during periods of heavy precipitation also can threaten water supplies (Karl and Knight, 1998; Knutson and Tuleya, 1999, Meehl et al., 2000).

Geology of the Regional Aquifer System

The Gulf of Mexico Coastal Plain is a gently rolling to flat region of about 670,000 km^2 extending from the southern tip of Illinois to the Laguna de Te'rminos near the southwestern terminus of the Yucata'n peninsula (Grubb and Carrillo, 1988). It is underlain by a Gulfward-thickening wedge of unconsolidated to semi-consolidated sedimentary rocks of Cenozoic age (Hanshaw and Bredehoeft, 1968).

Groundwater is present in a complex series of alternating beds of sand and clay. The beds dip gently southward (on the order of 25 ft/mi) as a result of down warping on the southern flank of the Southern MS uplift. The dip increases progressively toward the coast as a result of subsidence caused by the sediment out-land migration and deposition in the Gulf of Mexico. The Southern MS uplift structural trough, a downwarp that parallels the present Mississippi River valley, is the geologic structure that affects the regional groundwater flow patterns (Grubb, 1984). The alternation of sand forms aquifers and the beds of clay form confining units between the aquifers. The LA southeastern aquifer system is defined as the succession of beds of sand and clay from the land surface to the base of the "1,200-foot" aquifer. The surficial deposits in the aquifer outcrop area consist of clay and interbedded thin beds of sand.

Climate

In winter the average temperature is 11^{O}C, and the average daily minimum temperature is 4^{O}C. The lowest temperature on record, which recorded at Amite weather station (as shown in Figure 3) on January 12, 1962, was –13^{O}C. In summer the average temperature is 27^{O}C, and the average daily maximum temperature is 33^{O}C. The highest temperature recorded was on July 1, 1954 as 40^{O}C. The monthly heat unit accumulation is used to schedule single or successive plantings of a crop between the last freeze in spring and the first freeze in fall. The daily maximum and minimum temperature records and the air temperature seasonal variability in Tangipahoa watershed are shown in Appendix I.

The average total annual precipitation is 34 inches. Of this, 19 inches, or 55%, usually falls between April and September. The growing season for most crops also falls within this period. In two years out of ten, the rainfall from April through September is more than 27 inches. The heaviest 1-day rainfall during the period of record was 8.55 inches at Amite on September 6, 1977. Thunderstorms occur on about 70 days each year, mostly in the summer. Snowfall is rare in the Tangipahoa watershed. In 90% of the winters, there is no measurable snowfall. In 10% of the winters, the snowfall is usually of short duration but more than 2 inches in depth. The average relative humidity in mid-afternoon is about 60%. Humidity is higher at night, and the average at dawn is about 90%. The sun shines 70% of the time in summer and 50% in winter. The prevailing wind is from the southeast. The maximum wind speed is at the average of 10 miles per hour in spring (USDA, et al., 1991). The daily rainfall depths are measured at Hammond, Amite, Kentwood, and McComb raingauge stations on regular basis. Rainfall historical records at those stations are illustrated in Appendix I.

Land Use

The Tangipahoa area consists primarily of forests and agricultural land. According to the 1982 annual report of the Louisiana Cooperative Extension Service, there were 1,267 farms in the Tangipahoa area. The average size of a farm in 1978 was about 133 acres, and by 1983 it had decreased to about 122 acres. In 1982, 3% of the total population was employed by agriculture industries. In 1983, there were 349 dairies in the area; 92,512 acres were cropland; and 48,989 acres were pastureland. The wetlands in the Tangipahoa watershed are located downstream of the Robert Bridge (which is located at the intersection of Highway 190 with the Tangipahoa River as shown in Figure 3). It constitutes about 2% of the total Tangipahoa basin. Those wetlands are covered with weeds and aquatic plants most of the year. The dominant land use/land cover (LULC) in the Tangipahoa watershed were estimated based on the U.S. Department of Agriculture (USDA) Census of Agriculture data during the period (1980-1996) and are shown in Table 1. LULC spatial distribution that was used for simulating the baseline hydrologic condition of the Tangipahoa watershed is discussed under 3.3.2.

Table 1 Dominant Land Uses in the Tangipahoa Watershed (average values for the period 1980-1996).

Land-Use	Acres	Percentage (%)
Crop Land	25,930	5
Pasture Land	155,580	30
Forest Land	305,974	59
Urban Land	15,558	3
Other Land*	15,558	3
Total	518,600	100

* Other land includes swamps, wetland, water, barren, farmsteads, and rural roads.

Water Resources

Surface water:: the Tangipahoa River and its tributaries are the major conveyers of surface water in the Tangipahoa watershed. The average annual runoff of the Tangipahoa watershed at the Robert bridge location (the simulated watershed outfall point as shown in Appendix II) is about 835,496 acre-feet per year (Carlos et al., 1983). The daily and seasonal variability streamflow record plots at the Tangipahoa River outfall (Robert location) are shown in Appendix I. Also, the peak flow at Robert location and other upstream locations are shown in Appendix I. The Tangipahoa River drains its water and pollution loads into Lake Pontchartrain at its outfall as shown in Figure 1.

Groundwater: the aquifers in the Tangipahoa watershed constitute one of the largest sources of fresh groundwater in Louisiana. They yield good quality water at rates of 1,000 to 3,000 gallons per minute (Nyman and Larry, 1978). The groundwater is a sodium bicarbonate type. In most aquifers, concentrations of iron and manganese are less than 0.5 mg/l. Hardness is less than 30 mg/l, and content of dissolved solids is less than 350 mg/l. Locally, water may contain objectionable amounts of hydrogen sulfide and silica.

Soil Classification

The Tangipahoa watershed is made up of two major land resource areas: the central and northern parts, mainly in woodland, pastureland, and truck crops; and the southern part, used mainly as habitat for wetland wildlife and for recreation. Soils of the central and northern parts are loamy and predominantly moderately well drained to well drained. Soils of the southern part are loamy, predominantly poorly drained, mainly ponded, and frequently flooded. These muddy and clayey soils are in swamps and marshes. Elevation ranges from 340 ft above mean

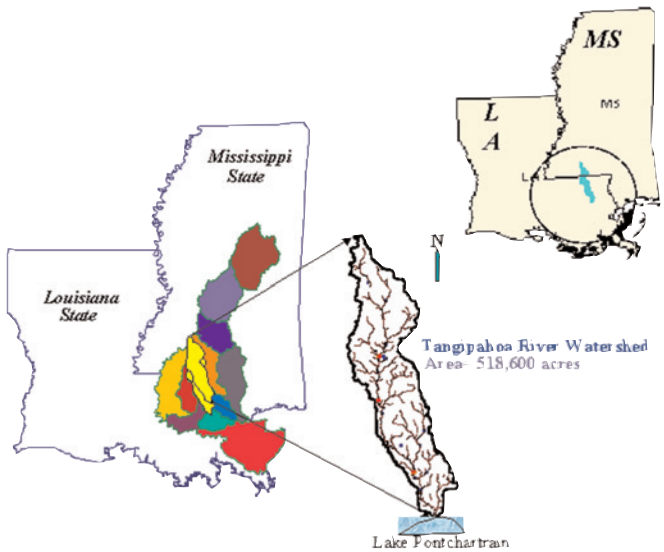


Figure 4. Location of the Tangipahoa Watershed in Lake Pontchartrain Basin.

sea level in uplands of the northern part to about 5 ft on stream or marine terraces of the southern part.

The Lake Pontchartrain Ecosystem

The headwaters of the Tangipahoa River originate in the southern portion of Lincoln County, Mississippi, approximately 30 miles north of the Mississippi-Louisiana state boundary as indicated in Figure 1. The water flows southward, entering Pike County approximately 5 miles west of Interstate Highway 55. The river continues in a southerly direction in the upper regions of Pike County. Then, it crosses into Amite County for a very short distance before re-entering Pike County and flowing directly into Lake Tangipahoa, located within Percy Quinn State Park, approximately 5 miles southwest of McComb, MS.

Lake Tangipahoa water spills from the southern area of the lake and flows, as the Tangipahoa River, in a southeasterly direction through the remaining portion of Pike County, MS, and into Tangipahoa Parish, LA. The waters continue on a south-south-easterly course across Tangipahoa Parish, flow into a wetland area and ultimately discharge directly into Lake Pontchartrain in southeast Louisiana (USDA et al., 1991). For the purpose of this research, the Robert bridge location (at the intersection of Highway 190 with the Tangipahoa River, at Lat. 30^{o} 30' 23" and Long. 90^{o} 21' 42") is hypothetically considered the outfall of Tangipahoa River, about 15 miles upstream of the Tangipahoa River mouth at Lake Pontchartrain (Figure 3). The downstream area of Robert bridge location is mainly wetlands.

The Lake Pontchartrain system in LA is a large impoundment in a complex estuary system (Figure 4). The unique mixture of biota in this ecosystem is composed of freshwater and marine species supported by physiochemical and hydrologic processes involving river inflows, exchanges with interconnected high salinity coastal waters, and interactions with surrounding watersheds, which have experienced major urban developments over the last five decades.

In 1988, Lake Pontchartrain experienced a phase of declining water quality accompanied by decreased productivity and limitations on its use for recreational activities (Ismail et al., 1998). These factors influence economic development and quality of life in this history-rich urban center of the state. Because of its proximity to New Orleans, Lake Pontchartrain has traditionally been important for such recreational activities as swimming, boating, and sport fishing. The lake produced commercial quantities of finfish and shellfish in the past, and presently supports an important commercial blue crab fishery.

10.2.2 Climate and Stream Flow Measurement Data

The purpose of this case study is to contribute to the assessment of the potential consequences of climate variability and climate change in the Gulf Coast region. The focus is the potential and the consequences of extreme flood events.

The current climate baseline conditions were established and the projected climate forcing scenarios/future trends were projected using the Canadian General Coupled Model. The climate data used for establishing the baseline and projected conditions for the Gulf Coast region were obtained from the Canadian Centre for Climate Modelling and Analyses. The established climate baseline conditions provided information needed for projecting of the climate forcing scenarios. The baseline hydrological conditions included regional historical and current data such as temperature, precipitation, stream flow, soil moisture, soil properties, crop development, and land-use practices for the period of 1938 – 2000. Data obtained from the baseline condition and projected climate forcing scenarios were used to assess and model extreme flood events over the next 100 years using the Soil and Water Assessment Tool (SWAT) model.

The Climate Data

Simulating the hydrological conditions of the study area requires historical spatial data records about daily temperature and precipitation (Neitsch et al., 1999). SWAT has a weather generator engine to predict the precipitation within an ungauged watershed based on stochastic and probabilistic methods (Richardson, 1981), however, it is more realistic to use actual rainfall measurement, especially for research purposes. The real rain data for the Tangipahoa watershed were collected using the US Geological Survey (USGS) database. Four weather stations were located inside or around the Tangipahoa watershed at Amite, Kentwood, Hammond, and McComb cities as shown in Figure 3. The Thiessen graphical method was used to allocate the daily real rain depth for each subbasin. The available rainfall and temperature data used in this study are shown in Appendix I.

The weather generator engine of the SWAT model selected the closest weather station to the center of each subbasin (Neitsch et al., 1999). The predicted daily rainfall or temperature by the SWAT model weather generator engine was used in the Tangipahoa watershed simulation only when the measured data were missing for a specific period of time during the simulation period. Also, the SWAT model weather generator engine was used to predict the solar radiation, wind speed, and relative humidity trends to be used in the hydrologic processes simulation.

The Stream Flow Measurement Data

Historical stream flow daily data of 1938 – 2000 were used to establish a powerful modeling baseline for the study area. The initial conditions for the SWAT model were created based on year 1938. The period of 1980 – 1989 was used to calibrate the model results. Finally, the period of 1990 – 1995 was used to validate the model performance.

The SWAT model hydrologic component of the stream flow (on a daily, monthly, and annual basis) was calibrated at its outlet to Lake Pontchartrain (Robert bridge location). The Robert location was considered the simulated outfall of the Tangipahoa River, since the remaining downstream portion of the watershed is wetlands (constitutes less than 3% of the whole watershed area), which was excluded from this study. The measured stream flow data of the Water Data Storage and Retrieval database (WATSTORE) of the USGS were used to calibrate the hydrologic component of the SWAT model. Long-term flow trend plots as well as peak flow comparisons were implemented at some other locations (graphs are available in Appendix I).

10.2.3 The SWAT Model Application

Recently, there has been considerable effort devoted to utilizing a Geographic Information System (GIS) to extract the SWAT model inputs data from various geographic layers (topography, soils, land-use/cover, and groundwater). This approach saves time that would be devoted to constructing the tremendous amount of input data files required, especially for large watersheds. The final effort was the development of an interface for the SWAT model (Srinivasan and Arnold, 1994) using the Graphical Resources Analyses Support System (GRASS) by the U.S. Army, 1988.

The Tangipahoa Watershed Delineation

The SWAT-GRASS interface is an interactive program used to create the necessary environment variables that are needed by the SWAT-GRASS interface project manager. Based on the aforementioned GIS map layers of resolution 5 km x 5 km, the SWAT-GRASS interface has automatically subdivided the Tangipahoa watershed into 76 subbasins, of approximately 7,000 acres each (about 25 km^2) as shown in Figure 5. Then the spatial data were extracted from the 1:100,000 scale map layers in association with the relational databases. Finally, the spatial data, e.g., soil characteristics, topography, channel geometry and schematization, land-use, weather, crop and land management have been aggregated and written to the appropriate model input data files.

Hydrologic Data Extraction

Land-use data were extracted by the SWAT-GRASS interface using a knowledge-based approach, where a set of rules along with model-supported crop database are incorporated in the programs that automate inputs required by the model using a GIS land-use map layer (Neitsch et al., 1999) as shown in Appendix II.

The SWAT-GRASS interface supports relational soil databases such as STATSGO (USDA, 1992), where each soil polygon identifier has more than 10 attribute tables. Accuracy of the soil data is limited to the accuracy and resolution of the land-use raster map used in addition to the reliability of the aggregation method used by the SWAT-GRASS interface. The topographic features, which are required for the entire basin and for each subbasin, were gathered using the GIS raster elevation map as shown in

Appendix II. The stream lengths, stream slopes, and stream dimensions were estimated (Srinivasan and Arnold, 1994) using the appropriate aggregation methods. The drainage area of each subbasin was computed along with the drainage sequence of which subbasin flows into which subbasin. Those data have been used to automate the routing structures of the Tangipahoa watershed by the SWAT-GRASS interface. Overland slope and slope length were estimated and aggregated by the mode method (Srinivasan and Arnold, 1994). Some groundwater parameters have been created for each subbasin using the groundwater *"alpha"* map (Neitsch et al., 1999). *"Alpha"* parameter is required to lag the groundwater flow as it leaves the shallow aquifer to return to the stream (Arnold et al., 1993). An *"alpha"* map has been identified in the SWAT-GRASS interface.

The Weather Data Prediction Capability

If a daily (or a period of time) record of measured weather data is not available, the SWAT model predicts it by its weather generator engine. It estimates that weather parameter based on statistical and probability approach from approximately 1130 weather stations to estimate that daily record, such as precipitation, maximum and minimum temperatures, solar radiation, wind speed, and relative humidity. The selected weather stations are based on their proximity to the study area. The SWAT also estimates the daily weather parameters for each subbasin (Khairy, 2000).

10.2.4 Data Consistency Check and SWAT Hydrologic Verification

The consistency check between the input data files of the SWAT model was implemented. It was essential to do that check since the mechanism of extraction of the data from the GIS map layers depends mainly on the resolution and accuracy of the raster maps used. The discrepancy among the input data could lead to unrealistic estimation and doubtful results.

The Stream Flow Calibration

The hydrologic calibration was conducted for the Tangipahoa watershed during the period of 1980 – 1989 then, the calibrated parameters were used for the model validity check during the period of 1990 – 1995. To setup/initialize the different parameter values for the SWAT simulation, the model has run for 10 years under the conditions of year 1979. For evaluating the stream flows predicted by the model during the calibration and validation periods, graphical comparisons and linear regression methods were used. Also, by using one of the most important statistical criteria for evaluation of hydrologic goodness-of-fit, the Nash-Suttcliffe coefficient, R^2, (Khairy, 2000; ASCE, 1993, and Suttcliffe and Nash, 1970).

Figure 5. The Tangipahoa Watershed Delineation into 76 Subbasins by the SWAT Model (based on a GIS map resolution of 5 km x 5 km).

To obtain better and more realistic simulation results, numerous changes were made to the input parameters used in the original simulation of the SWAT model on the Tangipahoa watershed (Khairy, 2000). A comparison between the simulated and observed annual average stream flow at the Tangipahoa watershed outfall (Robert location) during the calibration period is shown in Figure 6.

The SWAT model is intended as a long-term yield model and is not capable of accurate details, e.g., single-event flooding. SWAT over-estimates the storm peak flow values unless it is calibrated with high consideration for the interactive effects of a group of hydrologic input parameters at the same time using the objective function approach (Arnold and Allen, 1996). One of the major causes of the over-estimation problem of peak flow using the SWAT model is that the SWAT-GRASS interface ignores the spatial distribution of rainfall over large watersheds. Also, the storm intensity and duration are not considered in the simulation, since the SWAT model uses the SCS-CN method in calculating surface runoff. Those two causes are considered the major weak points in the SWAT model simulation.

