Report as of FY2006 for 2006TX230B: "Modeling the Effect of Urbanization and Optimizing Land Use For Estuarine Environmental Flows"

Publications

Project 2006TX230B has resulted in no reported publications as of FY2006.

Report Follows

Monitoring the Effect of Urban Growth on Freshwater Inflows using Wavelet Analysis

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Introduction

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. 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 (NRC, 2005) along with the associated nutrients such as N and P, metals, and organic matter from the terrestrial environment. Freshwater inflows help in ecological processes such as dilution of salt water that creates a unique environment; creation of habitats for several species; regulation of bay water temperature and are essential for marine bio-geochemical cycles. Variations in freshwater inflows can alter the ecology of estuarine environment, potentially hampering productivity. Freshwater inflow, nutrient, and metal delivery are influenced by the land use/land cover and water management practices in the contributing watershed, particularly in watersheds that are experiencing rapid human induced disturbances. San Antonio, TX, the 8th largest city in the US, is situated in the San Antonio River basin. The San Antonio River Basin encompasses 4180 square miles from the headwaters to the point at which this river joins with the Guadalupe River, before draining into Gulf of Mexico. Rapid urbanization has changed the land use and land cover in this river basin. Studies in the river basin suggest that change in land use has primarily been an increase in impervious surface. Increase in impervious surface can change the flow regime by altering timing, magnitude, scale, and frequency of freshwater inflows.

This study used continuous wavelet transformation (CWT) on the geo-physical signal (environmental flow) to analyze changes in frequency and scale in the San Antonio River flow regime (seasonal flows in particular) using 63 years (1940-2003) of average daily discharge obtained from USGS gauging station number 8188500 situated most downstream in the river. This study also applied similar technology on seasonal baseflow, which was separated from total flow.

Wavelet analysis of the hydrologic stream flow data helps to understand the cyclic changes and patterns present in the time series. It helps to link these cyclic changes to river basin water management to maintain estuarine ecological health.

Methodology

Data from daily average flow were aggregated into three distinct seasonal periods (Dec-Mar, Apr-Jul, and Aug-Nov), for each year. From this aggregated datasets, maximum, minimum, and total seasonal flows were calculated. Baseflow was estimated from total flow using a baseflow separation program (digital filter technique) developed by Arnold, and Allen, 1999. Similar analysis was conducted on baseflow.

Wavelet analysis was conducted using MATLAB. For the current analysis, a complex Morlet wavelet function was used. The wavelet transformation *Wn* is the convolution of a vector *x* (with time dimension n) with a wavelet function *ψ*

$$W_{n(s)} = \sum_{n'=0}^{N-1} x_n \psi^*\left[\frac{(n'-n)\delta t}{s}\right] \qquad (1)$$

where *s* is the scale, or dilation, n' – n shows the number of points from time series origin (translation), *δt* is the time interval, *N* is the number of points, and the overbar designates the complex conjugate. Scale is the width of the wavelet; a larger scale means that more of the time series is included in the calculation and that finer details are ignored. Scale is approximately equal to the Fourier period (inverse of frequency). Translation of the wavelet is accomplished by calculating the convolution from n' = 0….. N-1. In other words, a wavelet of varying width (scale) is moved, or translated, through the entire time series. The wavelet transformation is therefore localized in both time (through the translation) and frequency (through the range of scales). Wavelets are advantageous in that they simultaneously localize frequency and time, allowing for the detection of variations in the amplitude and timing of periodic signals present in the time series (White et al., 2005).

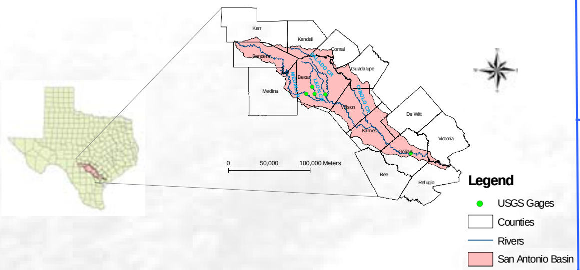
In this analysis, a complex Morlet wavelet function *ψ0(η)*, which is commonly used for signals with strong wave-like features (such as streamflow data), was used and is calculated as:

$$\psi(\eta) = \pi^{-1/4} e^{i\omega_0 \eta} e^{-\eta^2/2} \qquad (2)$$

where *ω0* is the non-dimensional wave number and *η* is a time parameter (non-dimensional, also could represent other metrics such as distance).

The continuous wavelet transform can then be calculated using a fast Fourier transform (FFT). The wavelet power spectrum (WPS), as for the Fourier power spectrum, is defined as | *Wn(s)* |². In addition to viewing the entire wavelet power spectrum, wavelets can be averaged in time and space.

