Impacts of land use and climate change on hydrologic processes in shallow aquatic ecosystems

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Abstract- **Mobile Bay is a significant resource for human uses with important implications on commercial fisheries, coastal development, industry and tourism. Submerged aquatic vegetation (SAV) provides habitat in the littoral zone important to Gulf fisheries. Alabama coastal systems have been increasing in population and this with LCLU change in the surrounding areas of the coast are causing changes in streamflow discharges. The change in river outflow can affect the quality of the water in the bay, which is essential to the health of the ecosystem. Watershed and hydrodynamic modeling has been performed to evaluate the impact of land use and climate change in Mobile and Baldwin counties on the aquatic ecosystem in Mobile Bay. Remote sensing data (Landsat Images) were used as model input for the LCLU scenarios for the years of 1992 and 2001. The Prescott Spatial Growth Model (PSGM) was used to project the 2030 land use scenario based on observed trends. The data provided by Intergovernmental Panel on Climate Change (IPCC) for the South region on future temperature and precipitation projections were used to create future climate scenarios of 2025 and 2050. Results indicate that the LCLU changes are increasing the freshwater flows into the Bay. The projected drier and hotter climate will decrease the freshwater flows into the Bay too. Variations in flow into the Bay can change the sediment loads, salinity and temperature of the water. These changes affect the normal conditions of the habitat, distribution and abundance of particular species of plants and the amount of light that SAVs need for survival.**

I. Introduction

Mobile Bay is located along the southeastern coast of the United States in the state of Alabama and is considered the fourth largest estuary in the United States with an inflow of 1755 cubic meters of water per second (62,000 cubic feet per second) [1]. This large estuary receives 20 % of the freshwater supply in the United States [2]. The surface waters of Mobile Bay cover 1059 km² (409 mi²), and the average depth is about 3.048m (10 ft) [3][4]. Mobile Bay is the intermediary area between freshwater of the watershed and open water, the Gulf of Mexico. The primary opening of the Bay to the Gulf of Mexico is called the Main Pass and is located between Dauphin Island and the Fort Morgan Peninsula [5].

Mobile Bay is home to a large diversity of species and distinct habitats. Habitat types characterized in the Bay include soft sediments, seagrass beds, barrier island dune and inter-dune wetland swales, fresh and saltwater marshes, pitcher plant bogs, wet pine savannas, upland pine-oak forests, tidal marshes, cypress swamps, bottomland hardwoods forest and oyster reefs [5][6]. These habitats are essential food sources for species such as shrimp, oysters, and flounder. Because of its vital function as an ecosystem, the Clean Water Act of 1987 established Mobile Bay as a National Estuary in 1995 [7]. The Mobile Bay Estuary is a habitat to 46 species of mammals, 126 amphibians and reptiles, 355 species of birds and 337 saltwater and freshwater fish species [4]. The Bay has one of the richest freshwater fish populations in North America, however, 36 of the Bay's 337 fish species are listed as at risk [4][8]. Also, Mobile Bay is a significant resource for human uses with important implications on commercial fisheries, coastal development, industry and tourism. The fish species in the Bay are commercially and recreationally important for the local and national economy [9].

Submerged aquatic vegetation (SAV) is an important natural resource in the Mobile Bay aquatic ecosystem. SAV provides forage for wintering waterfowl and food and habitat for many native, exotic and endangered species (sea turtles and manatees). Besides, SAV offer a nursery habitat for species and refuge from predators. SAV prevents erosion by buffering the impacts of waves, removing nutrients and other pollutants from river and runoff inputs to coastal areas, reducing wave energy and trapping sediment [10][11]. The SAV requires specific habitat characteristics to survive. The factors most relevant to the health of SAV are light, salinity, wave energy, and nutrients [11]. The major factor controlling distribution of SAV is the penetration of light through the water column [12]. Light penetration will be influenced by the quantity of sediment in the water column. The average condition in salinity for high salinity submerged aquatic vegetation is between 15 and 26 ppt; while freshwater SAV is from 1 to 2 ppt [13]. Fonseca *et al*, 1998 [14] analyzed the effect of wave exposure and currents on SAV coverage in Core Sound and found an inverse relationship between percent cover of SAV and wave exposure indices or current speed. Therefore with more wave exposure there is less coverage of SAV. The growth and availability of the SAV on bays could be affected by numerous factors including weather events, industrial pollutants, agricultural herbicides and decline in water quality.

The distribution and condition of the SAV in Mobile Bay have likely been affected by the changes in LCLU [15]. The sedimentation increases the turbidity and inhibits the penetration of sunlight into the water in the Bay. This affects the necessary amount of light that submerged aquatic vegetation and other aquatic life needs for survival.

During the 1950s, the SAV covered 20 km² (5,000 acres) in Mobile Bay and 30 km² (7,500 acres) in the lower delta [16]. The loss in spatial coverage, distribution, and species composition of SAV in coastal Alabama were documented in another inventory made in 1980 showing that SAV covered 11km² (2,763 acres) [17]. In addition, over the past century Alabama lost coastal and estuarine wetlands [18]. Between the mid-1950s and the late 1970s, 34% of the wetlands in northern Mobile Bay were lost [19]. These losses cause damage to species diversity, water quality, flood control and aspects of the economy. There has been a decline of the distribution and abundance of seagrasses during the past 50 years in Mobile Bay and adjacent coastal areas [10]. Like much of the Gulf coast, Alabama coastal systems have been subjected to increasing pressure from a variety of activities including urban and rural development, shoreline modifications, industrial activities leading to point and nonpoint source runoff, commercial and recreational fishing, oil and gas extraction, and dredging of shipping and navigation channels [20]. The two major stressors that cause habitat loss are land cover/land use (LCLU) change and surface water runoff [21]. Other causes of habitat loss in the Mobile Bay are natural erosion processes, sedimentation and hydrologic modifications [4]. Research indicates climate change is related to coastal habitat losses; specifically driven by sea level rise, precipitation and temperature changes [22]. Climate change and habitat destruction are two of the greatest threats to global biodiversity [23] modifying the species composition within areas. The climate changes combined with LCLU change modifies the quantity of surface water runoff that affects the water quality in the Bay.