The monthly and daily comparisons between the simulated and observed stream flow at the Tangipahoa watershed outfall (Robert location) are shown in Appendix III. The coefficient of determination (R^2) for the linear regression between the monthly observed and simulated stream flow was 0.977. The slope of the regression line was 1.306 and was marginally different from 1.0 at 95% confidence level. The average Nash-Suttcliffe coefficient during the calibration period was 0.867. The average Root Square Error and Standard Error were 0.777 and 344.783 respectively; also the average deviation (D_v) was 2.004%. Therefore, the SWAT model performance considering daily average flow rates over the entire simulation period achieved considerable success.

The modified recursive digital filter technique that was developed by Nathan and McMahon in 1990, and recommended by Arnold and Allen in 1999 was used for the base-flow calibration in the Tangipahoa watershed during the period (1984 – 1995). For more details, please see Khairy, 2000.

The Stream Flow Verification

Flow validation was conducted using the observed stream flow data at Robert location for the period 1990 to 1995. A comparison between the measured and simulated average annual stream flow at Robert location is shown in Figure 7. The time series plots of monthly observed and simulated stream flow comparison at Robert location are given in Appendix III. The figures show acceptable correspondence of simulated stream flows with the observed values. In the analyses of the scatter-plot of the observed vs. the simulated monthly stream flow values, the observed values had a strong linear relationship with the predicted results. R^2 between observed and simulated stream flow ranged from 0.864 to 0.809. The average Nash-Suttcliffe coefficient during the validation period was 0.769. The average RSE and SE were 0.759 and 371.138 respectively; also the average D_v was –1.608%. Based on that analyses, the SWAT model predicted the annual, monthly, and daily stream flow at the Tangipahoa watershed outlet satisfactorily.

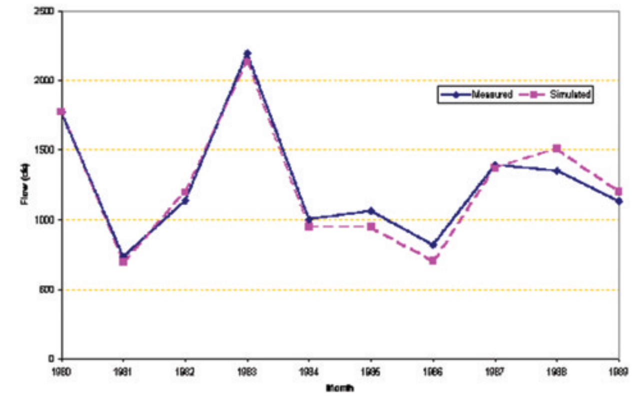


Figure 6. Simulated Against Observed Annual Average Stream Flow at the Tangipahoa Watershed Outlet (Robert location) During 1980 – 1989.

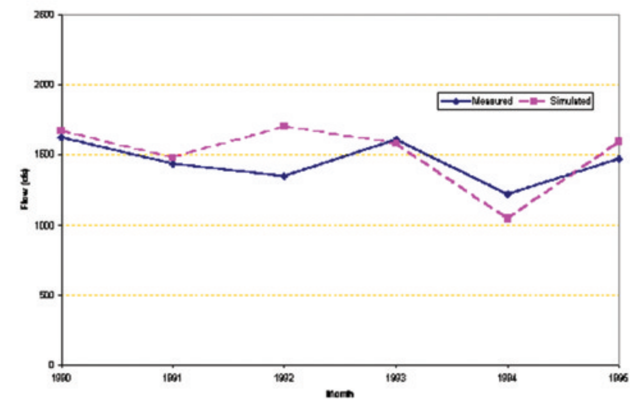


Figure 7. Simulated Against Observed Annual Average Stream Flow at the Tangipahoa Watershed Outlet (Robert location) During the Period 1990 – 1995.

10.2.5 The Climate Change Forcing and Prediction

The earth's climate is predicted to change because human activities are altering the chemical composition of the atmosphere through the buildup of greenhouse gases (primarily water vapor, carbon dioxide, methane, ozone, and nitrous oxide). The heat-trapping property of these gases is still undisputed clearly. Uncertainty exists about exactly how the earth's climate responds to these gases. Worldwide concern about possible climate changes resulting from increasing concentrations of greenhouse gases has led governments to consider international action to address this issue, particularly, through the development of the United Nations Framework Convention on Climate Change (UNFCCC). The extent and urgency of action required to mitigate the sources of the problem, namely the emission of greenhouse gases by human activities, depend on the level of human and natural resources vulnerability. This level can be defined as the degree to which human conditions and natural environment are vulnerable to the potential effects of climate change. The fundamental policy needed to tackle climate change consequences depends not only on information regarding greenhouse gas emissions and climate system changes but also on the likely impacts on human activities and the environment, e.g., extreme flood hazard, which is the primary concern of this case study.

The General Circulation Model

A key advantage of climate models is that they are quantitative and grounded in scientific measurements. They are based on fundamental laws of physics and chemistry, and incorporate human and biological interactions. They allow examination of a range of possible futures that cannot be examined experimentally. The General Circulation Model (GCM) based scenarios are the most credible and frequently used projections of climate change. Other types of climate projections include synthetic and analogue scenarios. They vary in their approaches and limitations. In addition, most climate change experiments have not accounted for human-induced landscape changes and only recently has the effect of aerosols been investigated. Both of these factors can further affect projections of climate change particularly on a smaller than global – regional scale. From the hydrologic point of view, GCMs can predict future regional climate parameters, for example, precipitation and (to a lesser extent) temperature. The use of GCM-produced scenarios with the hydrologic models adds a further degree of uncertainty in studying the hydrologic events impact assessments.

Confidence in the accuracy of climate models is growing. The best models have been carefully evaluated by the Intergovernmental Panel on Climate Change (IPCC) and have the ability to replicate most aspects of past and present climate. Two of these models have been used to develop climate projection scenarios for the U.S. climate impact assessment studies (e.g., the National Assessment Synthesis Team, Climate Change Impacts on the United States: the Potential Consequences of Climate Variability and Change, NAST, USGCRP, 2000). Projections of changes in climate from the Hadley Center in the United Kingdom and the Canadian Center for Climate Modeling and Analysis served as the primary resources for the assessment studies. While the physical principles driving these two models are similar, the models differ in how they represent the effects of some important processes. Therefore, the two primary models paint different views of 21st century climate. On average over the US, the Hadley model projects a much wetter climate than does the Canadian model, while the Canadian model projects a greater increase in temperature than does the Hadley model. Extreme flood events are more associated with wet weather conditions more than greater temperature conditions. The Canadian model might be more reasonable for this case study to avoid excessive flood predictions if the Hadley model is being used, especially because the Gulf Coast region is located close to the Equator where GCM generally over-predict worming and wetting conditions. Also, selected results of the Canadian model simulations were contributed to the IPCC Data Distribution Center to facilitate its use for climate impact studies (Boer et al., 2000 a, b). Based on this justifications, the Canadian model was selected for this case study for studying extreme flood events in the Gulf Coast region.

The Canadian model integrates the Atmospheric General Coupled Model (AGCM2) with a specially adapted version of the Modular Ocean Model (MOM) and a thermodynamic sea-ice model (Flato and Boer, 2000). The ocean mixing parameterization is included in the Canadian model through the isopycnal/eddy stirring parameterization of Gent and McWilliams, 1990. Also, sea-ice dynamics is included recently. In addition, some technical modifications were made in the ocean spinup and flux adjustment procedure. A description of the Canadian model can be found in Flato and Boer, 2000. An overview of the Canadian model is available at http://www.cccma.bc.ec.gc.ca/models/cgcm2.shtml.

Historical Climate

The time series of anomalies in mean annual temperature for the entire North American continent reveals temperatures increasing through the 1920s and 1930s, peaking around 1940, and then gradually decreasing through the early 1970s. From this point through the late 1980s, temperatures increased to levels similar to the 1940 era; they have remained mainly above normal, with the exception of 1996. The more recent warmth has been accompanied by relatively high amounts of precipitation, unlike the dry and warm 1930s.

The precipitation amounts over the Gulf Coast region are probably the largest in United States. Precipitation is centered mainly along the central Gulf

Coast states during winter, spring, and autumn and over Florida in the summer (Higgins et al., 1997). The mean annual precipitation amounts along the central Gulf Coast exceed 150 cm. By reviewing the analyses of U.S. Historical Climatology Network data by Karl and Riebsame in 1998 over North America, the following findings can be extracted. Annual precipitation amounts from 1901 to 1995 showed evidence of a gradual increase since the 1920s, reaching their highest levels in the past few decades. The Gulf Coast region has experienced the largest increase in annual precipitations, which was estimated at 10 – 20%.

Current trends in regional variations of precipitation and temperature are important parts of the hydrologic baseline conditions against which the potential effects of climate change should be assessed. The Gulf Coast region of the United States possesses a multitude of diverse climates as a consequence of its topography and being adjacent to a large body of water with widely varying thermal characteristics. The regional atmospheric circulation is dominated by disturbances (waves) in the upper-level westerly winds. In summer and autumn, tropical storms of the Atlantic, Caribbean, or Gulf of Mexico origin occasionally impact the coastal areas of the Gulf of Mexico. For the purpose of this case study, historical baseline precipitation and temperature are collected for the Tangipahoa watershed during the period of 1960 – 2000. These data will be used to evaluate the Canadian model predictability. Daily maximum and minimum temperature, and precipitation intensity records in the Tangipahoa watershed during the period of 1960 – 2000 are shown in Appendix I.

Projected Climate Forcing Scenarios

The wide range of projected changes in temperature and precipitation suggest that caution is required in treating future climate scenarios developed using the GCMs. Such scenarios should be regarded as internally consistent patterns of plausible future climates, not as predictions. The climate scenarios were projected using future climate trends based on assumptions of one percent per year increase in greenhouse gas concentration, and stabilization of greenhouse gas concentration occur. Some other important assumptions in projecting climate scenarios are that by year 2100: 1) population will nearly double; 2) the economic growth rate will continue at an average rate similar to the existing one; and 3) total energy production from non-fossil sources will continue to increase to more than ten times the current amounts (IPCC, 2000).

Projected climate data from an ensemble of four 50-year simulations using the IPCC "IS92a" forcing scenario in which the change in greenhouse gases (GHG) forcing corresponds to that observed from 1900 to 1996 and an increases in CO_2 at a rate of 1% per year thereafter until year 2100 were used to project the climate forcing parameters in the next 100 year. The direct effect of sulphate aerosols (A) was also included. All Canadian model runs were performed with the same greenhouse gas and aerosol forcing. The only difference was that the runs were initiated from different initial conditions. The reason for doing an ensemble of integrations is to reduce the natural climate variability by taking the ensemble average over the four runs. Therefore, differences between the individual integrations were entirely due to natural variability and not due to the differences in the model computation or forcing. The data were provided on one Gaussian grid (approximately 3.75^{O} lat x 3.75^{O} long or 1000 to 1500 km in mid-latitudes). The Canadian Model Gaussian grid showing the Gulf Coast region is included in Appendix IV.

These Gaussian grids were linearly interpolated to Northern and Southern Hemisphere polar stereographic grids. There is only one Gaussian grid box roughly covers the whole Gulf Coast region. The Canadian model attempts to represent the full climate system from first principles on a large scale probably greater than the Gulf Coast region. In this case study — Tangipahoa watershed is only about 518,600 acres however the Gaussian grid box used by the Canadian model probably exceeds 800 times the Tangipahoa watershed area. Therefore, projected climate parameters adaptation process was needed before comparing climate model output with observations or analyses on spatial scales smaller than the Gaussian grid size, or when using model output to study the hydrological impacts of climate variability and change. The Canadian model climate trends were integrated in a total of two sets of monthly projection data for the period of 1900 – 2100 for the Gulf Coast region. The first record was for year 1900 month 1 and the last one was for year 1999 month 12. The second record was for year 2000 month 1 and the last one was for year 2100 month 12. The projected climate trends included monthly temperature (maximum and minimum), precipitation, evaporation, solar radiation, specific humidity, and soil moisture. The whole set of the Canadian model climate parameters trends are presented in Appendix IV.

The Canadian model results, particularly monthly precipitation and temperature (maximum and minimum), were disaggregated to estimate the daily values using basic statistics in addition to the known measured trends in precipitation and temperature as described earlier under 3.2.1 and as shown in Appendix I. Ignoring the spatial and temporal variability and uncertainty of the projected precipitation over a local or relatively small area (Tangipahoa watershed) are among the major weaknesses of the existing regional GCMs generally. Therefore, to reduce this inherent uncertainty associated with the regional GCMs, part of the first set of Canadian model precipitation trends of 1960 – 1999 was compared to the actual measurements in the Tangipahoa watershed. The projected daily time series precipitation plot was generally flat passing by the average annual precipitation value and did not show the storm peak events. It was obvious that the Canadian model ignored the temporal variability of precipitation; furthermore, it averaged the projected precipitation over the study period of time. This situation reveals that, regional GCMs mainly are incapable of determining wet periods of the individual storm events on a sub-regional area, so that, the amount of rain was distributed over the storm duration period. This situation underestimated the amount of surface runoff and as a result the stream flow. Consequently, this situation significantly underestimated the extreme flood events since the storm peaks were not clearly defined.

A simple daily correction factor was determined based on the actual seasonal rainfall variability and the available historic daily rainfall observations of 1960 – 1999 in the Tangipahoa watershed. The adapted (corrected) daily precipitation projection values were estimated by multiplying the Canadian model daily precipitation values of 1960 – 1999 by the correction factor in order to enhance the daily precipitation prediction of the Canadian model. This calibration process was repeated several times until the adapted daily precipitation values showed satisfactory matching trends and agreement with the actual daily precipitation observations during the period of 1960 – 1999. The final correction factor was used to adapt the projected precipitation during the period of 2000 – 2100. Daily plots of the Canadian model adapted precipitation results during the period of 2000 – 2100 versus the actual measurements during the period of 1960 – 1999 are available in Appendix V.

The Canadian model projection to the year 2100 determined that annual precipitation will increase by 7–10%, and changes in spatial and tem-poral precipitation patterns would occur with higher variability (Figure 8). The Canadian model showed also that the mean annual surface temperature will increase by 5 – 8^{O}C, which agreed with the general finding of global warming in the United States, (Figures 9). In the meantime, the temperature variability in the next 100 years recorded a significant increase if compared with its trend in the period of 1960 – 1999 as shown in Figure 9 and the yearly moving-average graph shown in Appendix V. Daily presentation of the Canadian model temperature results during the period of 2000 – 2100 versus the actual measurements during the period of 1960 – 1999 are available in Appendix V.

The Canadian model predicted the continuous increase in annual average precipitation amounts from 56 inches to 60 inches, and to 62 inches during the periods of 1960 – 1999, 2000 – 2049, and 2050 – 2100, respectively. The percentage of precipitation increase over the period of 1960 – 2100 was estimated to be about 7 – 10%. This finding agreed with the analyses of U.S. Historical Climatology Network data described under 3.5.2 and with Lettenmaier and Sheer (1991). Figure 8 shows the increase in annual average precipitation during the same periods of 1960 – 1999, 2000 – 2049 and 2050 – 2100 as 4.15, 4.20, and 4.30 mm/day, respectively. In addition, annual variability of the precipitation increased during the period of 2000 – 2100 if compared with its trend during the period of 1960 – 1999. The same finding can be extracted from the precipitation yearly moving-average as shown in Appendix V. Based on the Canadian model adapted daily precipitation (Appendix V), it was obvious that, stronger storms with higher peak intensities are more likely to occur during the next 100 years. Instead of getting storm with peaks of about 250 mm/day during 1960 – 1999, it is expected to get storms of peaks up to 450 – 500 mm/day during the next 100 years. Furthermore, intervals between consequent storms are getting shorter, which increases the possibility of flood hazard. Based on this discussion, the Canadian model projected and adapted climate data for the period 2000 – 2100 can be used by the hydrological model with a significant degree of confidence to estimate the future extreme flood events in the Tangipahoa watershed. Therefore, the daily data of adapted precipitation, maximum and minimum temperatures; monthly data of solar radiation, specific humidity; and annual increase in greenhouse gases rate +1% were used by the SWAT model in order to estimate the extreme flood events in the next 100 years to the year 2100 in the Tangipahoa watershed.

10.3 Typical Hydrologic Results of the Projected Climate Forcing (2000-2100)

The annual average stream flow of the Tangipahoa River at its outfall during the period of 1938 – 2100 is presented in Figure 10. The monthly estimated stream flow at the Tangipahoa River outlet during the period of 1938 – 2100 is shown in Figure 11. The seasonal variation in precipitation versus stream flow at the Tangipahoa River outfall is illustrated in Figure 12. In addition, typical monthly SWAT model stream flow results based on the Canadian model projected climate data at the Tangipahoa River outfall during the periods of 2000 – 2049 and 2050 – 2100 as well as the SWAT estimation based on the actual climate data during the period of 1938 – 1999 are available in Appendix VI.

10.3.1 Impacts of Climate Forcing, Anthropogenic Activities, and the Greenhouse Effect on Extreme Flooding

Other studies concerning recent trends in precipitation and streamflow have shown generally increasing values throughout much of the United States. Total precipitation trends indicate an increase and monthly streamflow analyses show varying seasonal changes. Lettenmaier et al., (1994) analyzed the precipitation data over the period of 1948 – 1988 and found generally increasing trends during the months of September to December and increasing trends in streamflow during the months of November to April, particularly in the central and north-central portions of the United States. Similarly, Hurd et al., (1999a; b) reported that streamflow has increased throughout much of the conterminous United States since the early 1940s, with the increases occurring primarily in autumn and winter. Groisman, et al., (2001) explained the changes in the intensity of precipitation and streamflow during the period of 1939 – 99 based on over 150 unregulated streams across the US with nearby precipitation measurements. It was found that, the largest changes have been the significant increases in the heaviest precipitation events and the highest streamflows. It was found that changes in streamflow follow changes in precipitation, but are amplified by about a factor of 3. In the Gulf Coast region, precipitation and surface runoff have increased significantly over the past 100 years (Keim et al., 1995).

