Title of Proposal: Modeling the Effect of Urbanization and Optimizing Land Use For Estuarine Environmental Flows

Statement of Critical Regional Water Problem:

Freshwater availability to meet both the demands of a growing population and ecological needs is gaining importance within U. S. federal and state governments. Texas State Senate Bill 2 requires maintaining the productivity and integrity of aquatic ecosystems, including estuaries. Productivity of an estuarine ecosystem depends on the quantity, quality and timing of environmental inflows. The quantity, quality, and timing of freshwater inflows change with changes in land use land cover (LULC), urbanization in this case, water resources management (e.g. reservoir operations, return flows), and precipitation pattern. The San Antonio River Watershed is experiencing rapid urbanization. Changes in this watershed may be altering the freshwater inflows to the San Antonio Bay/Guadalupe Estuary system. Proper allocation of land use can help achieve the goal of meeting both ecological and human demands for water. Therefore, the research that is needed to address this problem can be investigated by (1) modeling the effect of watershed development due to urbanization using remotely sensed data and a hydrologic model such as HSPF (2) using a genetic algorithm (GA) to optimize the allocation of land use to meet the freshwater demands of both the increasing population of the City of San Antonio and the freshwater inflow requirements to main a healthy San Antonio Bay/Guadalupe Estuary ecosystem. Researchers with agencies including USGS and SARA are modeling the streams in and around Bexar County and studying various ecological processes such as net ecosystem metabolism and benthic respiration in the San Antonio Bay/Guadalupe Estuary system. However, no studies have yet been conducted to quantify and model the effect of urban growth on freshwater availability to the downstream estuary. The proposed study will aid scientists and policy makers to allocate water resources to meet both human and estuarine demand in Texas, and can be used as a methodology in other parts of U.S. that are facing similar issues.

Nature, Scope, and Objectives of the Research:

Estuaries are the connecting link between terrestrial and marine ecosystems, and provide a critical coastal habitat that is essential ecologically and economically to the world economy (Kennish, 2001). Important species depend on estuaries for their survival and contribute more than 90% of the total fisheries activity in the Gulf of Mexico (Kennish, 2000). Estuarine and coastal marine fisheries return more than $23.0 billion annually to the US economy. In addition estuaries support multi-billion dollar commercial and recreational activities, and employ millions of people world wide. Therefore, it is important to maintain the productivity and ecological integrity of estuarine ecosystems. The productivity of these systems depends on the timing and magnitude of freshwater inflow along with the associated nutrients, metals, and organic matter from the terrestrial environment (Longley, 1994). Variations in freshwater inflows can alter the ecology of estuarine environment, potentially hampering productivity.

Freshwater inflows along with nutrient and metal delivery are influenced by LULC and water management practices in the contributing watershed, particularly in watersheds that are experiencing rapid human induced disturbances such as urbanization. The San Antonio River

Watershed is a semi-arid to subtropical region experiencing rapid growth in human population. Urbanization is significantly impacting various ecological services through land fragmentation and changes in land cover.

Texas Senate Bill 2 (2001) has instructed the state agencies: the Texas Water Development Board (TWDB), the Texas Parks and Wildlife Department (TPWD), and the Texas Commission on Environmental Quality (TCEQ), to develop a state program of environmental flows to support a sound ecological environmental on rivers and streams by 2010. In previous studies, TWDB and TPWD determined methods for quantifying coastal freshwater inflows using computer optimization and hydrodynamic modeling as the predictive technique. The modeling quantified theoretical estimates of minimum and maximum freshwater inflows and maximum fisheries harvest inflow for each estuary along the Texas Gulf Coast. However, studies have not yet been conducted on a watershed scale to model the effect of urban growth on freshwater availability.

The primary purpose of this research is to quantify the regional hydrologic budget response (freshwater inflow and urban water demands) to change in LULC in the rangeland ecosystem of the San Antonio River Watershed. This study will quantify freshwater inflow based on current and historic LULC. Detailed study in this watershed will aid in shaping water policy to maintain water quality, biodiversity and estuarine ecosystem health while meeting the demands of land and water for the increasing population.

The objectives of the present study are: (a) model the variation in freshwater inflows associated with regional hydrologic processes due to changes in LULC by using land cover classification derived from LANDSAT imagery, and HSPF (b) optimize land use in the San Antonio Watershed for both estuarine ecological and economical benefits using HSPF and a genetic algorithm (GA).