San Antonio River Basin showing major streams, and USGS gauging stations



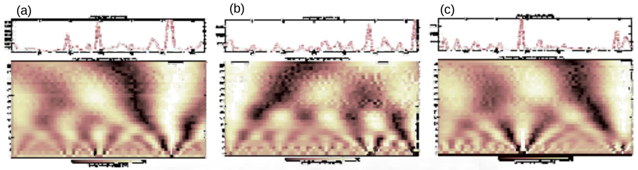


Figure 6: (a) Dec-Mar Maximum Baseflow, (b) Apr-Jul Maximum Baseflow, (c) Aug-Nov Maximum Baseflow

Results and Discussion

The x-axis in the figures show wavelet location in time (Time Translation) and y-axis is the wavelet period in years (Scale Dilation). Total seasonal flow analysis (Figure 1) suggested the presence of highest magnitude at 11-17 year scale in Dec-Mar and Apr-Jul, with a 10 year cycle (oscillation). Total minimum flow (Figure 2) for each of the season suggested the presence of highest magnitude at 11-17 year scale across all seasons before 1980. However, after 1980 higher magnitudes are observed at the lower scale. Total maximum flow (Figure 3a and Figure 3b) suggested presence of some dominant features at 11-15 year scale with 10 years of oscillation prior to 1980. Analysis of total baseflow (Figure 4a and Figure 4b) suggested that signals have become erratic after 1980. Highest magnitude dominated 11-15 years scale with 10 years oscillation. However, that magnitude is not observed at 11-15 years scale after 1980. Higher frequencies are observed in smaller scale. This may suggest that the baseflow is affected by the continuous discharge from waste water treatment plants. These plants being established between 1972 and 1980, following the Clean Water Act. Similar signatures were observed in Minimum and Maximum baseflow of Dec-Mar, and Apr-July seasons (Figure 5a, 5b and Figure 6a, 6b).

Further analysis will include wavelet analysis of rainfall, and spectral analysis of total flow, baseflow, and rainfall.

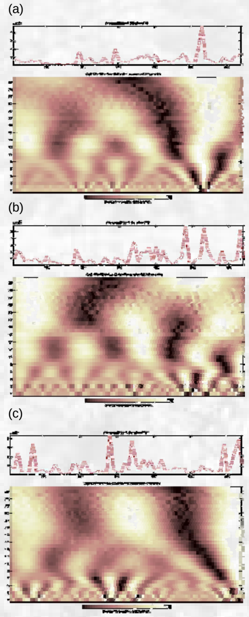


Figure 1: (a) Dec-Mar Total Flow, (b) Apr-Jul Total Flow, (c) Aug-Nov Total Flow

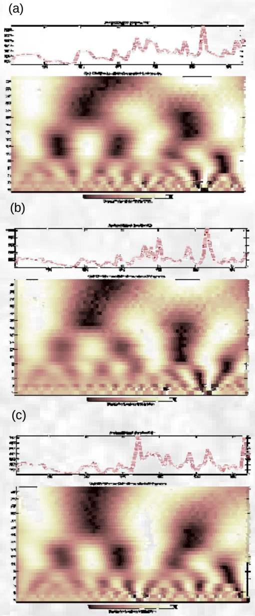


Figure 2: (a) Dec-Mar Total Minimum Flow, (b) Apr-Jul Total Minimum Flow, (c) Aug-Nov Total Minimum Flow

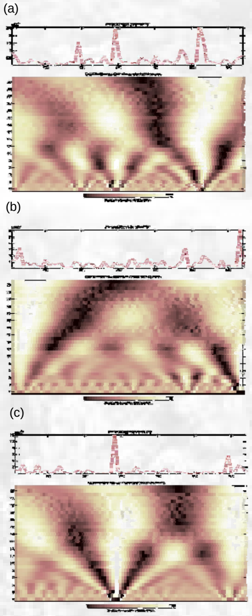


Figure 3: (a) Dec-Mar Total Maximum Flow, (b) Apr-Jul Total Maximum Flow, (c) Aug-Nov Total Maximum Flow

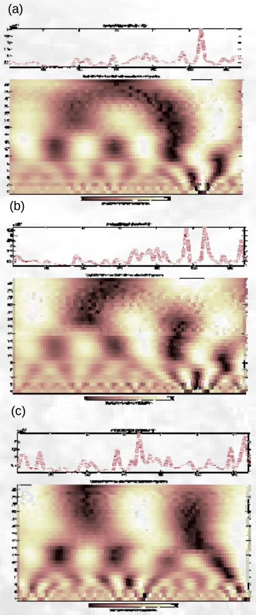


Figure 4: (a) Dec-Mar Total Baseflow, (b) Apr-Jul Total Baseflow, (c) Aug-Nov Total Baseflow