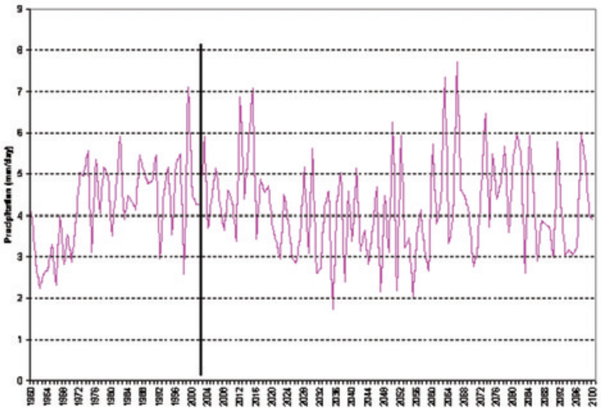


Figure 8. Annual Average Precipitation at the Tangipahoa Watershed (1960-2100).

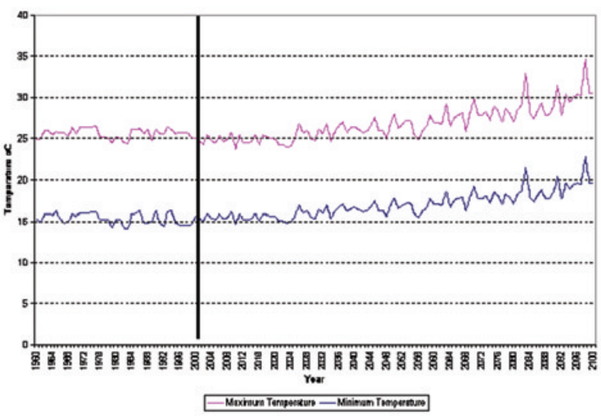


Figure 9. Annual Average Maximum and Minimum Temperature at the Tangipahoa Watershed (1960-2100).

The annual average stream flow trend during the period of 1938 – 2100, as shown in Figure 10, indicated a significant increase in the Tangipahoa River projected discharges in the next 100 years. These results strongly confirmed the reported findings of Lins and Michaels (1994); and Keim et al., (1995). However, the Tangipahoa River annual average discharge recorded 892 cfs, 1,319 cfs, and 1,286 cfs during the periods of 1938 – 1999, 2000 – 2049, and 2050 – 2100, respectively. These results suggest that, the projected climate forcing could decrease the stream flow of the Tangipahoa River in the second half of this century, but still the flood hazard will remain since the average annual discharge is expected to exceed the existing average records by about 44%. During the early period (1938 – 1962), the Tangipahoa watershed was virtually undeveloped.

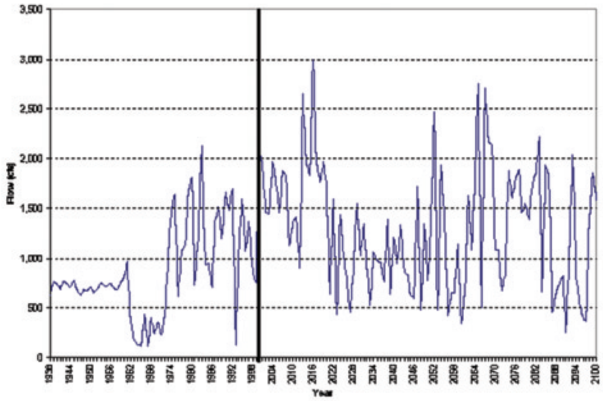


Figure 10. Annual Average Stream Flow at the Tangipahoa River Outfall (1938-2100).

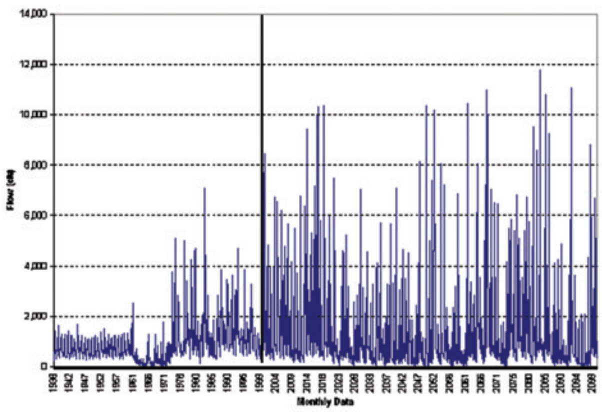


Figure 11. Monthly Estimated Stream Flow at the Tangipahoa River Outlet (1938-2100).

Introduction of development, urbanization, and other human activities to the area seemed to result in the river flow increasing. The projected climate data, in association with the SWAT model monthly stream flow prediction (Figure 11), indicated that the Tangipahoa River flow increase will continue with a rising trend of the mean value and could cross the safe threshold band causing severe flood events during the next 100 years. These results supported and strengthened the previous studies findings and analyses, and indicate a high possibility of stream flow rise and increased flood risk in the Tangipahoa watershed and probably the Gulf Coast region as well based on the study assumption which considered Tangipahoa watershed as a good prototype of the Gulf Coast region.

Although the Canadian model projects an increase in precipitation over the Tangipahoa watershed, the rates of evaporation and perhaps transpiration also are likely to increase with increasing temperatures (Appendix IV). Therefore, in locations where the changes in precipitation do not offset the increasing rates of evaporation and transpiration they may experience declines in surface runoff and consequently show a decline in Tangipahoa River flow trends. Such offsets could explain the seasonal projected stream flow for the Tangipahoa River in the period of 2050 – 2100, as shown in Figure 12. The increase in temperature and evaporation trends would also result in a lower soil moisture trend especially in the summer seasons during the next 100 years as indicated in Appendix IV. Alternatively, the substantial increases in precipitation are likely to have associated substantial increases in surface runoff and Tangipahoa River flow trends as indicated in Figures 10–12. On the other hand, the soil radiation trend did not show significant change, however, the specific humidity trend scored significant increase of about 25% (Appendix IV).

Projected change of the Tangipahoa River annual stream flow using the Canadian model climate change scenarios indicate potential increases as well as declining trends. Seasonal changes in stream flow also could be substantial. The climate change scenarios suggest increased winter precipitation, which could result in increased stream flow of the Tangipahoa River in winter and spring. On the other hand, the climate change scenarios show declines in summer precipitation and as a result declines in summer soil moisture levels could occur, which could result in significant declines in summer and autumn stream flows. However, climate change scenarios would likely show summer decline in precipitation or soil moisture trends generally if simulations were done using doubled CO_2 forcing alone; but since aerosol forcing was included, summer precipitation and soil moisture levels increased only slightly. This pattern highlighted the large uncertainty in climate change projections of stream flow and as a result the flood event analyses.

10.3.2 Variation in Climate and Flooding Mechanisms

Global climate models are not capable of predicting extreme flood events because they lack regional and local spatial and temporal resolution. While, there is no clear evidence that sustained changes in extreme flood events have occurred in the past few decades in the Gulf Coast region, such events can be serious. They can cause loss of life and endanger human health or property. Extreme flood events can results in the spread of infectious diseases, incidence of stress-related disorders, and other adverse health effects associated with social and environmental disruptions (e.g., flooding of sewage systems).

During the period of 1938 – 1974, as long as the Tangipahoa River flowed close to the average or expected level (892 cfs), there was no significant flood hazard and the discharge was perceived as a resource, as shown in Figure 11. Smith and Ward, 1998 stated, that when the river flow exceeds some predetermined threshold of local significance and extends outside the band of tolerance, it ceased to be beneficial and was perceived as a flood hazard. In this case study, the Tangipahoa River showed an increased tendency to be a flood hazard during the period of 1974 – present. It is expected that the flood risk will rise dramatically during the next 100 years due to the projected sharp rise in stream flow and increase in the flow variability as shown in Figure 10. However, determination of the safe band of tolerance is uncertain because it depends on the overall ecosystem integrated with the anthropogenic activities and socioeconomic systems in place as well. Also, the impact of the hazard is, in part, determined by the magnitude of the flooding event (expressed by the peak deviation beyond the damage threshold on the vertical scale) and the duration of the event (expressed by the length of time of which the threshold value is exceeded on the horizontal scale). The true significance of any flood disaster will depend primarily on the vulnerability of the local community. The Tangipahoa River often overflows its banks in some areas along its length, without creating a significant hazard and such hydrologically defined "flood flows" may create little economic damage and produce no response from the emergency services.

10.4 Implications of Projected Climate Forcing and Anthropogenic Activities

Four points must be kept in mind when considering the extent to which adaptive strategies should be relied upon. First, adaptation is not without cost. Sometimes, they are not expensive but may also bring unexpected benefits. Natural and financial resources must be diverted away from some activities into adaptive practices. Second, the economic and social costs of adaptation will increase the more rapidly climate change occurs. Third, although many opportunities exist for technological and behavioral adaptation, uncertainties exist about potential barriers and limitations to their implementation. Fourth, uncertainties exist about the efficacy and possible secondary effects of particular adaptive strategies. Climate change creates long-term components for decision makers and policy makers that influence natural and human systems and pose significant challenges (environmental, social, and economic issues). For example, climate change assessment of the potential impacts and variability on extreme flood events must account for the qualities of water in the storage, supply, and distribution systems that are being used for various anthropogenic activities.

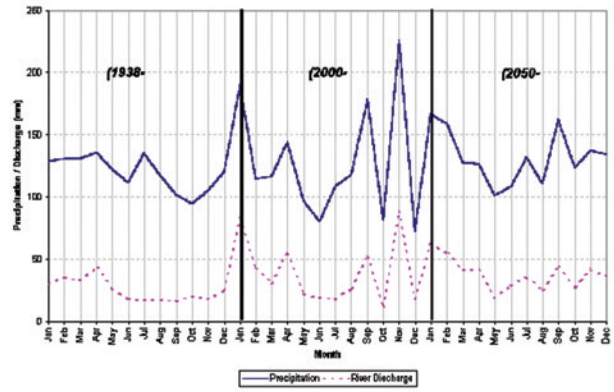


Figure 12. Seasonal Precipitation vs. River Discharge in Tangipahoa Watershed (1983-2100).

10.4.1 Socioeconomic Impacts of Projected Ecological Change

Changes in the climate system such as extreme flood events can affect natural and human systems in a chain of consequences. Some of these consequences are results of direct effects of climate change and variability on physical, biological, and socioeconomic systems. Some impacts are the result of indirect links between climate-sensitive systems and related social and economic activities. And some impacts result from feedbacks between human activities that affect the climate system that in turn can lead to further impacts on human health, the environment, and socioeconomic systems.

Wetlands in the Gulf Coast region traditionally have been viewed as wasted land available for conversion to more productive uses. Alteration of the original wetland functions leads to significant ecological impacts such as extinction of various plants, animals, and birds species, loss of hydrological and cultural wetlands functions, and overall disturbance in the natural chemical, physical, and biological balance. The projected extreme flood events in the next 100 years have the potential to impact those wetlands to an extent equivalent to these expected ecological changes described above. These two forces would contribute to the loss of millions of wetland hectares. In general, the United States lost approximately 53% of the original wetland area in the lower 48 states (Maltby, 1986; Mitsch and Gosselink, 1986). In 1997, the FEMA estimated damage caused by weather-related natural disasters (wildfires, hurricanes, extreme floods, ice, tornadoes, and other extreme weather events) during the years 1992–96 in the United States by about $39 billion per year.

Socioeconomically, for example, wetlands surrounding Lake Pontchartrain, LA (Figure 1), provide direct benefits through the harvesting of timber, wild rice, cranberries, and horticultural peat as well as through recreational activities such as hunting, fishing, and bird watching. The cultures and spiritual values of many First Nation peoples are linked to the health of such wetlands. However, vulnerability of the Pontchartrain ecosystems and the related socioeconomic sectors may be affected by changes in climate system. For example, the projected extreme flood events in the Tangipahoa watershed in the next 100 year will directly affect the quality of life, alter patterns of settlement and human activities, and subject humans to risks regarding their health, safety, and property in the Pontchartrain ecosystem.

The projected extreme flood events could include secondary impacts on market activities. For example, extreme flood events directly affect crop yields and hence agricultural production and prices. These effects, in turn, influence the prices of goods and services that use agricultural commodities in their production, which feed back to the agricultural sector and agricultural prices. Shifts in agricultural production could have a large impact on freight transport patterns and may require adjustments in the transportation network with marine, road, rail, and air links potentially needing expansion into areas not currently serviced. In severe flood events, water transport could be affected by changes in river navigability. During the 1993 flood in the upper Mississippi valley, it disrupted the barge transportation system. Also during the 1997 hurricane George, increased siltation associated with floods prevented ships from reaching the port of New Orleans, LA for several days. Furthermore, offshore oil and gas exploration and production in the Gulf of Mexico could be influenced by the projected extreme flood events in the next 100 years. Generally, extreme flood events have direct impacts on: economic activity in the industry, energy, and transportation sectors, markets for goods and services, offshore oil and gas production, manufacturing dependent on water, tourism and recreation, and natural resources in the Gulf Coast region.

10.4.2 Human Health Aspects

Extreme flood events in the Gulf Coast region are likely to have wide-ranging and mostly adverse impacts on human health. These impacts could arise by direct pathways (e.g., contaminated drinking water by chemical and/or biological leakage) and indirect pathways (e.g., potential increase in: transmission of vector-borne and waterborne diseases; mold spores; malnutrition; and general public health infra-structural damage). Extreme flood events could also jeopardize access to traditional foods garnered from land and water (such as game, wild birds, fish, and berries), leading to diet-related problems such as obesity, cardiovascular disorders, and diabetes of indigenous peoples as they make new food choices (Government of Canada, 1996; IPCC, 2000).

Warming may at first appear beneficial. Plants may be fertilized by warmth, moisture, more CO_2, and nitrogen. But warming and increased CO_2 can also stimulate microbes and their carriers, and added heat can destabilize weather patterns. In the Gulf Coast region, the frequency of very hot days in temperate climate is expected to approximately double in the summer. Heat waves cause excess deaths (Kilbourne, 1992), many of which are caused by increased demand on the cardiovascular system required for physiological cooling. Aging can be expected to be accompanied by multiple, chronic illnesses that may result in increased vulnerability to infectious disease or external/environmental stresses such as extreme heat (Hobbs and Damon, 1998). Warmer temperatures can accelerate production and increase concentrations of photochemical oxidants in urban and rural areas and thus exacerbate respiratory disorders. Consequences of warming on human illness and health of livestock and fisheries may be significant (Santer et al., 1996). The resurgence of infectious diseases thus poses threats to food and biological security, and to economic development. Probable water-borne pathogens due to extreme flood events in the Pontchartrain ecosystem, LA include viruses, bacteria, and protozoa. Examples include Vibriovulnificus, a naturally occurring estuarine bacterium responsible for a high percentage of the deaths associated with shellfish consumption (Shapiro et al., 1998); Cryptosporidium parvum and Giardia lamblia, protozoa associated with gastrointestinal illnesses (Craun, 1998); and biologic toxins associated with harmful algal blooms (Baden et al., 1996).

In the United States, 145 natural disasters resulted in 14,536 deaths from 1945 to 1989. Of these events, 136 were weather disasters; these extreme weather events caused 95% of all disaster-related deaths. According to the National Weather Service, severe storms caused 600 deaths and 3,799 reported injuries in 1997 (NWS, 1999). Floods are the most frequent natural disaster and the leading cause of death from natural disasters in the US; the average annual loss of life is estimated to be as high as 146 deaths per year (NWS, 1992).

The probable risk of water-borne diseases in the next 100 years as a result of extreme flood events depends mainly on policy responses and level of maintenance or improvement of infrastructure. Current adaptations for assessing and preventing water-borne diseases include legal and administrative measures such as water safety criteria, monitoring requirements, and health outcome surveillance, as mandated under the Safe Drinking Water Act, with amendments in 1996 (USEPA, 1997b). Recent legislative and regulatory attention has focused on improved treatment of surface water to address microbial contaminants and on ground water and watershed protection (ASM, 1998; USEPA, 1998b).

10.5 The Control of Flood (Coping Strategy)

Strategies for technological and behavioral adaptation offer an opportunity to reduce the vulnerability of sensitive systems to the effects of climate change and variability. The purpose of flood control is to modify the hydrodynamic characteristics of river flows in order to reduce the flood risk. Flood control in the Gulf Coast region can be achieved by two ways. First, traditional flood protection methods, e.g., channel modifications, using artificial materials for constructing levees and dams. In coastal areas, sea walls are highly recommended to resist the energy of incoming waves and tides. Second, by flood abatement methods, e.g., using essential natural materials, whether of geological or biological origin, and the existing environmental processes to control flooding and land erosion. In coastal areas, salt marshes are important to protect the banks of estuaries and beaches. Vegetation cover management is one of the most effective methods of flood control. A complete vegetation cover helps to reduce soil erosion and flooding through the detention of rainfall by interception, increased infiltration, and reduced runoff through enhanced evaporation and evapotranspiration. Also, local flood abatement can be achieved in urban areas by encouraging the maximum infiltration rates in parks and water detention basins.

10.6 Information and Research Needed in the Future

Most future climate impact studies have assessed how natural systems will respond to climate change resulting from projected climate forcing scenarios. These scenarios are subjected to regional-scale analyses to the extent that they inadequately correspond to the local scale studies, e.g., the Tangipahoa watershed. They also lack the resolution to permit an examination of the effects of climate variability on physical, biological, and socioeconomic systems.