The Gulf of Mexico and surroundings have experienced multiple oil spills during the last decades. The U.S. Environmental Protection Agency estimates approximately seventy small oil spills that occur each day and larger spills happen less frequently [24]. Cleaning up oil spills is a long task and will depend on how much oil was spilled, its location and the inhabitants in the area. The worst oil spill in the history of United States occurred on April 28, 2010 along the northern coast of the Gulf of Mexico. Large oil slicks on the ocean surface reduce light penetration into the water column. Oil spills potentially affect all the living organisms, aquatic plants, coral and reefs that live in the sea and their surrounding areas. Some of the species that can be affected by the oil are sea otters, marine mammals without much blubber, fish, humans, invertebrates, birds, polar bear, plants and others [24]. Aquatic vegetation like marsh grass, mangrove, and some intertidal plants can be killed or damaged by oil [24]. Laws have been put into place to protect oceans from future oil spills. In 1990, the Oil Pollution Act (OPA) was signed by U.S. President George H. W. Bush. The OPA put several things into action; it established a federal liability system, reinforced oil spill penalties, developed a trust fund assisting the cost of clean-ups, and required companies to create spill-scenario plans before they were legally allowed to operate [25].

Problems such as those described above need additional tools and research to find optimal solutions. The Gulf of Mexico Regional Collaborative (GoMRC) was established in 2005 to provide natural resource managers and policymakers in the United States and Mexico with a set of tools to manage the Gulf's marine and coastal environment. The data and tools provided through GoMRC can help with choosing the best options for natural resources planning and management. Conceptual models have become a popular tool used to support coastal habitat restoration planning [26].

Coastal Alabama has been rapidly developing, which causes an increase in streamflow discharges. The freshwater influx changes the water quality in Mobile Bay. In order to manage and plan the recovery and restoration of Mobile Bay for the future, the effect of these stressors to the Bay must be understood. The objectives of this research are to determine: (1) how LCLU and climate changes affect streamflow; (2) how river outflow impacts the water quality in the Bay; (3) how changes in water quality will affect the seagrass/SAV habitat in the Bay. These research results will provide environmental managers with additional data to assist with SAV and sea grasses restoration decisions.

II. Methodology

In this study, we focused on 22 watersheds adjacent to Mobile Bay in Mobile and Baldwin Counties. Figure 1 shows the Mobile Bay study area, the 22 subwatersheds, and the current submerged aquatic vegetation in Mobile Bay used in the model simulations. Watershed and hydrodynamic modeling has been performed for Mobile Bay to evaluate the impact of land use and climate change in Mobile and Baldwin counties on the shallow aquatic ecosystems in Mobile Bay, AL. This study focuses on the watershed modeling effort.

WATERSHED MODEL- Loading Simulation Program in C++ (LSPC) model is a watershed modeling system that includes streamlined Hydrologic Simulation Program Fortran algorithms for simulating hydrology, sediment, and general water quality on land as well as a simplified stream transport model [27]. The LSPC model was used for simulating streamflow, temperature and general water quality for the 22 discharge points into Mobile Bay using different LCLU and climate change inputs based on historical, current and future scenarios.