(a) *Hypothesis*: *An increase in impermeable land surface due to urbanization coupled with water management practices will increase freshwater inflows to the estuary in seasonally wet periods and decrease freshwater inflows in seasonally dry periods.*

Spectral and textural data from LANDSAT images, digital elevation maps (DEMs) and ground truth data will be used to classify land cover in the San Antonio Watershed. Each classified image for each year will be aggregated to make a composite image. The generated data set will be used as an input to HSPF to estimate the variability in freshwater inflows in the San Antonio Bay System due to LULC change over the past 20 years. HSPF will be calibrated for the year 1984 using the obtained land use data, weather data, and GIS based soils data (SURRGO). A GA will be used to extensively search through combinations of parameters to achieve the set that is “best” in terms of satisfying the criterion of accuracy. The criterion will be the sum of the squares of the differences between corresponding simulated and observed values at a given time scale. The overall objective in calibration process will be to achieve a reasonable simulation of the stream flow, by minimizing the root of the mean square of errors (RMSE) between the observed and simulated streamflow. The calibration process will proceed as follows: (1) code the HSPF parameters as “genes” in the chromosomes, (2) initialize the population of the chromosomes, (3) evaluate the fitness of each chromosome by using the decoded parameter values as inputs to run HSPF to obtain the RMSE between the observed and simulated

streamflow, (4) the chromosomes undergo the selection processes where the fittest survive and the weakest die, (5) the surviving chromosomes will undergo reproduction by the process of crossover, (6) the generated offspring are subjected to mutation (7) iteration processes continues from step 3 until optimum values are obtained.

Once the model is calibrated for 1984 using GA, the model will be used in freshwater inflow predictions. In simulations to assess the effect of urbanization on freshwater flows, all other model input parameters (weather data such as rainfall, wind speed, temperature etc. and soil) will be kept constant and only LULC will be changed for the years 1990, 1994 and 2003, utilizing the classified LANDSAT imagery. Wavelet analysis will be conducted on the simulated freshwater inflows, to identify a change in frequencies of freshwater inflows for each of the years, and if a change is identified, at what scale the change is occurring.

Once the effect of LULC change on freshwater inflows is simulated for all three time periods, measured rainfall will be used in the model for the respective years to quantify the combined effect of landuse and precipitation on freshwater inflows. This will either validate the hypothesis that freshwater inflow is affected by human induced disturbance alone, or alternatively indicate the additional importance of precipitation pattern.

(b) Hypothesis: Increasing urbanization will put pressure on land resources that will stress environmental endpoints in the estuary. However, proper land management can help achieve coexistence of urban growth (economical significance) and environmental flows (ecological significance).

Land use optimization for ecological and economical benefits follows the decision of what land use and to what extent land use has to be optimized to obtain the benefits. A GA coupled with a distributed hydrologic model will be used to optimize land resources in a watershed to maximize urban growth without causing damage to the environmental flow requirement to the estuary. GA will be used to search through combinations of land uses to achieve the "best" economic and ecological objectives. The ecological objective will be to maintain a flow of 0.532 million acre-ft/yr (Longley, 1994), which is about 20-30 % of the historical total flow to the Guadalupe Estuary/San Antonio Bay, without jeopardizing the best economic return. Mathematically the optimization process can be represented by:

$$\text{Min } \Sigma (Q' - Q'') \text{ and Max } \Sigma (L1, L2, L3, L4\ldots) \text{ with a constrain } Q' \geq Q''$$

where Q' is model simulated flow, Q'' is seasonal flow, and L1, L2, L3, L4… are percentages of land use in the basin.

Time Schedule of Proposed and Related Work:

(1) Time series analysis of freshwater inflows using USGS gauging station data: Completed and presented at AGU Fall, 2005; (2) Wavelet Analysis: In progress; (3) LANDSAT Image Acquisition: Completed; (4) HSPF calibration using GA: Summer 2006; (5) complete objective (a): Fall 2006 (6) complete objective (b): Spring 2007.

References:

Kennish, M. J. 2000. Estuary Restoration and Maintenance: The National Estuary Program. CRC Press, Boca Raton, FL.

Kennish, M. J. 2001. Practical Handbook of Marine Science, 3rd ed. CRC Press, Boca Raton, FL.

Longley, W. L. 1994. Freshwater inflows to Texas bays and estuaries: ecological relationships and methods for determination of needs. Texas Water Development Board and Texas Parks and Wildlife Department. Austin, Texas.

Results Expected from this Project:

This study will create an automated calibration procedure for HSPF that will aid agencies such as USGS, SARA and SAWS that work in this watershed. Modeling the effect of urbanization on freshwater inflows and using a genetic algorithm to obtain the optimal solution for effective land allocation will aid in water resources management that meets both economic and ecological needs.