Understanding historic changes, or projecting future changes in streamflow conditions will require more evaluation of the complex role of changing precipitation and temperature patterns as well as the role of land-use change on streamflow. These unresolved issues further reinforce the importance of maintaining adequate nationwide networks of precipitation and streamflow gages to help describe and predict changes in average streamflow and, more importantly, streamflow variability. Projecting future changes in streamflow conditions will require more evaluation of the complex role of changing precipitation and temperature patterns as well as the role of land-use change on streamflow. There is a need to continue to refine existing GCMs, and improve model validation and comparison. Hydrologic and climate modeling tools integration could be improved if scaling problems between the models are better understood. Output should be tailored to users needs. Key areas for model development include better physically based parameterizations for groundwater/surface water interactions, atmospheric feedbacks, variability of precipitation, and land surface characteristics at a watershed scale.

Wetlands restoration in managed watersheds can reduce the impact of storm water runoff to waterways by slowing down or absorbing excess water. Providing wetland protection including buffer areas beyond the wetland boundary is a viable method of avoiding flood damage or the cost of flood protection.

There have been relatively few studies addressing the change in risk directly because of the lack of credible climate change scenarios at the level of detail necessary to predict, for example, extreme flood events. There is a lack of accurate information on: 1). Links between land use and water quality, through better assessment at the watershed level of the food-borne transport and fate of microbial pollutants associated with rain and snowmelt; 2) Methods to improve surveillance and prevention of water-borne disease outbreaks; 3) Epidemiologic studies; 4) Molecular tracing of water-borne pathogens; 5) Links between drinking water, recreational exposure, and food-borne disease monitoring; 6) Links between marine ecology and toxic algae; and 7) Vulnerability assessment to improve water and waste water treatment systems. We are living in a period of accelerated social, ecological, and climatic change. But will our global society react to the symptoms of environmental dysfunction in time to take corrective measures?

10.7 Findings and Conclusions

Multiple activities induced in the Earth's atmosphere (e.g., carbon buildup and gasses accumulation) are changing the chemistry of the air and in the process altering the heat budget of the world. These also constitute a destabilizing array of forcing factors. Together they have already begun to alter natural climatic modes. These modifications have begun to affect biological systems and human health. The purpose of this case study is to contribute to the long-term sustainability of the Gulf Coast region through credible evaluation of the consequences of climate change with a focus on the extreme flood events. Establishment of the regional baseline and scenarios is the first step of this assessment. Without a good understanding of the current conditions and future trends, one could not conduct any climate change impact assessment. The current climate baseline was established and the climate forcing scenarios/future trends were also projected. The established current condition provided information needed for the projection of the future scenarios. Results obtained from this case study can be helpful in assessing the impacts of future climate change on the natural environment, human, society, and economy of the Gulf Coast region through parallel research case studies.

Using the Canadian climate model that incorporates projected changes in greenhouse gases and aerosols into scenarios resulted in likely, projected trends of precipitation, tempera-ture, solar radiation, and humidity in the Gulf Coast during the next 100 years. The Canadian model projection to the year 2100 determined that the mean annual surface temperature will likely increase by 5 – 8^oC, annual precipitation will likely increase by 7–10%, and that changes in the spatial and tem-poral patterns of precipitation would occur. The increase in heavy rainfall events could increase the potential for flooding of human settlements in the Gulf Coast region. The expected severe storms (double the magnitude of the existing storms) could have widespread impacts on roads, railways, and other transportation links. As long as rainfall will become more intense, impacts on urban areas are likely to be significant. In the next 100 years, extreme flooding (+44%) could be one of the significant impacts of climate change because of the large amount of property and human life potentially at risk in the Gulf Coast region. The expected more frequent and stronger flood events could cause considerable disruption of transportation and water supply systems.

In this study, a 5 – 8^oC rise in temperature and a 7–10% increase in annual precipitation were projected for the next 100 years. This situation could create opportunities and limitations for outdoor recreation. Human activities and infrastructure are especially vulnerable to extreme flood events. Hence, there could be severe impacts if the frequency or intensity of extreme floods increases as predicted. The specific human and economic impacts from significantly large floods are difficult to measure. The ability to predict changes in the frequency or intensity of extreme flood events using global and regional models has been limited by their lack of small-scale spatial and temporal resolution and uncertainties about representation of some processes. The historical changes in frequencies of extreme flood events also provide some insights on possible changes. Several questions arise at this stage, among them, 1) If the current climate forcing trends continue, what are the environmental impacts that would result? 2) What if the slope of already observed trends gets steeper? 3) What has the cost already been just from the observed trends? 4) What if it continues? And 5) What if it gets steeper?

The projected extreme flood events in the next 100 years could impact the wetlands (e.g., Lake Pontchartrain ecosystem, LA) to an equivalent extent as that expected from ecological changes, such as extinction of various plants, animals, and birds species, as well as loss of hydrological and cultural wetlands functions, and overall disturbance in the natural chemical, physical, and biological balance. Extreme flood events are likely to have wide-ranging and mostly adverse impacts on anthropogenic activities and human health. These impacts would arise by direct pathways (e.g., contaminated drinking water by chemical and/or biological leakage) and indirect pathways (e.g., potential increase in: transmission of vector-borne and waterborne diseases; mold spores; malnutrition; and general public health infra-structural damage).

Scientific studies show that human health, ecological systems, and socioeconomic sectors (e.g., hydrology and water resources, food and fiber production, coastal systems and human settlements), all of which are vital to sustainable devel-opment, are sensitive to extreme flood events (including both the magnitude and duration of the flood). During the last 100 years, the Gulf Coast region was likely to experience several severe climate events and they brought both adverse and beneficial impacts. Climate change represents an important additional stress on those systems already affected by increasing resource demands, unsustainable management practices and pollution, which in many cases may be equal to or greater than those of climate change. Additional research is needed to better understand the sensitivity and vulnerabilities of human settlements and infrastructure to extreme flood events in the Gulf Coast region, including factors beyond climate that are changing those vulnerabilities.

Acknowledgment

The author expresses his deep appreciation for the great assistance of Professor Tommy Coleman, Director of the Center for Hydrology, Soil Climatology, and Remote Sensing (HSCaRS), Alabama A&M University, Huntsville, Alabama. His guidance pushed ahead this research. Many sincere thanks are owed to Professor Zhu Ning, Principle Investigator of the Gulf Coast Climate Change Assessment Project, Southern University and A&M College at Baton Rouge, Louisiana for her significant directions and enlightening conversations. Acknowledgment is also given to Professor Govind Sharma, Head of the Department of Plant and Soil Science (PSS), Alabama A&M University for his effective insights that furnished to finalize this research. Sincere gratitude goes to my colleagues and graduate students at the HSCaRS and PSS at Alabama A&M University for their encouragement, support and helpful conversations. The author expresses tremendous appreciation and thanks for the Canadian General Coupled Model developers and technical advocates at the Canadian Center for Climate Modeling and Analyses for giving him continuous technical support. This research is encouraged by the NASA Grant No. NCC8-140 of the HSCaRS Center.

The author wishes to express his gratitude and deep indebtedness to the professors, researchers, and graduate students of the University of New Orleans, Louisiana and for Freeport Mc MoRan Inc. for their support, encouragement, and for providing facilities that made the implementation of the hydrologic simulation and analysis of this research easier. Particular acknowledgement must be made for Drs. Alim Hannoura and Alex McCorquodale whose advice and guidance helped in the establishment of the hydrological modeling technique of this research.

References

American Society of Civil Engineers, 1993. Task Committee on Definition of Criteria for Evaluation of Watershed Models of the Watershed Management Committee, Irrigation and Drainage Division, Journal of Irrigation and Drainage Eng. 119(3): 429-442.

Andres, R. J., G. Marland, T. Boden, and S. Bischoff, 2000. Carbon dioxide emissions from fossil fuel combustion and cement manufacture, 1751 to 1991, and an estimate for their isotopic composition and latitudinal distribution, in The Carbon Cycle, edited by T. M. L. Wigley and D. Schimel, Cambridge University Press, Cambridge, United Kingdom, 312 pp.

Arnold, J. G., and Allen, P. M., 1996. Simulating Hydrologic Budgets for Three Illinois Watersheds. Journal of Hydrology 176: 57-77.

Arnold, J. G., Allen, P. M., and Bernhardt, G. 1993. A Comprehensive Surface-Groundwater Flow Model. Journal of Hydrology 142:47-69.

Baden, D. G., L. E. Glemming, and J. A. Bean, 1996. Marine toxins, in Handbook of Clinical Neurology, Intoxications of the Nervous System: Part II, edited by F. de Wolf, Elsevier Science, Amsterdam, 141-75.

Baumann, P. R, 1996. Flood Analysis: 1993 Mississippi Flood, the project The Remote Sensing, Department of Geography, SUNY at Oneonta, Oneonta, NY 13820, http://umbc7.umbc.edu/~tbenja1/baumann/baumann.html

Boer, G. J., Flato, G. M, and Ramsden, D., 2000. A transient climate change simulation with historical and projected greenhouse gas and aerosol forcing: projected climate for the 21st century, Climate Dynamics, 16:427-450.

Boer, G. J., Flato, G. M.; Reader, M. C.; Ramsden, D., 2000. A transient climate change simulation with historical and projected greenhouse gas and aerosol forcing: experimental design and comparison with the instrumental record for the 20th century, Climate Dynamics, 16:405-425.

Craun, G. F., 1998. Waterborne Disease in the United States, CRC Press, Boca Raton, Florida, pp.295.

Flato, G. M. and G. J. Boer, 2000. Warming Asymmetry in Climate Change Simulations, Geophysical Research Letters, submitted.

Frederick, K. D., and G. E. Schwarz, 1999. Socioeconomic impacts of climate variability and change on US water supplies, unpublished manuscript.

Gates, W. L., Houghton, J. T., Filho, L. G. F., Callander, B.A., Harris, N., Kattenberg, A., and Maskell, K., 1996. Climate Models – Evaluation, (eds), Climate Change 1995: The Science of Climate change, Cambridge University Press, Cambridge, 229-284 pp.

Gent, P. R. and J. C. McWilliams, 1990. Isopycnal Mixing in Ocean Circulation Models, Phys. Oceanography 20: 150-155.

Gornitz, V. and S. Lebedeff, 1987. Sea Level Fluctuations and Coastal Evolution, Tulsa, Oklahoma: SEPM Special Publication No. 41, pp 3-16.

Groisman, P. Ya., R. W. Knight, and T. R. Karl, 2001. Mean precipitation and high streamflow in the contiguous United States: Trends in the twentieth century, Bulletin of the American Meteorology Society, in press.

Grubb, H. F., and Carrillo, R. J. J., 1988. Region 23: Gulf of Mexico Coastal Plain, in: Back, W., Rosenshein, J. S., and Seaber, P. R., (eds), Hydrogoelogy: Boulder, Colorado, Geological Society of America, The Geology of North America, vol. 2.

Hanshaw, B. B., and Bredehoeft, J. D., 1968. On the Maintenance of Anomalous Fluid Pressure: II. Sources Layer at Depth: Geological Society of American Bulletin, vol. 79, p. 1107-1122.

Harvey, L. D., 2000. Climate and Global Environmental Change, Prentice Hall.

Higgins, R. W., Y. Yao, E. S. Yarosh, J. E. Janowiak, and K. C. Mo, 1997: Influence of the Great Plains low-level jet on summertime precipitation and moisture transport over the Central United States. Climate 10: 481–507.

Hobbs, F. B., and B. L. Damon, 1998. 65+ in the United States, Bureau of the Census, US Government Printing Office, Washington, DC.

Houghton, R. A., 1995. Land-use change and the carbon cycle, Global Change Biology 1: 275-287.

Hurd, B. J., N. Leary, R. Jones, and J. Smith, 1999a. Relative regional vulnerability of water resources to climate change, Journal of the American Water Resources Association, 35(6), pp.1399-1410.

Hurd, B, R. Jones, N. Leary and J. Smith, 1999b. A regional assessment and database of water resource vulnerability to climate change, Proceedings of the AWRA Specialty Conference on Potential Consequences of Climate Variability and Change to Water Resources of the United States, American Water Resources Association, Herndon, VA, pp.45-48.

Intergovernmental Panel on Climate Change (IPCC), 1996. IPCC Technical Guidelines for Assessing Climate Change Impacts and Adaptations. Prepared by IPCC Working Group II [Carter, T. R., M. L. Parry, H. Harasawa, and S. Nishioka (eds.)] and WMO/UNEP. University College, London, United Kingdom, and Center for Global Environmental Research, Tsukuba, Japan, 59 pp.

Intergovernmental Panel on Climate Change (IPCC), 1996. Climate Change 1995:Impacts, Adaptations and Mitigation of Climate Change: Scientific-Technical Analyses, Cambridge University Press, New York.

Intergovernmental Panel on Climate Change (IPCC), 2000. Special Report on Emissions Scenarios, N. Nakicenovic (lead author), Cambridge University Press, Cambridge, United Kingdom, 599 pp.

Ismail, I., Cothren, G. M., Hannoura, A., and McCorquodale, J. A., 1998. Water Quality Assessment in the Lake Pontchartrain. 4th Bi-Annual Basics of the Basin Research Symposium, University of New Orleans, May 12-13.

Karl, T. R., and Riebsame, W. E., 1998. The impact of decadal fluctuations in mean precipitation and temperature on runoff: A sensitivity study over the United States Climate Change, 15, 423- 47pp.

Karl, T. R., and R. W. Knight, 1998. Secular trends of precipitation amount, frequency, and intensity in the USA, Bulletin of the American Meteorological Society, 79, 231-241.

Keim, B. D., G. E. Faiers, R.A. Muller, J.M. Grymes III, and R.V. Rohli, 1995. Long-term trends of precipitation and runoff in Louisiana, USA. International Journal of Climatology, 15, 531–541.

Khairy M. W., 2000. Integrated Watershed Management for Optimum Environmental Quality of Aquatic Systems, Ph.D. Dissertation, Dept. of Civil & Environmental Engineering, University of New Orleans, Louisiana.

Kilbourne, E. M., 1992 Epidemiological Statistics. WHO Reg Publ. Eur. Series, 42, 5–25.

Kunkel, K. E., S. A. Changnon, and J. R. Angel, 1994. Climatic aspects of the 1993 Upper Mississippi River basin flood. Bulletin of the American Meteorological Society, 75(5), 811–822.

Knutson, T. R., and R. E. Tuleya, 1999. Increased hurricane intensities with CO2 -induced global warming as simulated using the GFDL hurricane prediction system, Climate Dynamics, 15, 503-19.

Lanier Lee, 1969. Bloody Tangipahoa. In the Hammond indicator, Feb. 2, p 4.

Leatherman, S. P., K. Zhang, and B. C. Douglas, 2000. Sea level rise shown to drive coastal erosion, Transactions of the American Geophysical Union, EOS, 81, 55-57,2000 (also see responses and reply in EOS, 81, 436-437 and 439-441).

Lettenmaier, D. P. and Sheer, D. P. 1991. Climate Sensitivity of California water resources. ASCE J. Water Resources Planning and Management 117(1), 108-25.

Maltby, E., 1986. Waterlogged wealth. Earthscan Publications International Institute, Washington, DC, USA, 200 pp.

Meehl, G. A., F. Zwiers, J. Evans, T. Knutson, L. O. Mearns, and P. Whetton, 2000. Trends in extreme weather and climate events: Issues related to modeling extremes in projections of future climate change, Bulletin of the American Meteorological Society, 81, 427-436.

Mitchell, J. F. B., T. J. Johns, W. J. Ingram, and J. A. Lowe, 2000. The effect of stabilizing atmospheric carbon dioxide concentrations on global and regional climate change, Journal of Geophysical Research, 27, 2977-2980.

Mitsch, W. J. and J. G. Gosselink, 1986. Wetlands. Van Nostrand Reinhold Co. Inc., New York, NY, USA, 539 pp.

Moore III, B., Anderson, J., and Canavan, G. H., 1999. Global Environmental Change: Research Pathway for the Next Decade, Committee on Global Change Research, National Academy Press, ISBN 0-309-06420-1, 191-236 pp.

Nakicenovic, N., Alcamo, J., and Davis, G., 2000. Emission Scenarios: Summary for Policy Makers, The Intergovernmental Panel for Climate Change, a special report of IPCC working group III, ISBN 92-9169-113-5.

Nathan, R. J. and McMahon T. A., 1990. Evaluation of Automated Techniques for Base Flow and Recession Analysis. Water Resources, v 26, No.7, pp.1465-1473.

National Assessment Synthesis Team (NAST), 2000. Climate Change Impacts on the United States: The Potential Consequences of Climate Variability and Change – An Overview, US Global Change Research Program, Cambridge University Press, ISBN 0-521-000742, 46-47 pp.

Neitsch, S. L., Arnold, J. G., and Williams, J. R., 1999. Soil Assessment Tool User's Manual, ver. 98.1, Blackland Research Center, Texas Agricultural Experimental Station, (www.brc.tamus.edu/swat/) and (www.brc.tamus.edu/swat/swatgrass/).

Nicholes, C. M., 1979. Tangipahoa Crossing: Excursions into Tangipahoa History. 74 pp.

Ning, Z. H., and Abdollahi, K. K., 1999. Global Climate Change and Its Consequences on the Gulf Coast Region of the United States, Franklin Press, Inc. and GCRCC, ISBN 1-930129-60-2, 2-3 pp.

Nyman, J. Dale, and Larry, D. Fayard, 1978. Groundwater Resources of Tangipahoa and St. Tammany Parishes, Southeastern Louisiana, LA Dep. of Trans. and Dev., Office of pub. Works Tech. Bull. Baton Rouge, LA. 76 p.