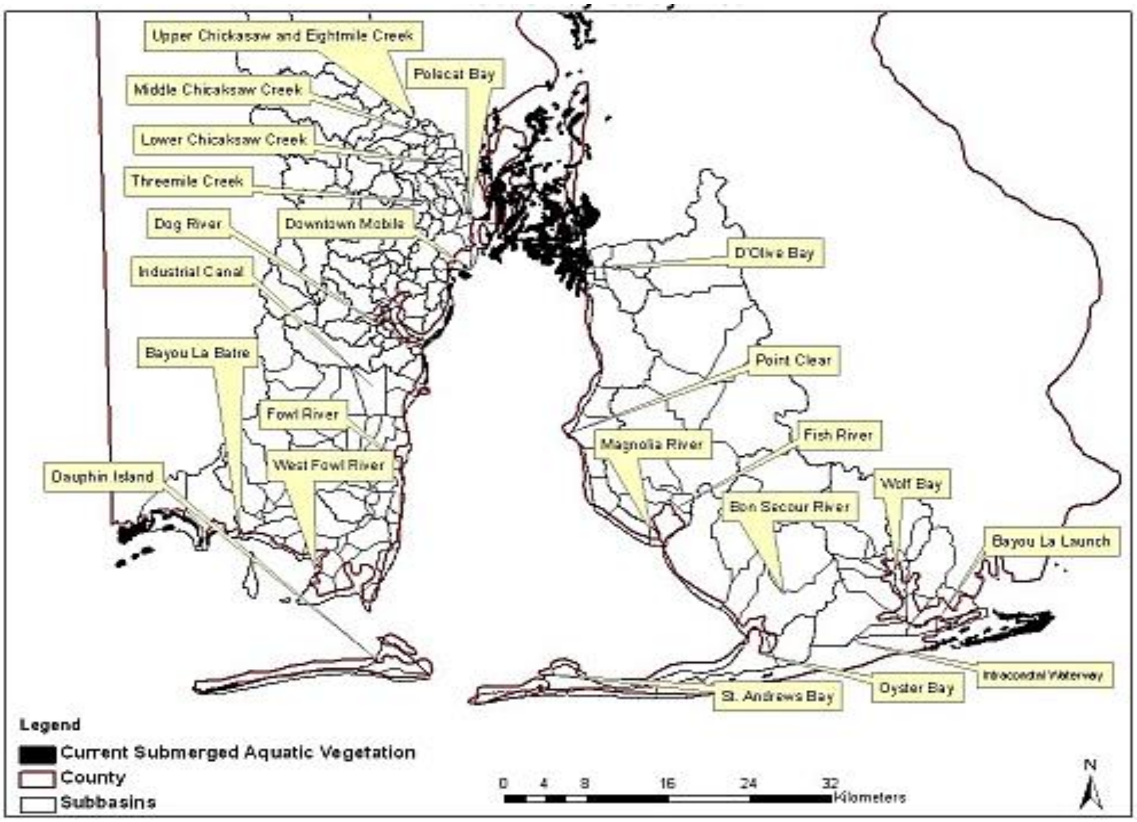

Figure 1. Mobile Bay Study Area

A. Land Cover/Land Use Change Scenarios

The LSPC model was run to simulate runoff for the 22 watersheds contiguous to Mobile Bay using the same climate data but different LCLU scenarios for 1948, 1992, 2001, and 2030. Historical LCLU maps were used for the 1948 LCLU scenario, which include urban, timber, crop and crop/pasture classes. The Landsat derived National Land Cover Data (NLCD) was used as model input for the LCLU scenarios for the years 1992 and 2001. The LCLU scenarios used a common land classification system that was developed for the 1992 and 2001 NLCD. The Prescott Spatial Growth Model (PSGM) was used to project the 2030 land use scenario based on observed trends using categories consistent with the common land classification system. The PSGM is a rule base model that runs on an ArcGIS platform. The PSGM assigns future growth into available land based on user-defined parameters. All variables except LCLU were held constant for each model simulation. Fig. 2 shows the maps of the 1992, 2001, and 2030 LCLU scenarios and the common classification used as an input to the LSPC model.

The LSPC model outputs for streamflow discharge for each LCLU scenario were analyzed using descriptive statistics and t-tests. The results were significant at $p<0.05$. The percent of areas in each type of LCLU per year in each watershed were compared to calculate the percent of change between the years. The impact of LCLU change on sediment loads was evaluated for the 2001 LCLU scenario by comparing the percent of land use, streamflow discharge and sediment concentrations in each watershed.

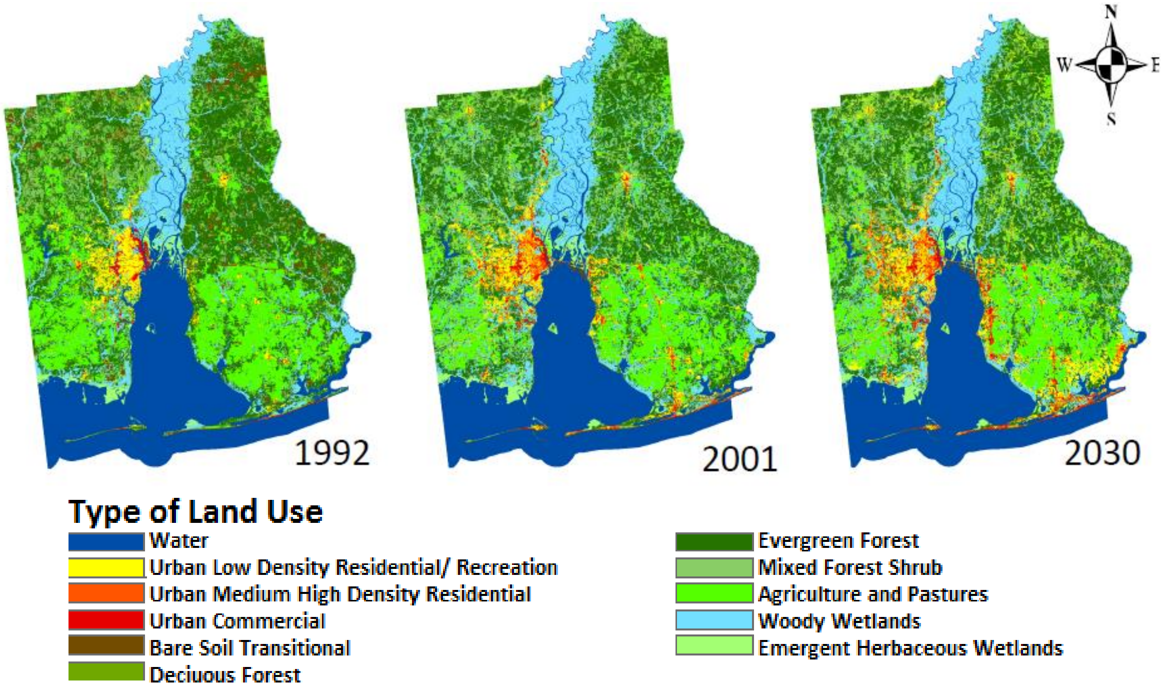

Figure2. Maps of the LCLU scenarios in Mobile Bay for the years 1992, 2001 and 2030.

B. *Climate Change Scenarios*

The LSPC model was run using the 2001 LCLU as a baseline and climate data from 2005 and future climate scenarios for 2025 and 2050. The input data for climate change in future scenarios used in the LSPC was provided by the Intergovernmental Panel on Climate Change (IPCC) business as usual A2 scenario [28]. All variables except climate were held constant for each model simulation. Table I shows the percent of change in precipitation and the absolute changes for temperature (C) per season during the years 1990-2050 for the A2 scenario used in the model.

TABLE I

MEDIANS FOR CLIMATE CHANGE- SOUTH REGION-A2 SCENARIO FOR YEAR 1990-2050 FROM IPCC

	% Precipitation	Temperature (C)
Dec, Jan, Feb.	-2.19	1.75
June, July, August	-9.93	2.18
March, April, May	-3.29	2.01
Sept, Oct, Nov	-0.19	2.08

The LSPC model outputs for streamflow discharge for each climate scenario were analyzed using descriptive statistics and t-tests. T-tests were performed for streamflow differences for the different climate scenarios. The results were significant at $p<0.05$.

III. Results

The impacts due to LCLU and climate changes were evaluated by analyzing the LSPC outputs of streamflow discharge and sediment load in each watershed for different climate and LCLU scenarios.