Richardson, C. W., 1981. Stochastic Simulation of Daily Precipitation, Temperature and Solar Radiation. Water Resources Research 17(1): 182-190.

Santer, B. D., Taylor K. E., Wigley, T. M. L., Johns, T. C., Jones, P. D., Karoly, D. J., Mitchell, J. F. B., Oort, A. H., Penner, J. E., Ramaswamy, V., Schwarzkopf, M. D., Stouffer, R. J., and S. Tett, 1996. A search for human influences on the thermal structure of the atmosphere. Nature 382: 39-46.

Shapiro, R. L., S. Altekruse, and P. M. Griffin, 1998. The role of Gulf Coast oysters harvested in warmer months in *Vibrio vulnificus* infections in the United States, 1988-1996, Journal of Infectious Diseases, 178(3): 752.

Smith, K. and Ward, R., 1998. Floods: Physical Processes and Human Impacts, John Wiley & Sons, England, p 20.

Srinivasan, R., and Arnold, J. G., 1994. Integration of A Basin Scale Water Quality Model with GIS. Water Resources Bulletin: 30(3): 453-462.

Suttcliffe, J. E., and Nash, J. E., 1970. River Flow Forecasting Through Conceptual Models, Part I-A Discussion of Principles. Journal of Hydrology. 10(3): 282-290.

U.S. Army, 1988. GRASS Reference Manual. USA CERL, Champaign, Illinois, (http://www.baylor.edu/~grass/) USDA Soil Conservation Service. 1983. National Engineering Handbook Section 4 Hydrology, Chapter 19.

U. S. Department of Agriculture (USDA) - Soil Conservation Service (SCS), 1992. States Soil Geographic Database (STATSGO) Data User's Guide. Pub. No. 1492, U.S. Government Printing Office, Washington, D.C.

U. S. Department of Agriculture, Soil Conservation Services, Forest Services, and Mississippi Department of Environmental Quality, 1991. Tangipahoa Cooperative River Basin Study, Portion of Amite, Lincoln, and Pike Counties, Ms. Pub. no. 1314, U.S. Government Printing Office, Washington, D.C.

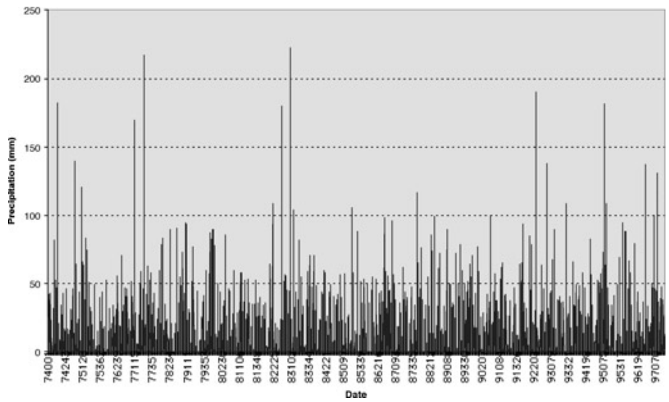
Watson, R. T., Zinyowera, M. C., Moss, R. H., and Dokken, D. J., 1997. The Regional Impacts of Climate Change: An Assessment of Vulnerability, The Intergovernmental Panel for Climate Change, a special report of IPCC working group II.

Weber, S. L., H. von Storch, P. Viterbo, and L. Zambresky, 1993. Coupling an Ocean Wave Model to an Atmospheric General Circulation Model. Climate Dynamics 9: 63-69.

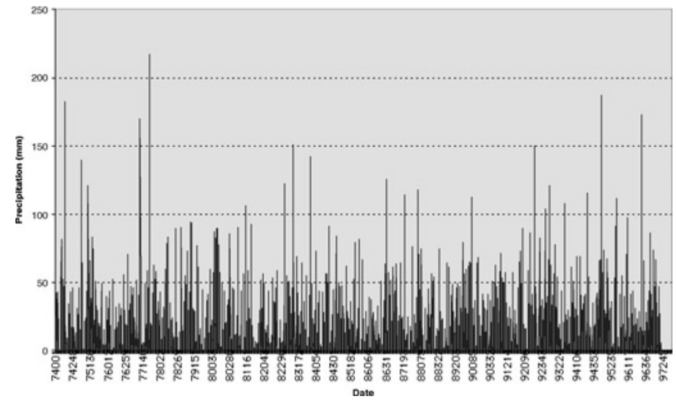
APPENDIX I

- Daily rain records measured at Hammond, Amite, Kentwood, and McComb rain gauge stations (1960 – 2000)
- Daily maximum and minimum temperature records and the air temperature seasonal variability in Tangipahoa watershed (1960 – 2000)
- Daily and seasonal variability stream flow records plots at the Tangipahoa River outfall (Robert location) – period (1938 – 2000)
- Peak flow at Robert location and other upstream locations

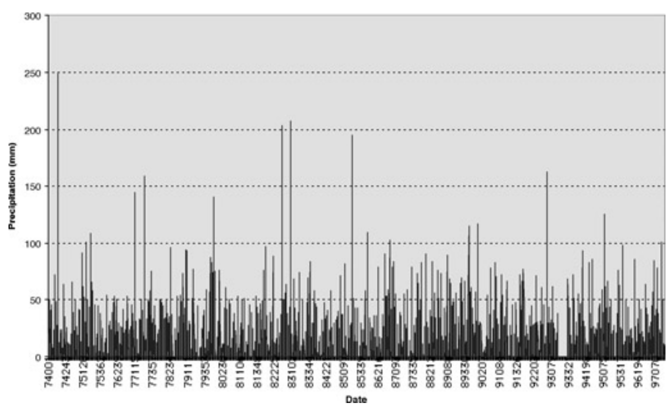
Amite Precipitation Station, Louisiana - SWAT file "Tan2.pcp"



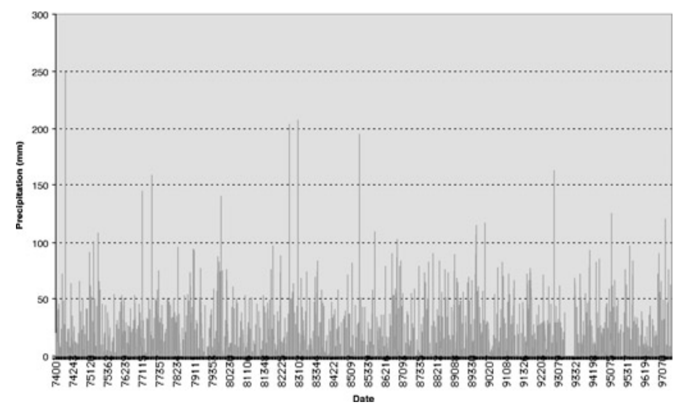
Hammond Precipitation Station, Louisiana - SWAT file "Tan3.pcp"



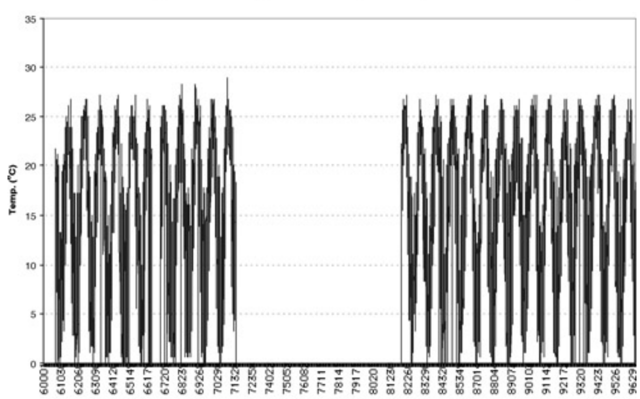
Kenwood Precipitation Station, Louisiana - SWAT file "Tan1.pcp"



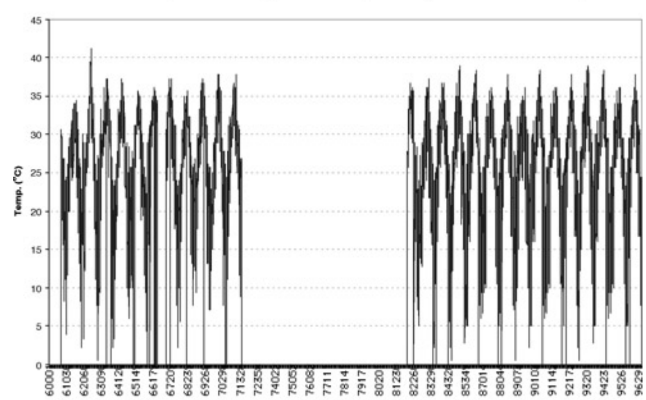
Mccomb Precipitation Station, Louisiana - SWAT file "Tan0.pcp"

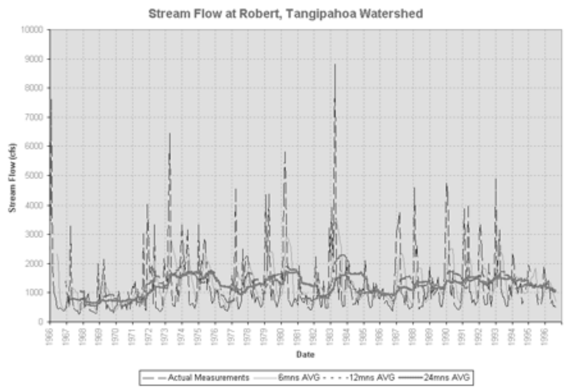


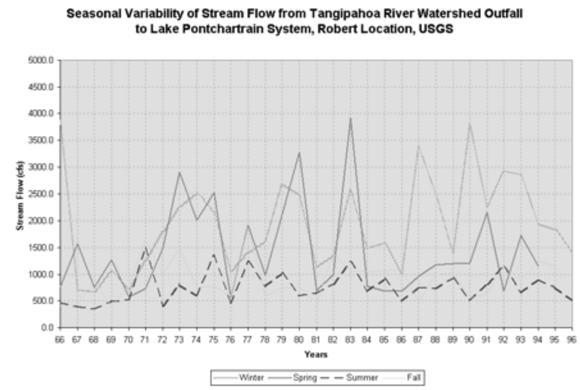
Minimum Temperature over Tangipahoa Watershed (Generated by SWEAT Weather Generator)

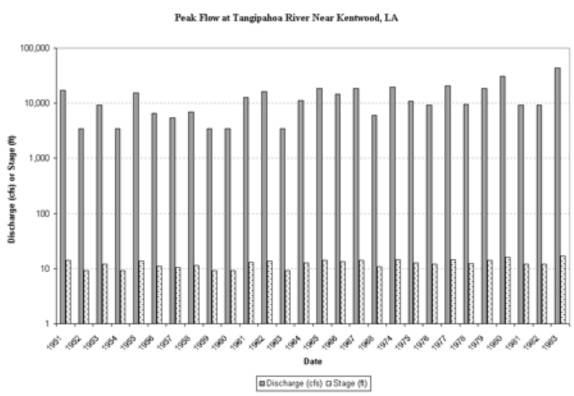


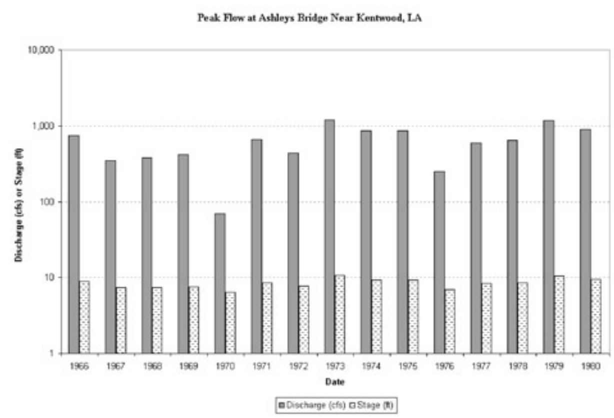
Maximum Temperature over Tangipahoa Watershed (Generated by SWEAT Weather Generator)

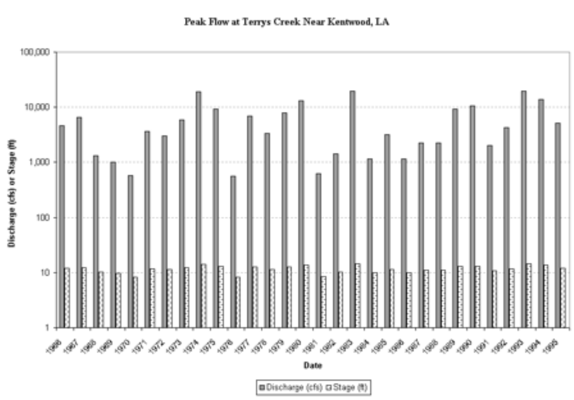


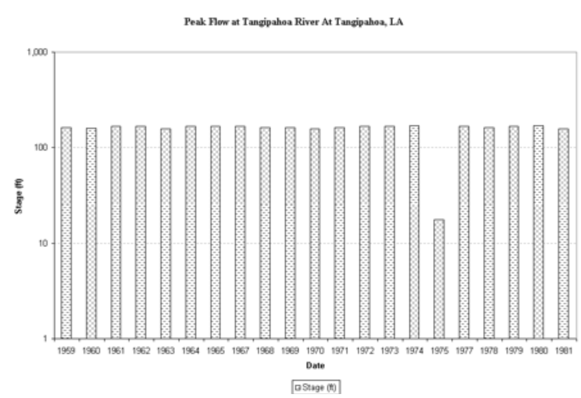

Stream Flow at Robert, Tangipahoa Watershed
Stream Flow (cfs)
Date
Actual Measurements
6mns AVG
12mns AVG
24mns AVG

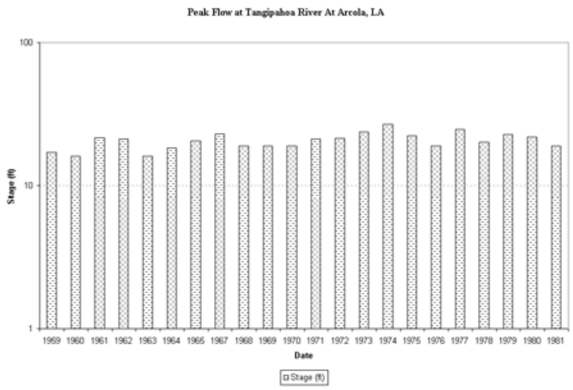

Seasonal Variability of Stream Flow from Tangipahoa River Watershed Outfall to Lake Pontchartrain System, Robert Location, USGS
Stream Flow (cfs)
Years
Winter
Spring
Summer
Fall


Peak Flow at Tangipahoa River Near Kentwood, LA
Discharge (cfs) or Stage (ft)
Date
Discharge (cfs)
Stage (ft)

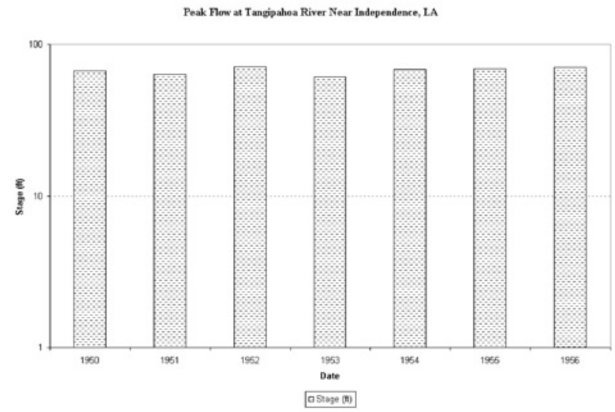

Peak Flow at Ashleys Bridge Near Kentwood, LA
Discharge (cfs) or Stage (ft)
Date
Discharge (cfs)
Stage (ft)


Peak Flow at Terrys Creek Near Kentwood, LA
Discharge (cfs) or Stage (ft)
Date
Discharge (cfs)
Stage (ft)

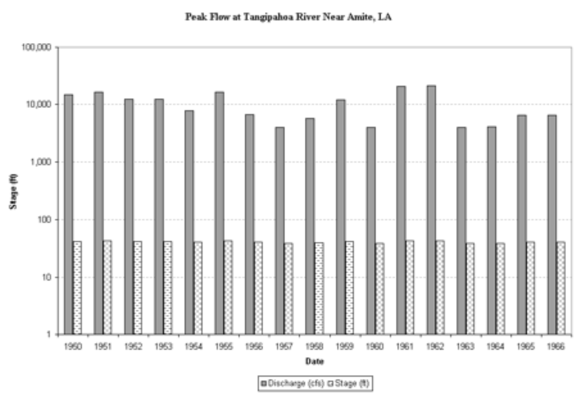

Peak Flow at Tangipahoa River At Tangipahoa, LA
Stage (ft)
Date
Stage (ft)



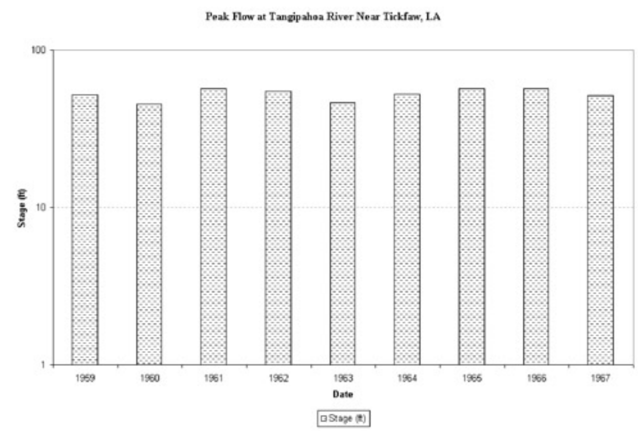
Peak Flow at Tangipahoa River At Arcola, LA
Stage (ft)
Date
Stage (ft)



Peak Flow at Tangipahoa River Near Independence, LA
Stage (ft)
Date
Stage (ft)



Peak Flow at Tangipahoa River Near Amite, LA
Stage (ft)
Date
Discharge (cfs)
Stage (ft)



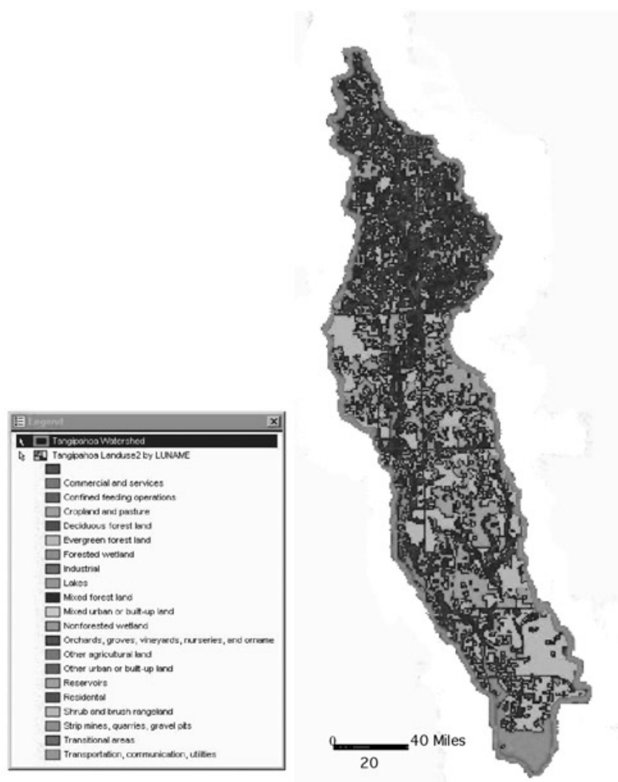
Peak Flow at Tangipahoa River Near Tickfaw, LA
Stage (ft)
Date
Stage (ft)

APPENDIX II

- Main Cities and Measurement Locations in The Tangipahoa Watershed
- The Tangipahoa watershed GIS land-use map layer
- The Tangipahoa watershed topographic GIS elevation map layer


N
McComb
Kentwoo
Amit
Hammond
Robert
0
5
10 Miles
Legend
DEQ sampling stations in Tangipahoa
Perrenial streams in Tangipahoa
Tangipahoa watershed
USGS gages in Tangipahoa

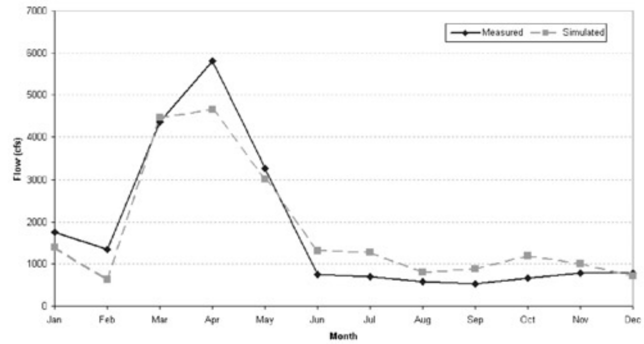

0
40 Miles
20


Tangipahoa Watershed
Tangipahoa Landuse2 by LUNAME
Commercial and services
Confined feeding operations
Cropland and pasture
Deciduous forest land
Evergreen forest land
Forested wetland
Industrial
Lakes
Mixed forest land
Mixed urban or built-up land
Nonforested wetland
Orchards, groves, vineyards, nurseries, and orname
Other agricultural land
Other urban or built-up land
Reservoirs
Residential
Shrub and brush rangeland
Strip mines, quarries, gravel pits
Transitional areas
Transportation, communication, utilities
0
40 Miles
20

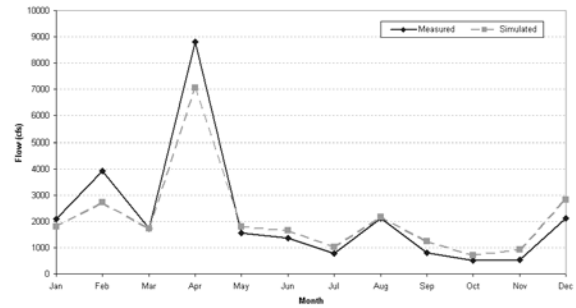
APPENDIX III

- Monthly comparisons between the simulated and observed stream flow at the Tangipahoa watershed outfall (Robert location)
- Daily time series plots observed and simulated stream flow comparison at the Tangipahoa watershed outfall (Robert location)

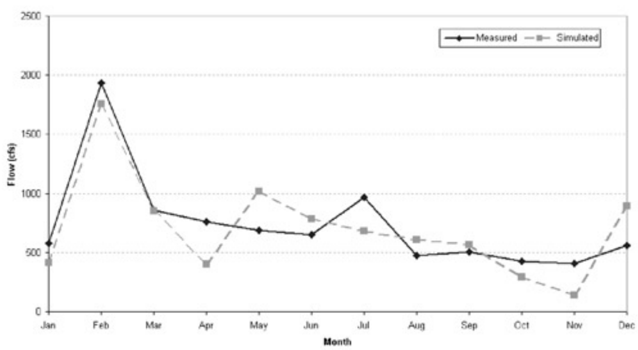
Comparison Between Measured and Simulated Stream Flow at Tangipahoa Watershed Outfall (Robert Location), Year 1980



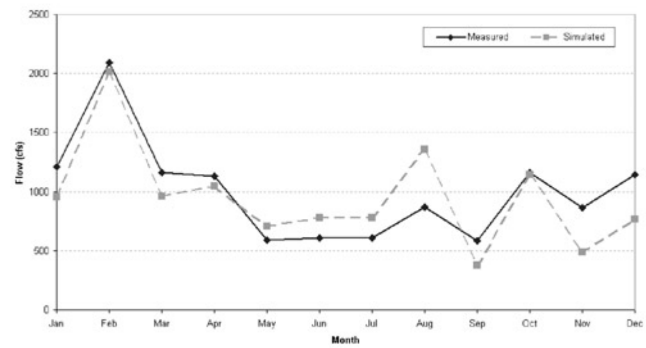
Comparison Between Measured and Simulated Stream Flow at Tangipahoa Watershed Outfall (Robert Location), Year 1983



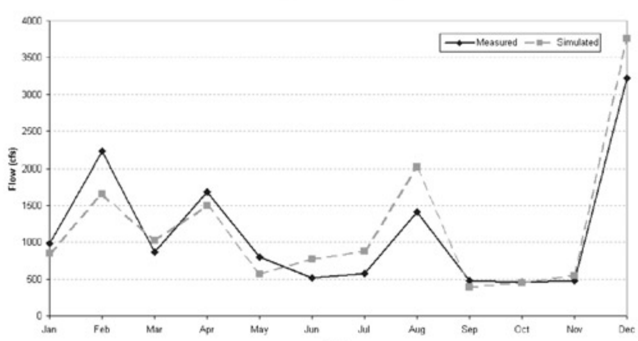
Comparison Between Measured and Simulated Stream Flow at Tangipahoa Watershed Outfall (Robert Location), Year 1981



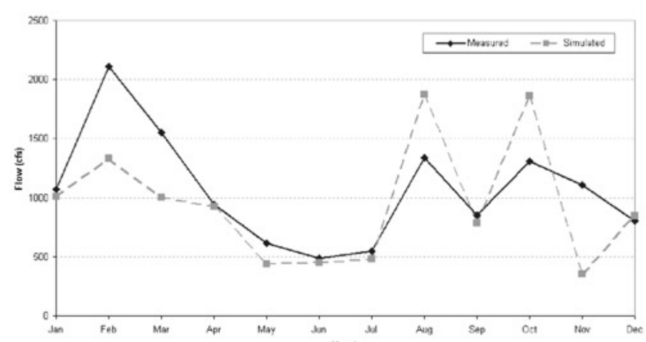
Comparison Between Measured and Simulated Stream Flow at Tangipahoa Watershed Outfall (Robert Location), Year 1984



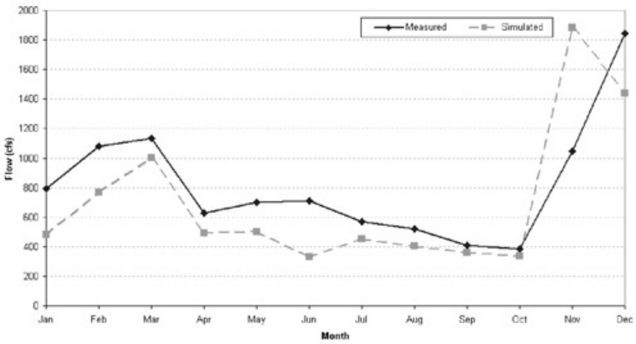
Comparison Between Measured and Simulated Stream Flow at Tangipahoa Watershed Outfall (Robert Location), Year 1982



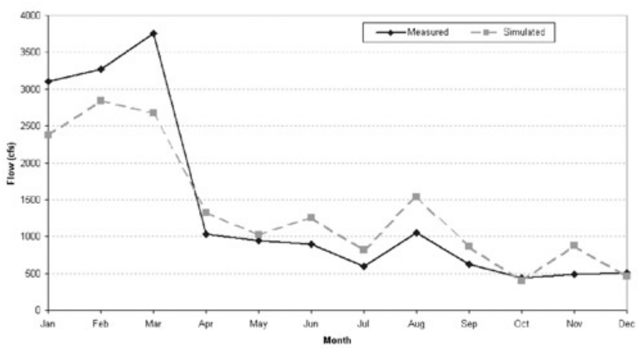
Comparison Between Measured and Simulated Stream Flow at Tangipahoa Watershed Outfall (Robert Location), Year 1985



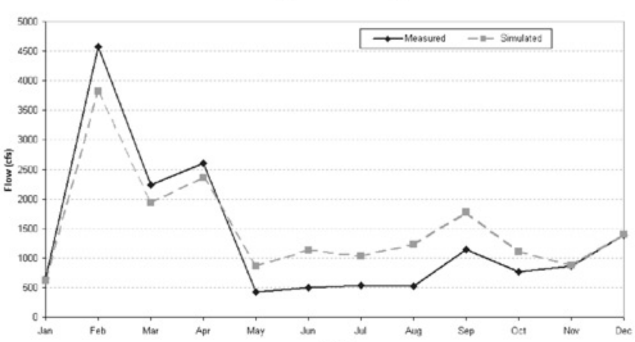
Comparison Between Measured and Simulated Stream Flow at Tangipahoa Watershed Outfall (Robert Location), Year 1986



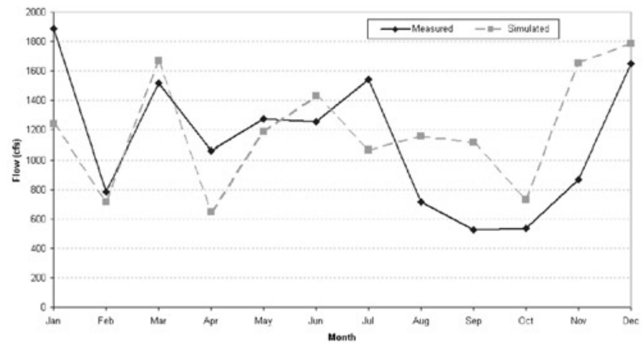
Comparison Between Measured and Simulated Stream Flow at Tangipahoa Watershed Outfall (Robert Location), Year 1987



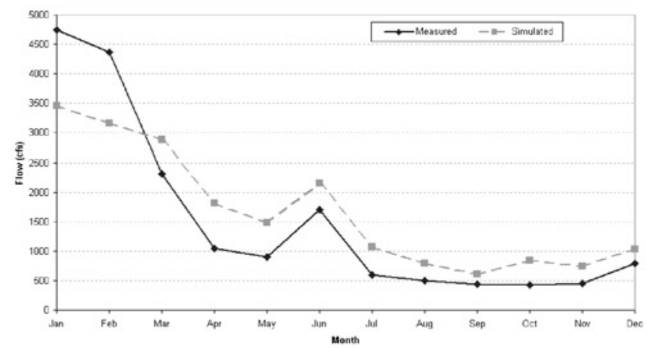
Comparison Between Measured and Simulated Stream Flow at Tangipahoa Watershed Outfall (Robert Location), Year 1988



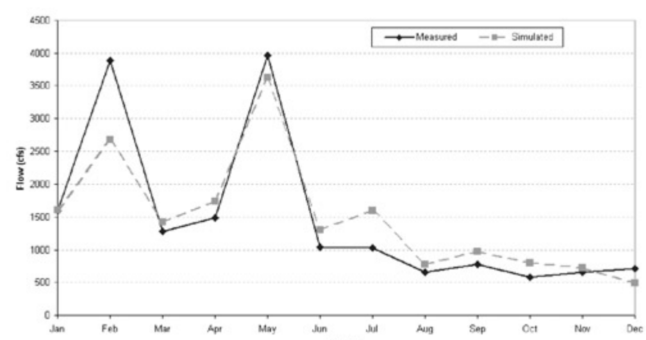
Comparison Between Measured and Simulated Stream Flow at Tangipahoa Watershed Outfall (Robert Location), Year 1989



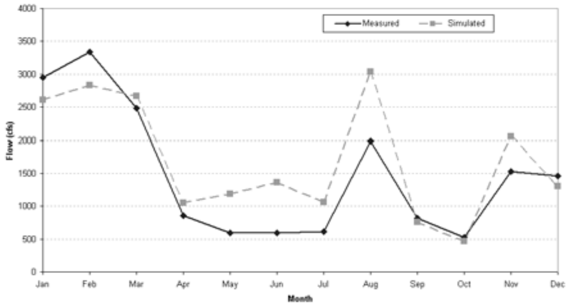
Comparison Between Measured and Simulated Stream Flow at Tangipahoa Watershed Outfall (Robert Location), Year 1990



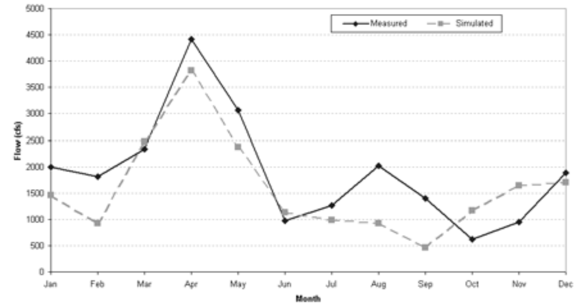
Comparison Between Measured and Simulated Stream Flow at Tangipahoa Watershed Outfall (Robert Location), Year 1991



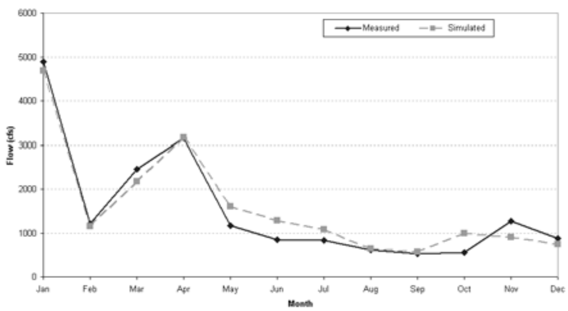
Comparison Between Measured and Simulated Stream Flow at Tangipahoa Watershed Outfall (Robert Location), Year 1992



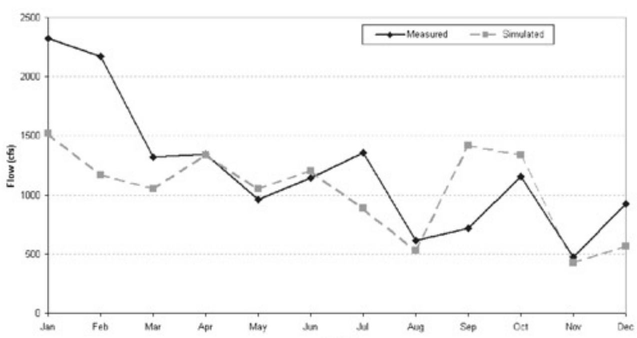
Comparison Between Measured and Simulated Stream Flow at Tangipahoa Watershed Outfall (Robert Location), Year 1995

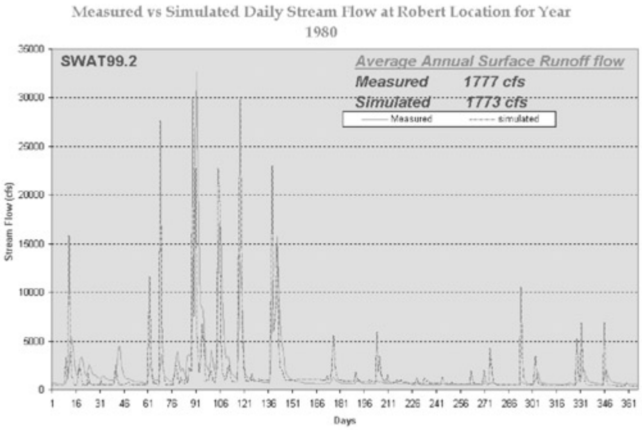


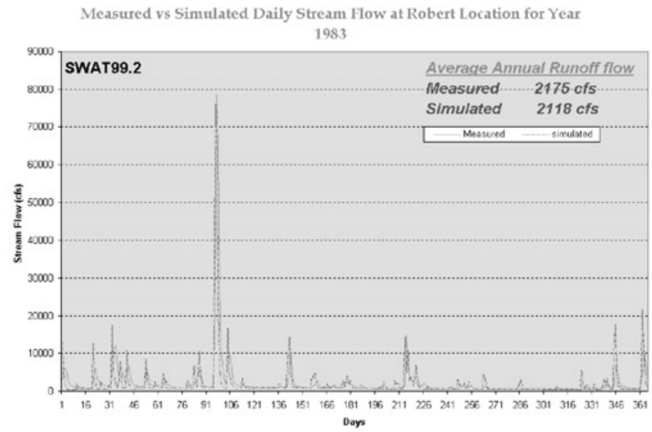
Comparison Between Measured and Simulated Stream Flow at Tangipahoa Watershed Outfall (Robert Location), Year 1993