A. *Land Cover/ Land Use Change*

The results indicate that the regions around Mobile Bay are increasing in urban areas and decreasing in natural land cover areas. Table II shows an increase in urban LCLU areas of 298% and a decrease of natural LCLU areas of -23% between the years 2001 and 1948. The trends are similar for the differences between 2030 and 1948 with an increase of 597% in urban areas and a decrease of -40% in natural areas. Overall results indicated that LCLU change to a more urban environment increases freshwater discharges into Mobile Bay (Figs. 3 and 4). The Dog River, Fish River and Wolf Bay watersheds have the largest streamflow discharge differences (Figs. 3 and 4).

The streamflow discharge into the estuary varies with the type of LCLU. Zones with an elevated percent of urban development had runoffs higher than zones with higher percentages of natural LCLU (Fig. 5). In this graph, natural LCLU do not include wetlands and water bodies, but include bare soil, evergreen forest, deciduous forest, mixed forest-shrub and agriculture-pasture. Since wetlands and water bodies are not typically available for land development, they were excluded from the analysis.

The watersheds of Threemile Creek and Downtown Mobile have the largest outflow per unit area of 287 cm/day (113in/day) and 274 cm/day (108 in/day). Also, these watersheds have a high percentage of urban LCLU, 65% and 73%, respectively. Magnolia River has the lowest outflow per unit area among all the watersheds and is 4.3% urban and 61% natural areas.

The percentage of agriculture-pasture area in the watersheds varies from 0.09% (Downtown Mobile) to 49 % (Magnolia River). A trend observed in the results is the direct relationship between the percentage of agriculture-pasture area and the sediment loads. The watershed regions with a higher percentage of agriculture-pasture area have higher sediment loads and watersheds with less agriculture- pasture areas have less sediment loads (Fig. 6). Magnolia River has the highest percentage of agriculture- pasture areas (49%) and generated the highest sediment load (2,683,698 $kg/day/km^2$). Other watersheds like West Fowl River has a lower percentage of agriculture areas (2.62%) and generates less sediment load (372,042 $kg/day/km^2$) (Fig. 6).

TABLE II

LAND COVER LAND USE AREAS AND CHANGES

	1948	**2001**	**2030**	**Change (2001-1948)**	**% Change (2001-1948)**	**Change (2030- 1948)**	**% Change (2030-1948)**
Urban Area (km^2)	27.58	109.82	192.39	82.23	298.11	164.81	597.48
Non Urban Area (km^2)	715.51	548.14	427.88	-167.37	-23.39	-287.63	-40.20