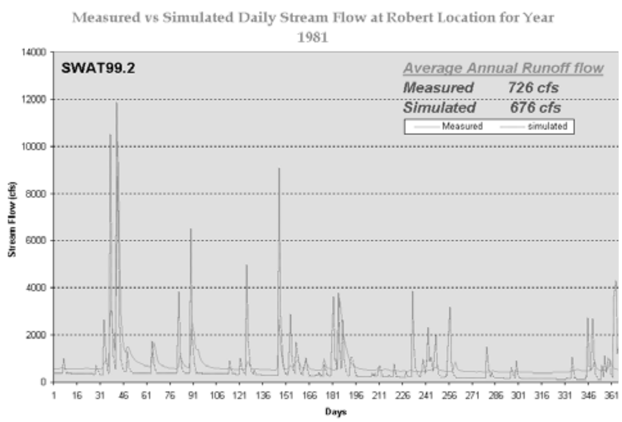


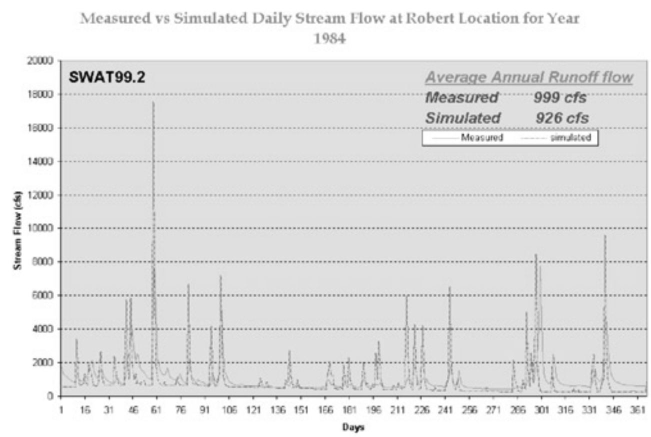
Comparison Between Measured and Simulated Stream Flow at Tangipahoa Watershed Outfall (Robert Location), Year 1994

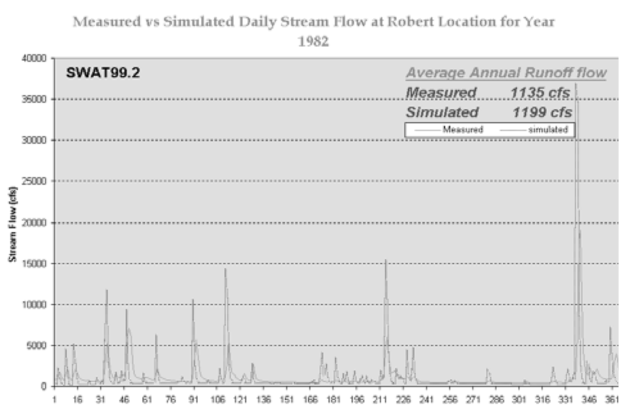


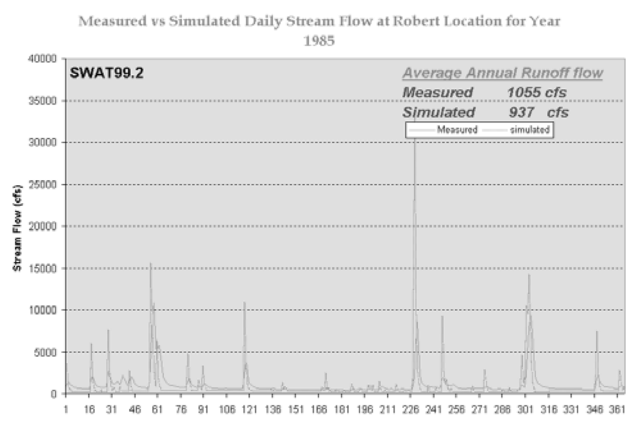

Measured vs Simulated Daily Stream Flow at Robert Location for Year 1980
SWAT99.2
Average Annual Surface Runoff flow
Measured 1777 cfs
Simulated 1773 cfs
Measured
simulated
Stream Flow (cfs)
Days

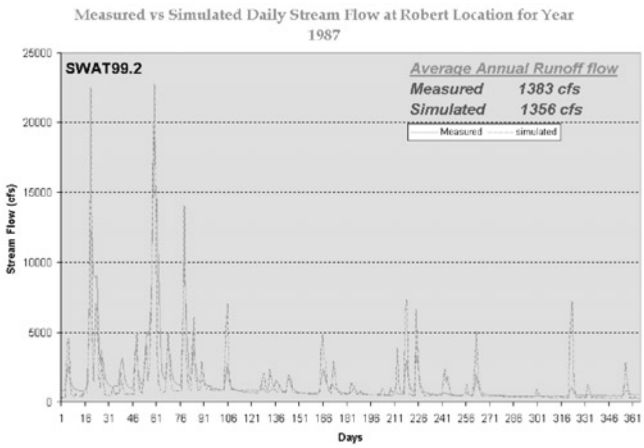

Measured vs Simulated Daily Stream Flow at Robert Location for Year 1983
SWAT99.2
Average Annual Runoff flow
Measured 2175 cfs
Simulated 2118 cfs
Measured
simulated
Stream Flow (cfs)
Days

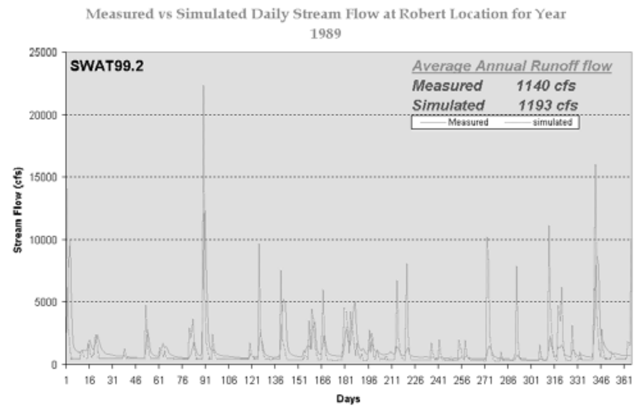

Measured vs Simulated Daily Stream Flow at Robert Location for Year 1981
SWAT99.2
Average Annual Runoff flow
Measured 726 cfs
Simulated 676 cfs
Measured
simulated
Stream Flow (cfs)
Days

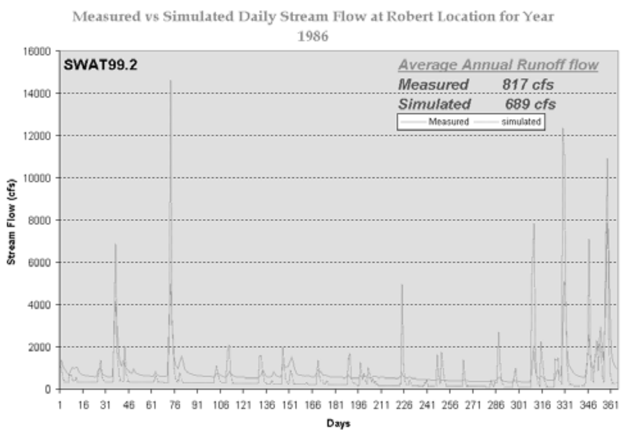

Measured vs Simulated Daily Stream Flow at Robert Location for Year 1984
SWAT99.2
Average Annual Runoff flow
Measured 999 cfs
Simulated 926 cfs
Measured
simulated
Stream Flow (cfs)
Days

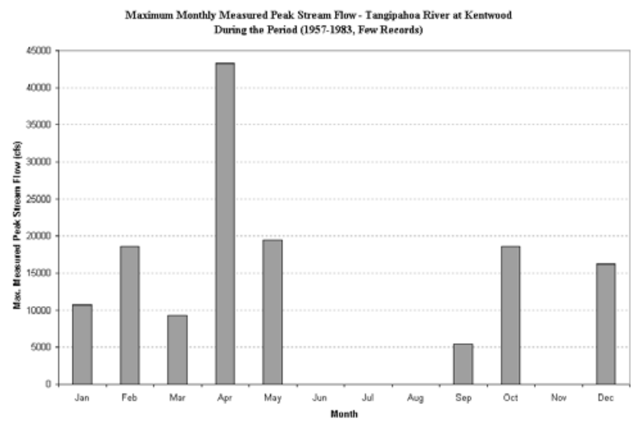

Measured vs Simulated Daily Stream Flow at Robert Location for Year 1982
SWAT99.2
Average Annual Runoff flow
Measured 1135 cfs
Simulated 1199 cfs
Measured
simulated
Stream Flow (cfs)
Days

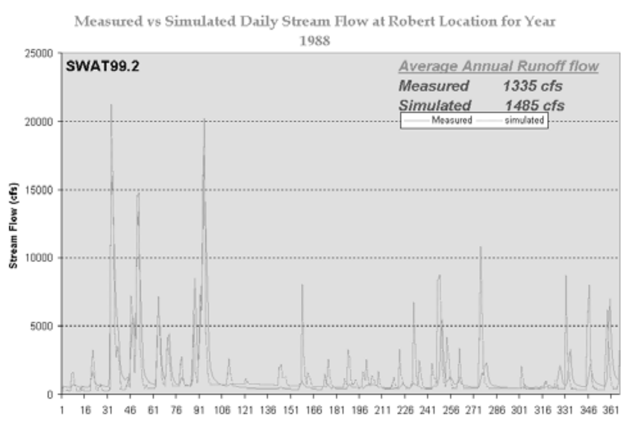

Measured vs Simulated Daily Stream Flow at Robert Location for Year 1985
SWAT99.2
Average Annual Runoff flow
Measured 1055 cfs
Simulated 937 cfs
Measured
simulated
Stream Flow (cfs)
Days

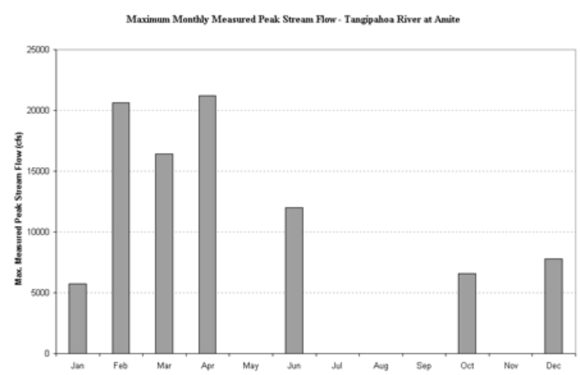

Measured vs Simulated Daily Stream Flow at Robert Location for Year 1987
SWAT99.2
Average Annual Runoff flow
Measured 1383 cfs
Simulated 1356 cfs
Measured
simulated
Stream Flow (cfs)
Days


Measured vs Simulated Daily Stream Flow at Robert Location for Year 1989
SWAT99.2
Average Annual Runoff flow
Measured 1140 cfs
Simulated 1193 cfs
Measured
simulated
Stream Flow (cfs)
Days


Measured vs Simulated Daily Stream Flow at Robert Location for Year 1986
SWAT99.2
Average Annual Runoff flow
Measured 817 cfs
Simulated 689 cfs
Measured
simulated
Stream Flow (cfs)
Days


Maximum Monthly Measured Peak Stream Flow - Tangipahoa River at Kentwood
During the Period (1957-1983, Few Records)
Max. Measured Peak Stream Flow (cfs)
Month


Measured vs Simulated Daily Stream Flow at Robert Location for Year 1988
SWAT99.2
Average Annual Runoff flow
Measured 1335 cfs
Simulated 1485 cfs
Measured
simulated
Stream Flow (cfs)
Days


Maximum Monthly Measured Peak Stream Flow - Tangipahoa River at Amite
Max. Measured Peak Stream Flow (cfs)
Month

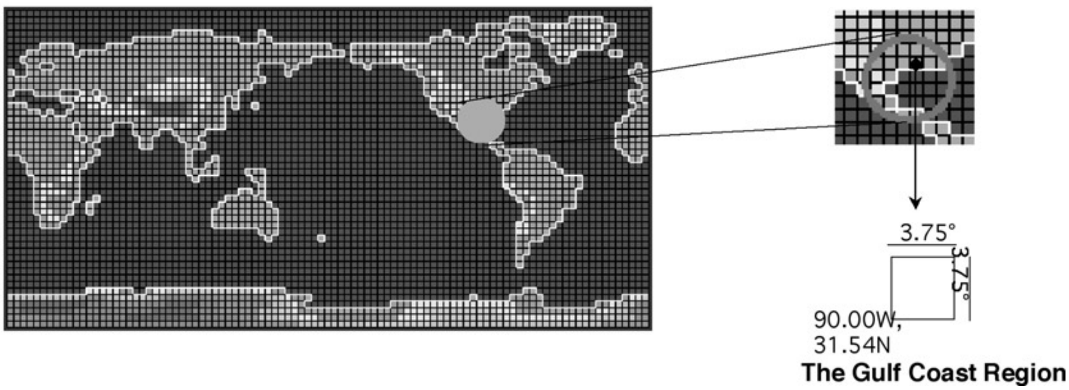
APPENDIX IV

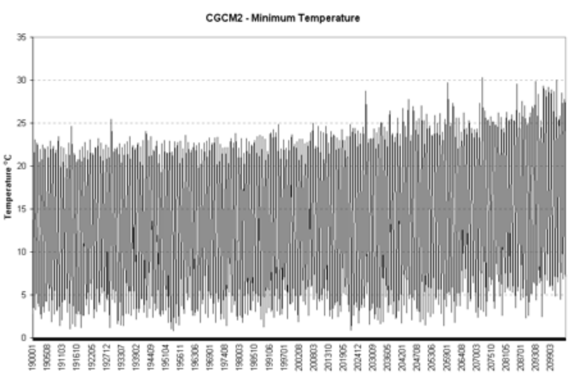
- The whole set of original Canadian model results including climate trends (precipitation, temperature, evaporation, solar radiation, specific humidity, and soil moisture)

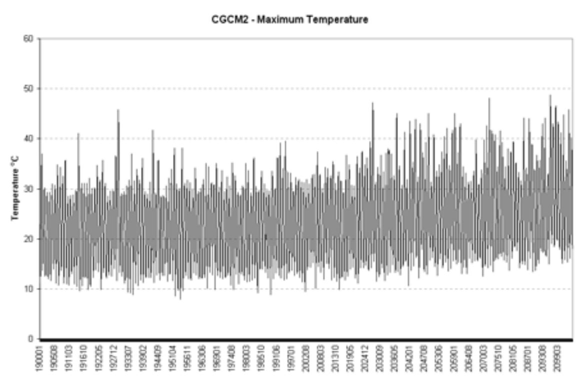
The Canadian Model (CGCM 2) Gaussian Grid
Future Forcing Climate Scenarios

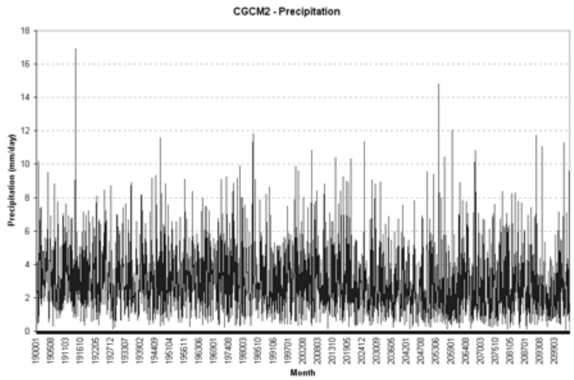
GHG+A IPCC Scenario 'IS92a' with the Canadian Model

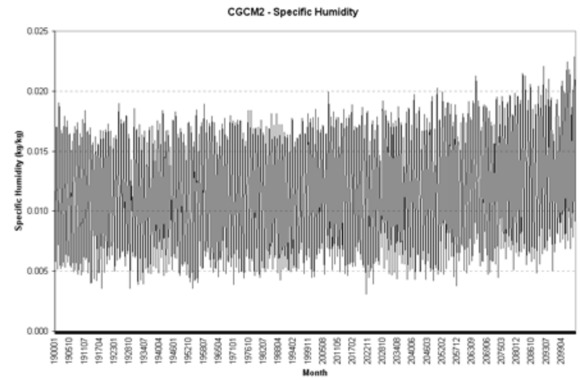
Grid Box Used
(approximately 1000 to 1500 km in mid-latitudes)
800 times the Study Area

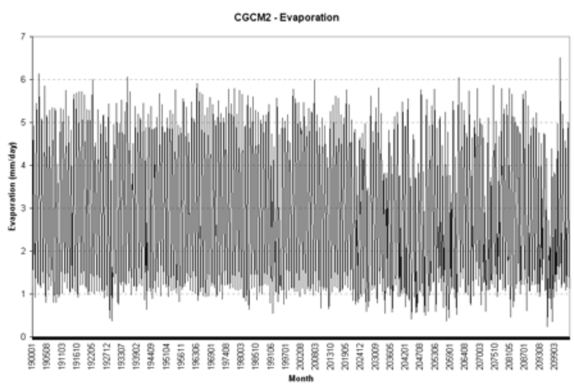


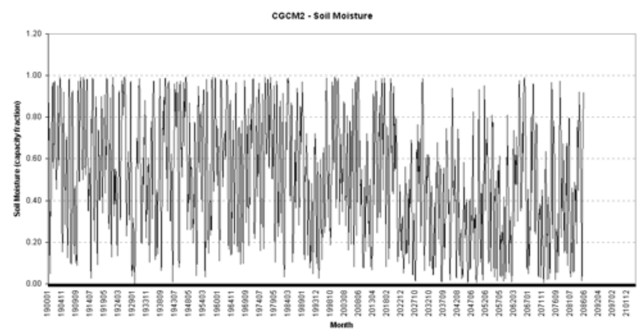


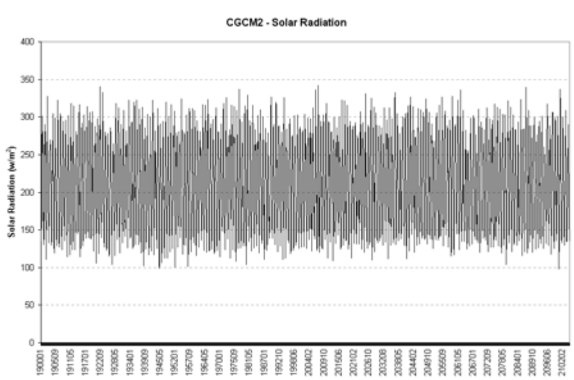



CGCM2 - Precipitation
Precipitation (mm/day)
Month


CGCM2 - Specific Humidity
Specific Humidity (kg/kg)
Month

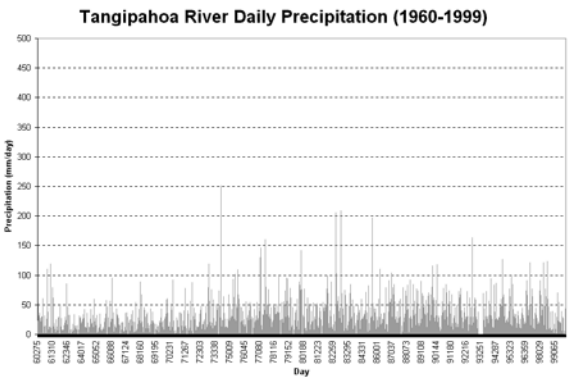

CGCM2 - Evaporation
Evaporation (mm/day)
Month

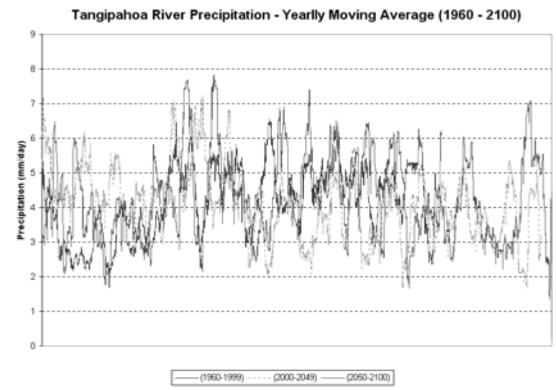

CGCM2 - Soil Moisture
Soil Moisture (capacity fraction)
Month

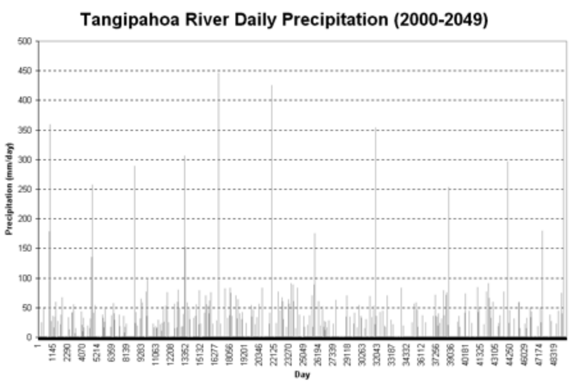

CGCM2 - Solar Radiation
Solar Radiation (w/m²)
Month

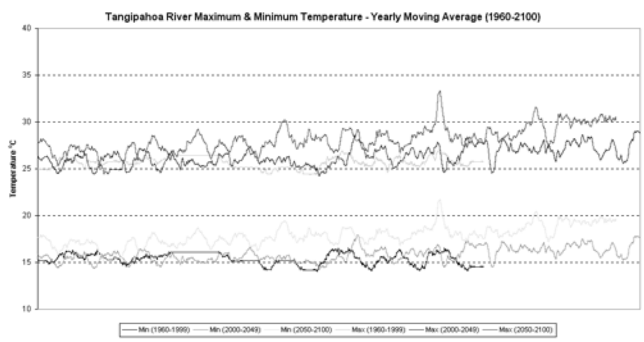
APPENDIX V

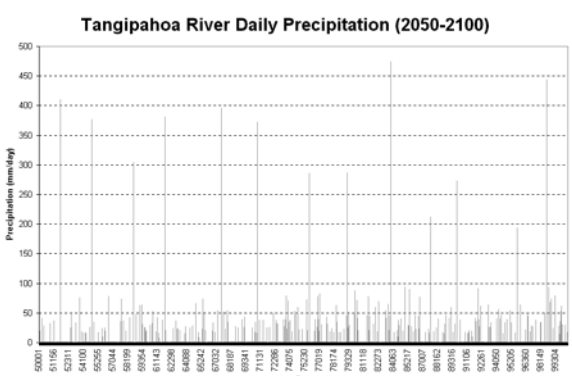
- Daily plots of the Canadian model adopted precipitation results during the period of 2000 – 2100 and the actual measurements during the period of 1960 – 1999
- Daily temperature results during the period of 2000 – 2100 using the Canadian model vs. the actual measurements during the period of 1960 – 1999
- Projected yearly-moving average precipitation
- Projected yearly moving average temperature

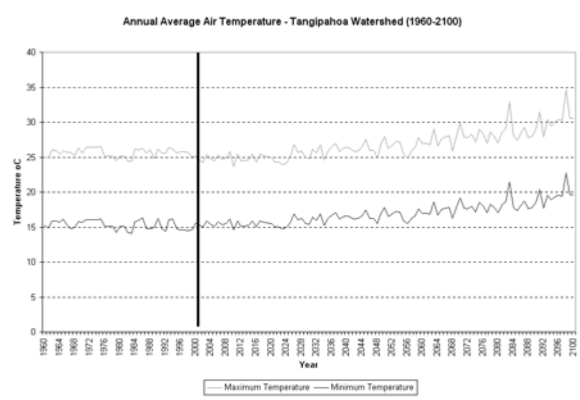

Tangipahoa River Daily Precipitation (1960-1999)
Precipitation (mm/day)
Day

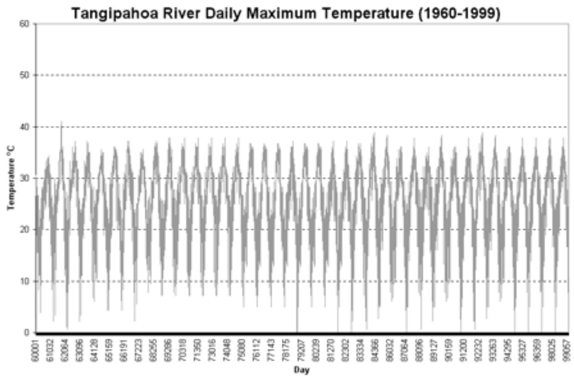

Tangipahoa River Precipitation - Yearlly Moving Average (1960 - 2100)
Precipitation (mm/day)
(1960-1999)
(2000-2049)
(2050-2100)

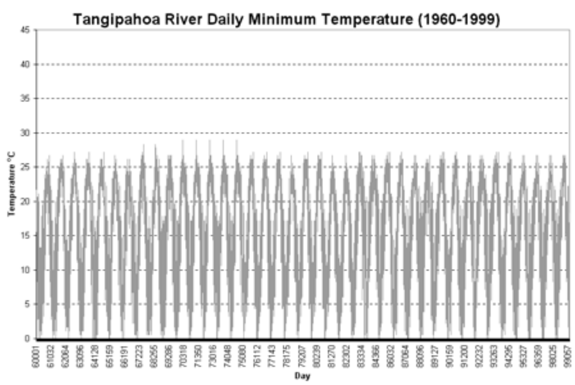

Tangipahoa River Daily Precipitation (2000-2049)
Precipitation (mm/day)
Day

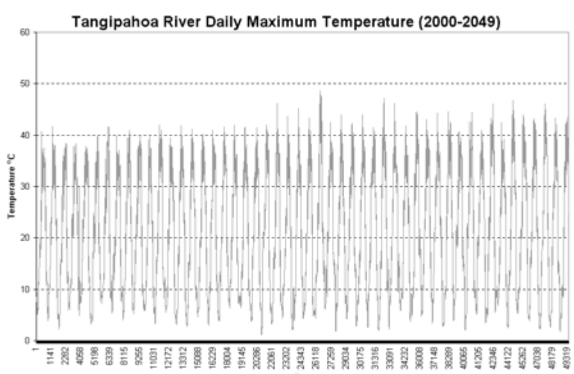

Tangipahoa River Maximum & Minimum Temperature - Yearly Moving Average (1960-2100)
Temperature °C
Min (1960-1999)
Min (2000-2049)
Min (2050-2100)
Max (1960-1999)
Max (2000-2049)
Max (2050-2100)

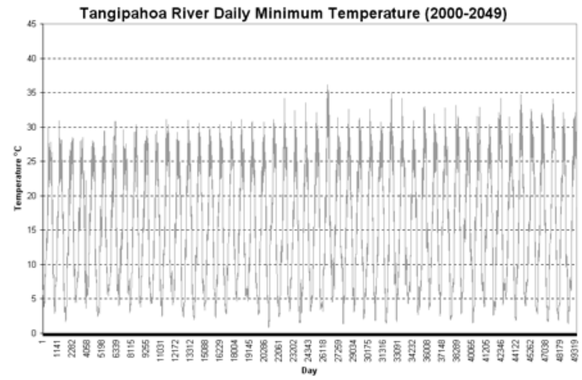

Tangipahoa River Daily Precipitation (2050-2100)
Precipitation (mm/day)
Day

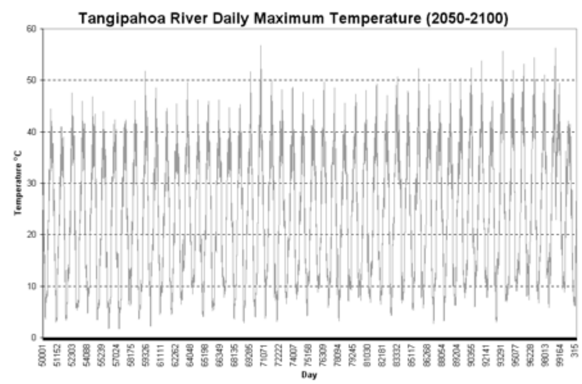

Annual Average Air Temperature - Tangipahoa Watershed (1960-2100)
Temperature oC
Year
Maximum Temperature
Minimum Temperature

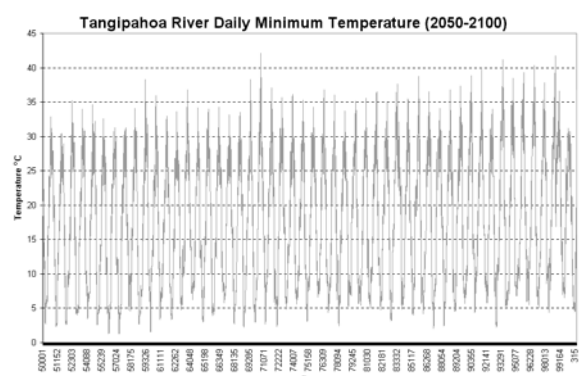

Tangipahoa River Daily Maximum Temperature (1960-1999)
Temperature °C
Day


Tangipahoa River Daily Minimum Temperature (1960-1999)
Temperature °C
Day


Tangipahoa River Daily Maximum Temperature (2000-2049)
Temperature °C
Day

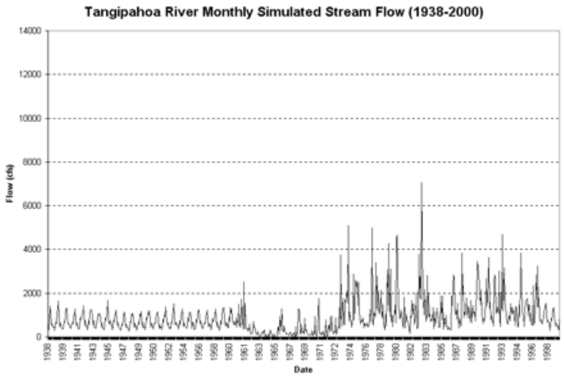

Tangipahoa River Daily Minimum Temperature (2000-2049)
Temperature °C
Day

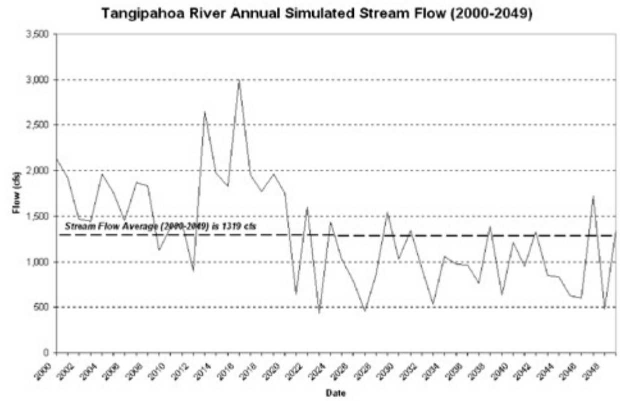

Tangipahoa River Daily Maximum Temperature (2050-2100)
Temperature °C
Day

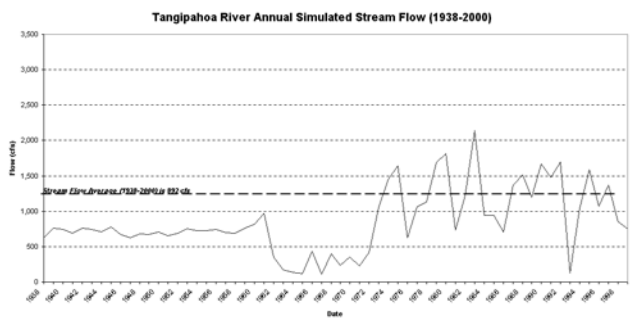

Tangipahoa River Daily Minimum Temperature (2050-2100)
Temperature °C
Day

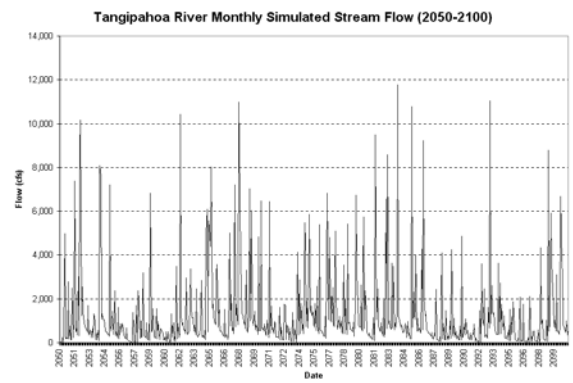
APPENDIX VI

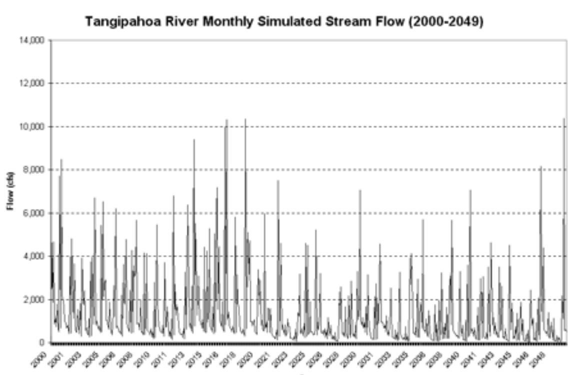
- Typical monthly SWAT model stream flow results based on the Canadian model projected climate data at the Tangipahoa River outfall during the periods of 2000 – 2049 and 2050 – 2100 as well as the SWAT estimation based on the actual climate data during the period of 1938 – 1999

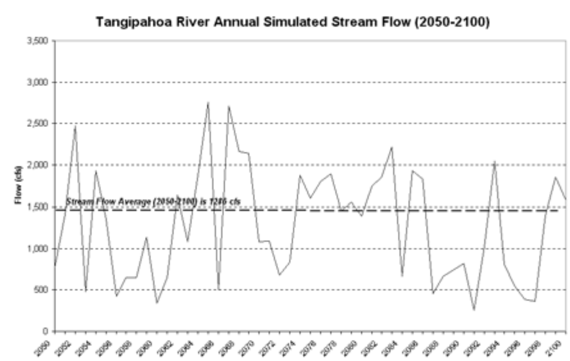

Tangipahoa River Monthly Simulated Stream Flow (1938-2000)
Flow (cfs)
Date


Tangipahoa River Annual Simulated Stream Flow (2000-2049)
Stream Flow Average (2000-2049) is 1319 cfs
Flow (cfs)
Date


Tangipahoa River Annual Simulated Stream Flow (1938-2000)
Flow (cfs)
Date


Tangipahoa River Monthly Simulated Stream Flow (2050-2100)
Flow (cfs)
Date


Tangipahoa River Monthly Simulated Stream Flow (2000-2049)
Flow (cfs)
Date


Tangipahoa River Annual Simulated Stream Flow (2050-2100)
Flow (cfs)
Date