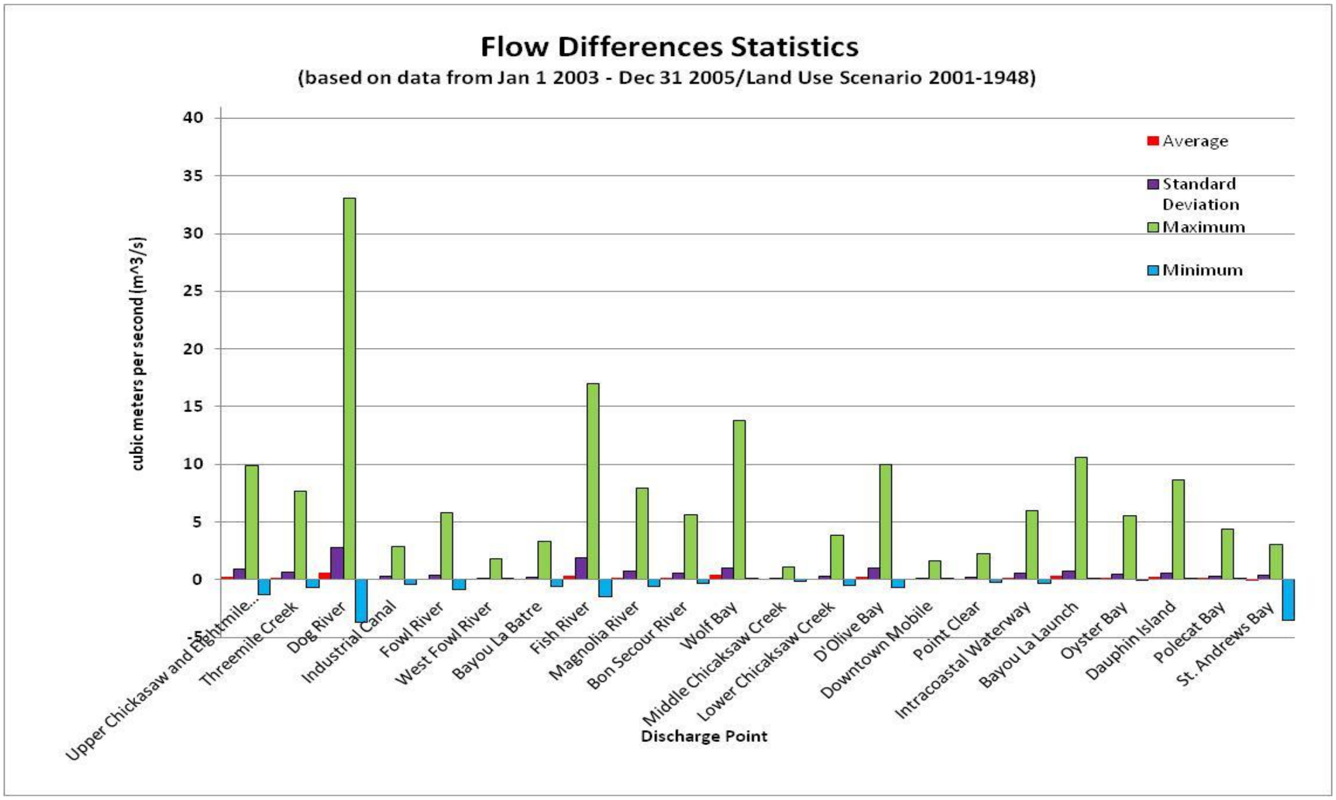

Figure 3. Flow differences per discharge point between 2001 and 1948

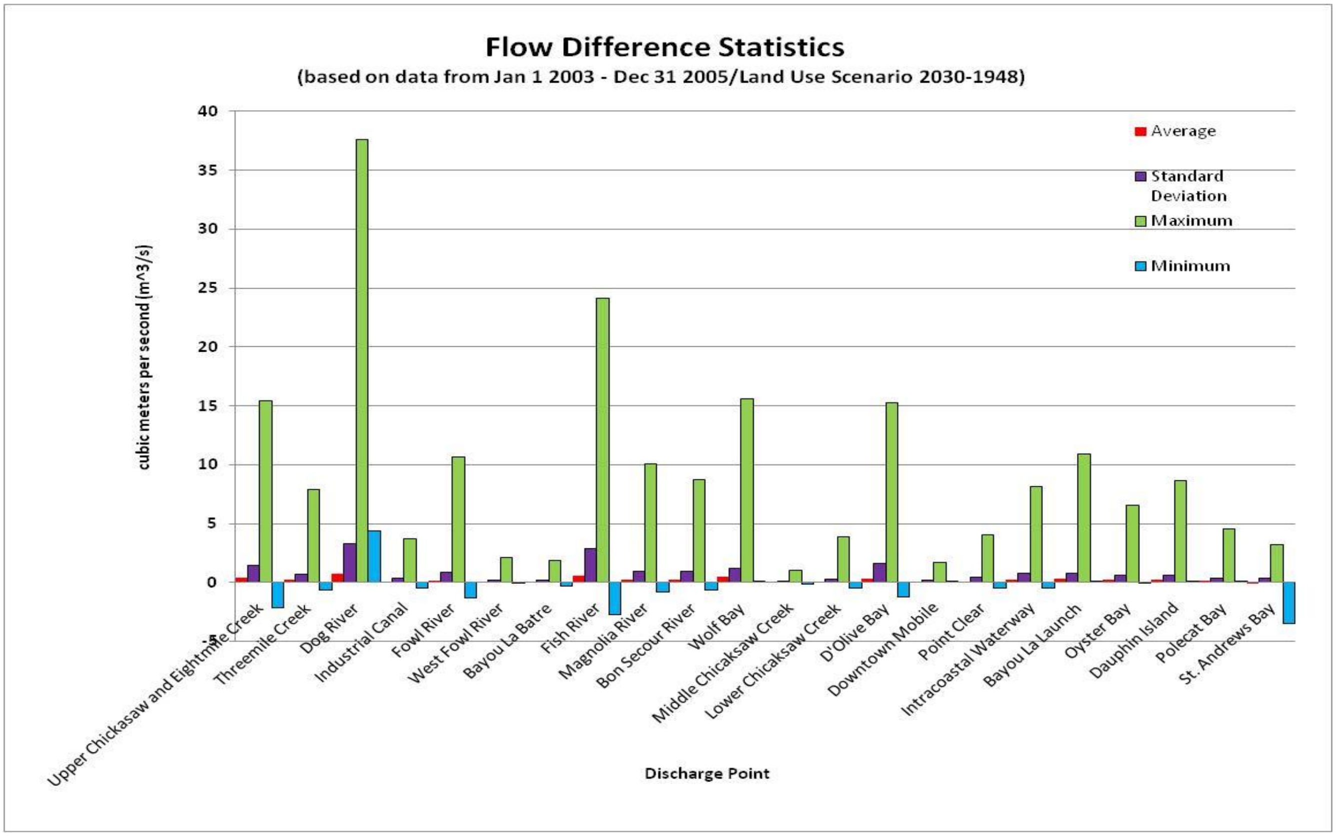

Figure 4. Flow differences per discharge point between 2030 and 1948

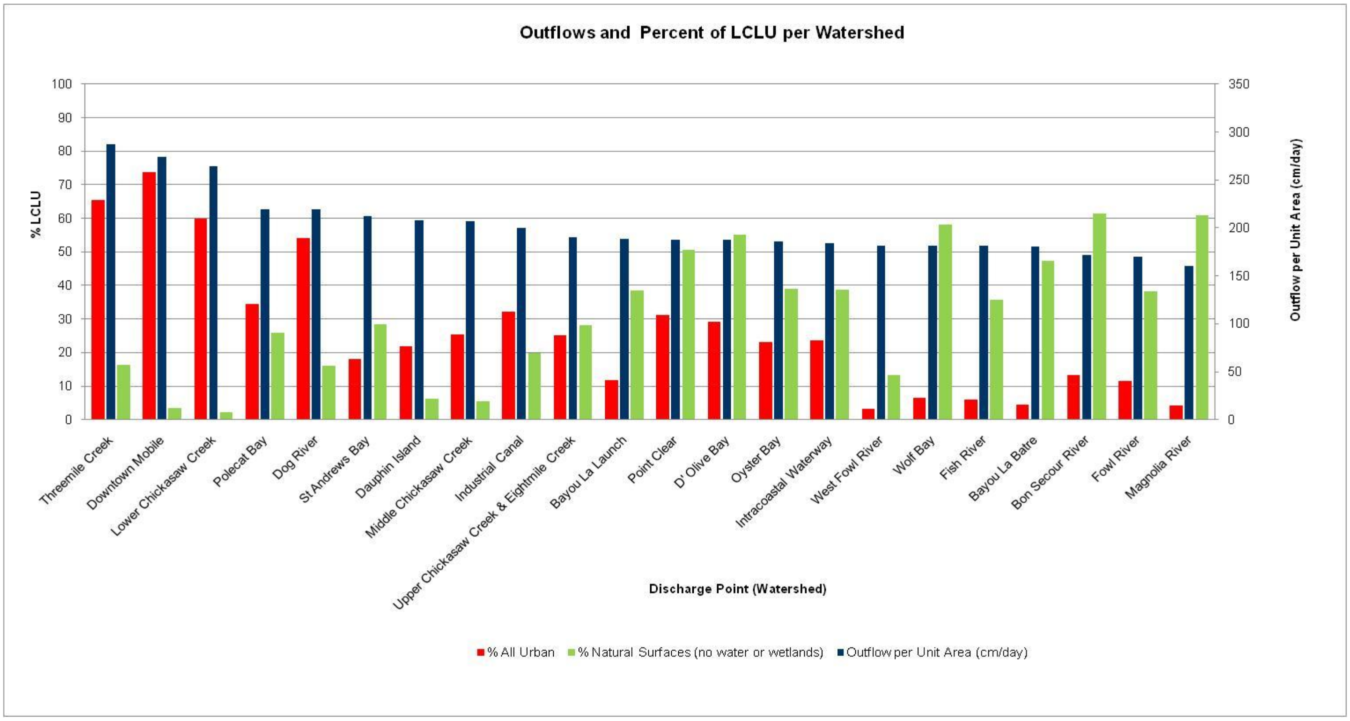

Figure 5. Comparisons between the percentage of natural and urban LCLU areas and outflow per unit area (cm/day) per watershed using 2001 LCLU.

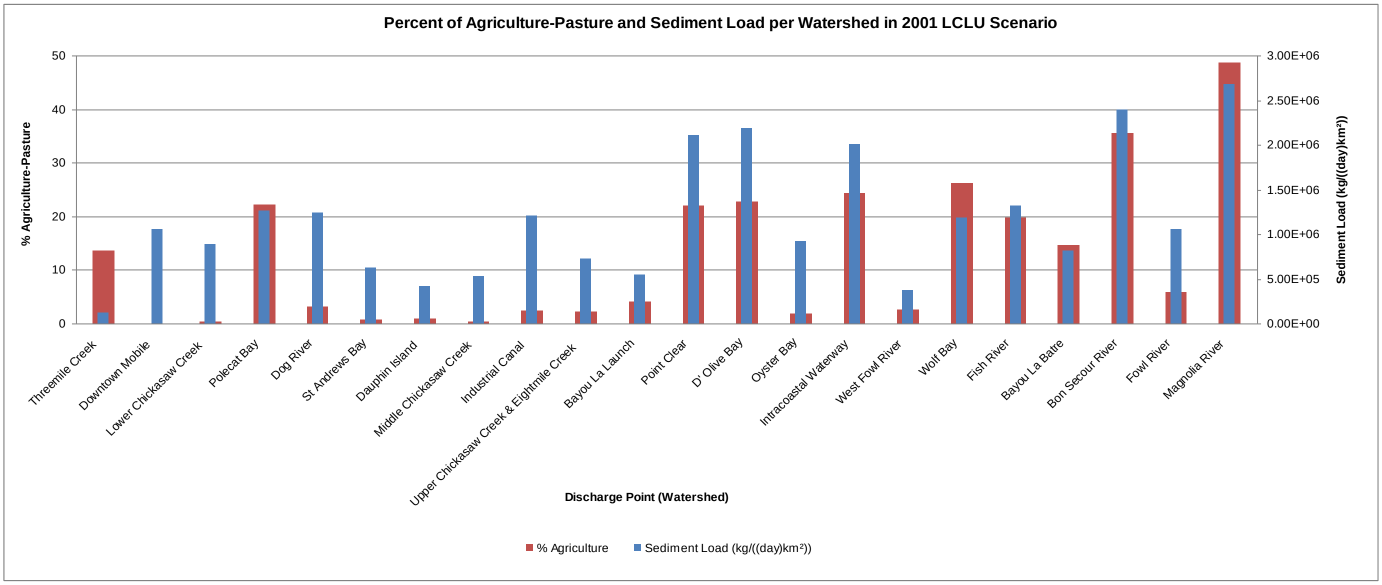

Figure 6. Comparisons between the percentage of agricultural LCLU and the sediment load per watershed using the 2001 LCLU.

B. Climate Change

Overall the results show a decrease in freshwater discharge into the Bay when the temperature increases and the precipitation decreases. Mean values of streamflow discharge for each watershed decrease over time with a drier and warmer climate as projected by the IPCC for the South Region (Fig. 7). Fish River has the largest amount of streamflow discharge among all the subwatersheds and simulations. Middle Chickasaw Creek and Lower Chickasaw Creek typically have low streamflow discharges; however they also showed decreases in streamflow due to the projected climate change. Descriptive statistics for streamflow discharge changes for all climate scenarios are shown in Fig. 8. This graph shows Fish River and Upper Chickasaw Creek & Eightmile Creek as the watersheds with the highest maximum, minimum, standard deviation and mean streamflow differences. Conversely, Middle Chickasaw Creek indicates minimal changes. The standard deviation of the differences shows the fluctuations in streamflow discharges among the watersheds. The trend in the climate change scenarios is to continue increasing temperature and decreasing precipitation, therefore the streamflow differences between 2005 and 2050 (Fig. 9) are higher than those between 2005 and 2025.

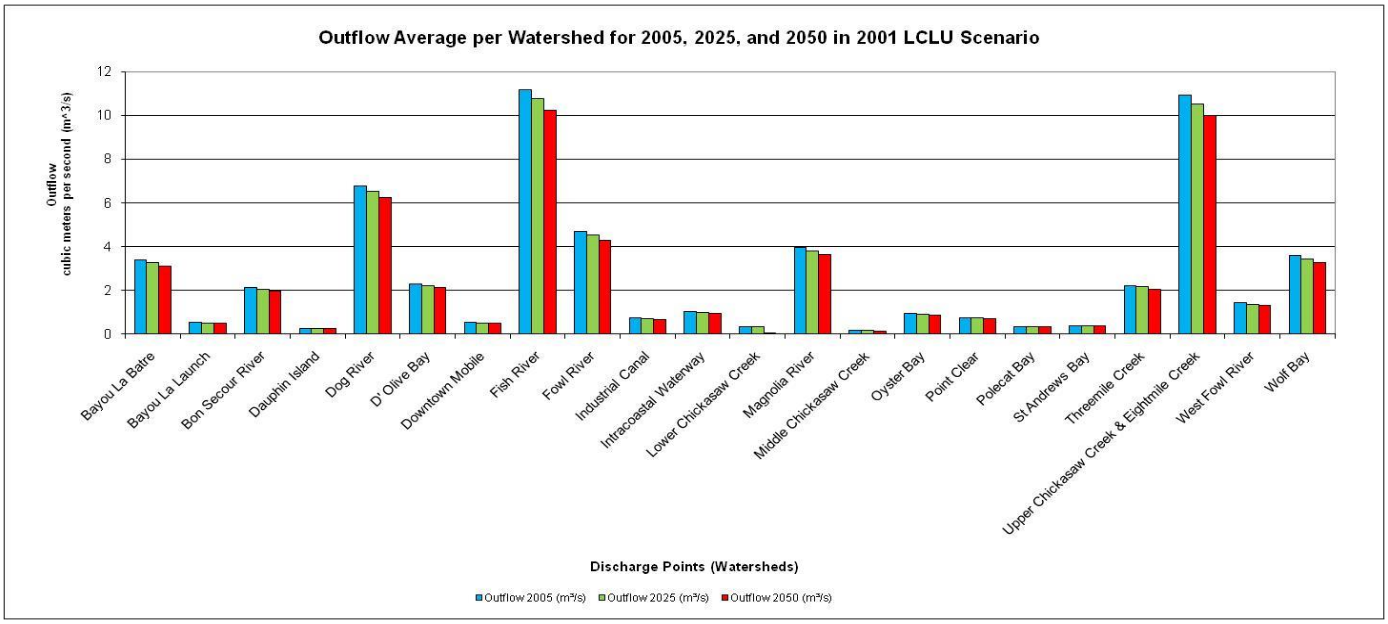

Figure 7. Streamflow discharge average (m³/s) per watershed for the 2005, 2025, and 2050 climate scenarios using 2001 LCLU.

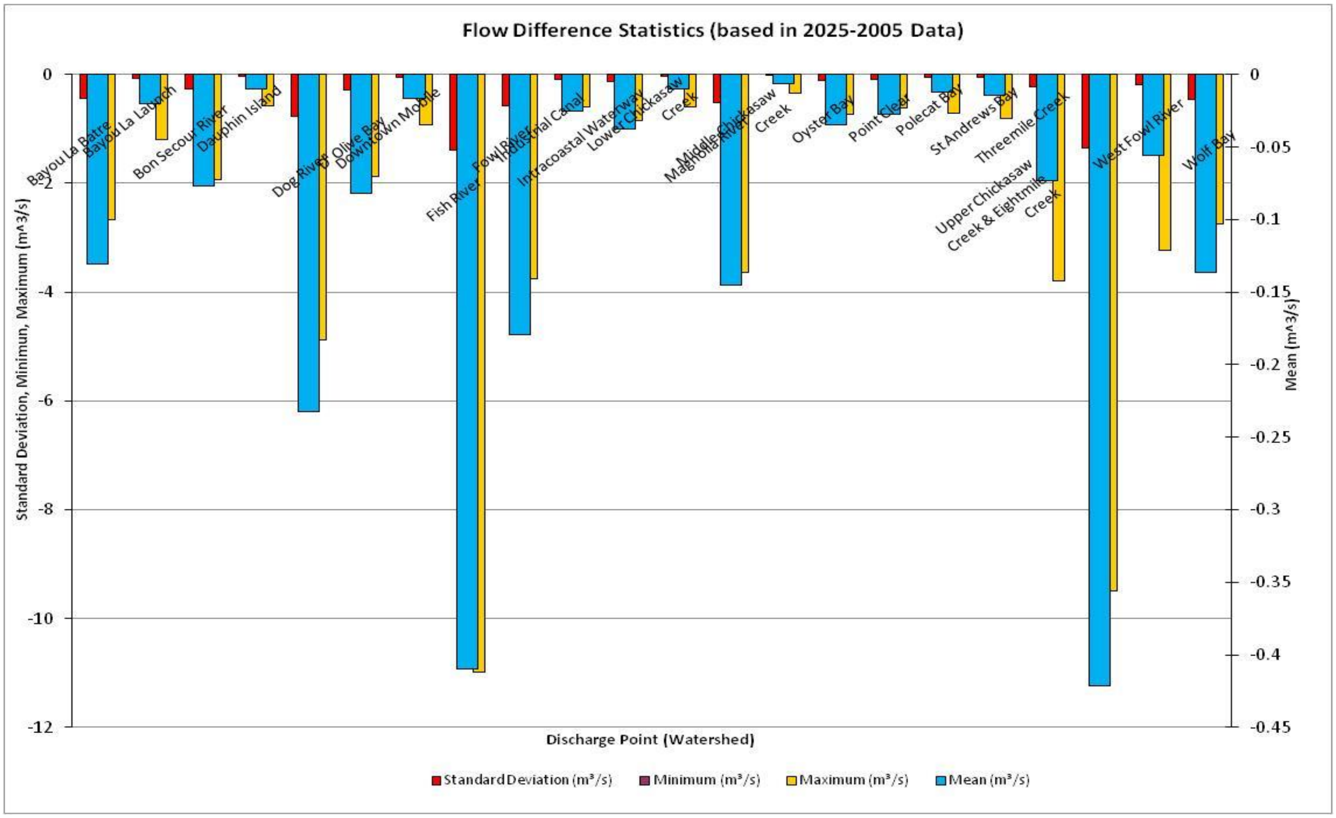

Figure 8. Descriptive statistics of differences in streamflow discharge (m³/s) between the baseline year (2005) and the future year (2025) climate scenarios using 2001 LCLU.

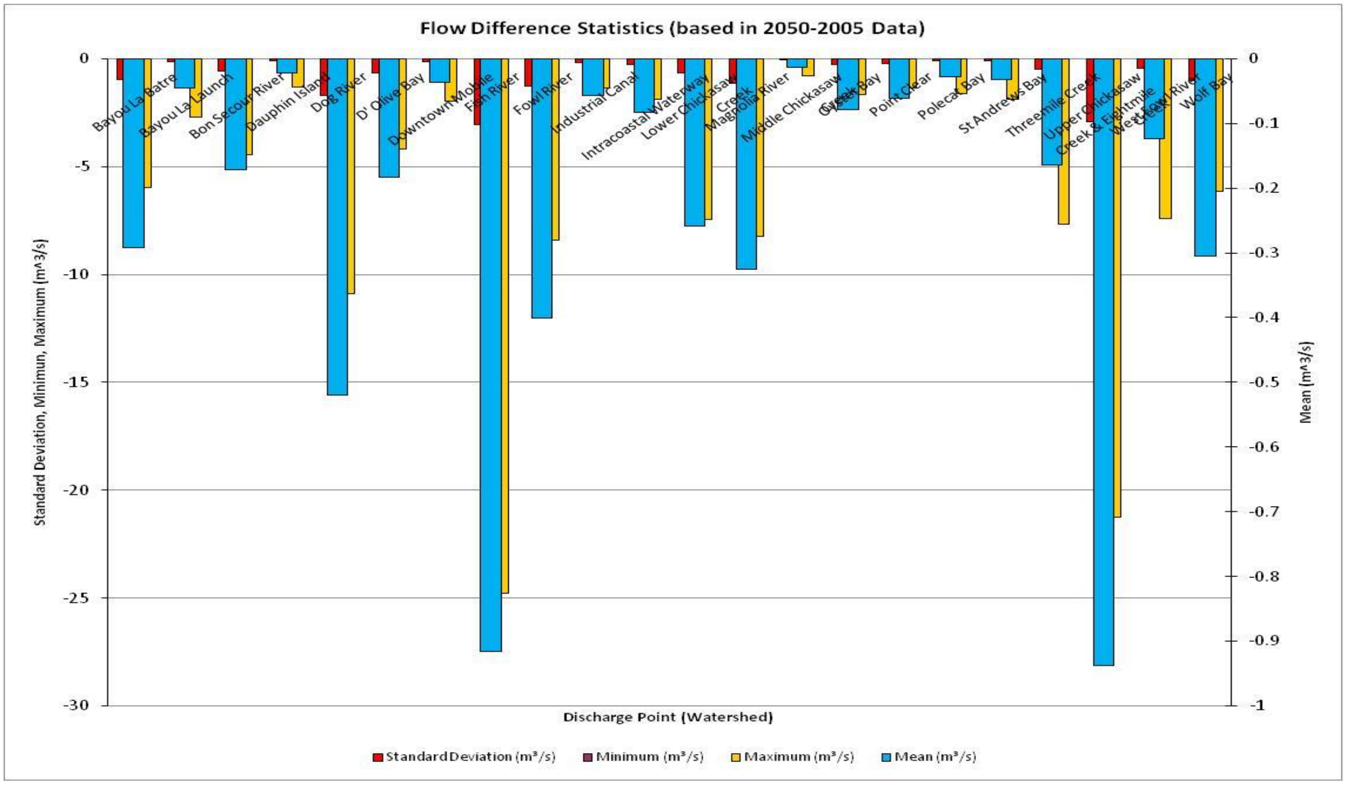

Figure 9. Descriptive statistics of differences in streamflow discharge (m³/s) between the baseline year (2005) and the future year (2050) climate scenarios using 2001 LCLU.

IV. Conclusion

In order to manage and plan the recovery and restoration of the SAV in Mobile Bay, the effect of stressors like LCLU and climate change must be understood. Urban development is continuing to increase in land areas surrounding Mobile Bay. The trend of increasing urbanization leads to a decrease in natural LCLU areas. These LCLU changes are increasing the freshwater flows discharging into Mobile Bay. The watersheds with elevated percentages of urban development have runoffs higher than zones with a higher percentage of natural land cover areas and contribute more freshwater flows into the Bay. Streamflows vary geographically in response to climate (precipitation and temperature) and watershed characteristics (topography, geology, land cover, catchment controls) [29]. These flows are a major influence on the physical habitat in streams, which in turn is a major determinant of aquatic organisms [30]. Variations in flow and velocity in the column of water can determine the distribution and abundance of particular species of animals and plants [31]. Overall, the increases of freshwater into the Bay will reduce the salinity and increase the sediment loads and temperature in the Bay changing the normal conditions of aquatic habitat. As the sediment loads increase, the penetration of sunlight into the water is decreased causing a direct effect in the health of the ecosystem and SAV's.

According to the IPCC data, the climate change trends in the South Region for the next forty years will be an increase in temperature and decrease in precipitation. This drier and warmer climate will decrease the freshwater flows into the Bay increasing the salinity in the shallow aquatic ecosystems. Overall, the effects of climate change on SAV habitat will compete with the urban LCLU change effects of increased freshwater flow into the estuary. Seagrasses and SAV's that prefer areas with higher levels of salinity may experience a decrease in habitat range in the shallow aquatic areas near river discharge points. The impact of the decreased flows on the sediment concentrations needs further analysis with the hydrodynamic model to determine if concentrations will be higher or lower in the water column and the effect on aquatic ecosystems.

Future work with the watershed and hydrodynamic models in the study area is needed to update LCLU data after the hurricane events in the Gulf region and to understand the effects of the 2010 Gulf oil spill on shallow aquatic ecosystems. Also, model simulations combining the climate and LCLU change scenarios to evaluate the effects of both stressors together are needed. Additional work using the IPCC Southeast Region climate scenario, which have different seasonal trends, would also be beneficial as the study area is on the boundary of South and Southeast IPCC regions. This information could be useful for the management of the coast, climate adaptation planning and the restoration of SAV habitats.

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