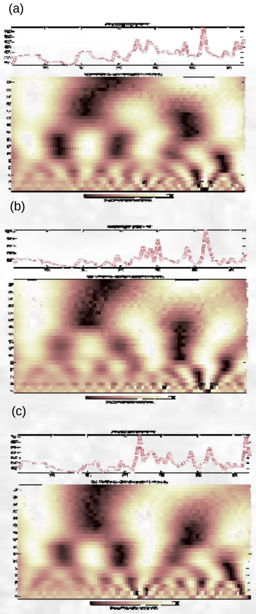


Figure 5: (a) Dec-Mar Minimum Baseflow, (b) Apr-Jul Minimum Baseflow, (c) Aug-Nov Minimum Baseflow

References

Arnold, J. G., and P. M. Allen. 1999. Automated methods for estimating baseflow and groundwater recharge from stream records. JAWRA. 35(2): 411-424.

National Research Council (NRC). 2005. The science of instream flows: A review of Texas instream flow program. Washington D. C. National Academy Press.

White, M. A., J. C. Schmidt, and D. J. Topping. 2005. Application of wavelet analysis for monitoring the hydrologic effects of dam operation: Glenn Canyon Dam and Colorado River at Lees Ferry, Arizona. River Research and Application. 21: 551-565.

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Evaluating the Effect of Land Use Land Cover Change in a Rapidly Urbanizing Semi-Arid Watershed on Estuarine Freshwater Inflows

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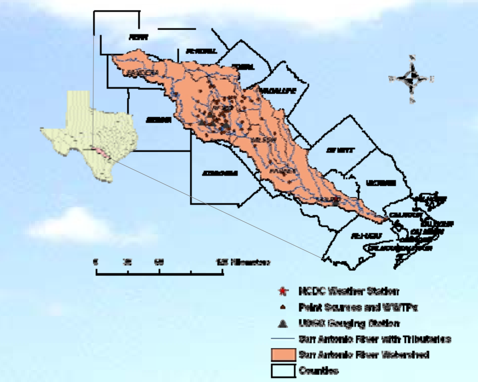

Figure 1: San Antonio River Basin showing major streams, and USGS gauging stations

Introduction:

The study of environmental inflows is an evolving science (NRC, 2005). Adequate environmental inflows are needed for proper ecological maintenance of aquatic ecosystems such as estuaries. Estuarine freshwater inflows along with their associated nutrient and metal delivery are influenced by the land use/land cover (LULC) and water management practices in the contributing watershed, particularly in watersheds that are experiencing rapid human induced disturbances. San Antonio, TX, the 8th largest city in the US, is situated in the San Antonio River basin. The San Antonio River Basin encompasses 4180 square miles from the headwaters to the point at which this river joins with the Guadalupe River, before draining into Gulf of Mexico. Rapid urbanization has changed the land use and land cover in this river basin. Studies in the river basin suggest that change in land use has primarily been an increase in impervious surface. Increase in impervious surface can change the flow regime by altering timing, magnitude, scale, and frequency of freshwater inflows.

Methodology:

LULC data set were obtained from LANDSAT TM satellite imageries for the years 1987, 1999, and 2003 from USGS and Texas View. Four row/path combinations: 2839, 2739, 2740, and 2640 covered the entire watershed area. ENVI 4.2 was used for image processing. Images with 28.5 m resolution were resampled for 30 m resolution. Unsupervised ISODATA classification was conducted on the images. Approximately 20 classes were used initially. These 20 classes were lumped into 4 classes. Each classified scene was then mosaiced for the required watershed area. ArcGIS 9.1 and Arcinfo were used for spatial analysis.

This study used 63 years (1940-2003) of daily average flow data from the most downstream USGS gauging station number 08188500 (Figure 1), and rainfall from NCDC COOP ID 413618 situated near the USGS gauging station (Figure 1). Average daily data was aggregated to estimate seasonal flow and seasonal rainfall (December-March, April-July, and August-November). A baseflow separation filter (Arnold, and Allen, 1999) was used to separate baseflow. Non parametric time series analysis was performed on all these hydroclimatic variables.

References:

Arnold, J. G, Allen, P. M., 1999. Automated method for estimating baseflow and groundwater recharge from stream flow records. Journal of the American Water Resources Association 35, 411-424.

NRC., 2005. The science of instream flows: A review of Texas instream flow program. Washington D. C. National Academy Press.

Sahoo, D., and P. Smith. 2006. (Submitted to the Journal of Hydrology) Analysis of seasonal environmental flows to a gulf coast estuary in a rapidly urbanizing semi-arid coastal river basin.

Sahoo, D., P. Smith, and F. Zhang. 2006. (Submitted to Estuarine Coastal and Shelf Science) Characterization of freshwater inflows draining to a gulf coast estuary in a rapidly urbanizing coastal watershed using wavelet techniques.

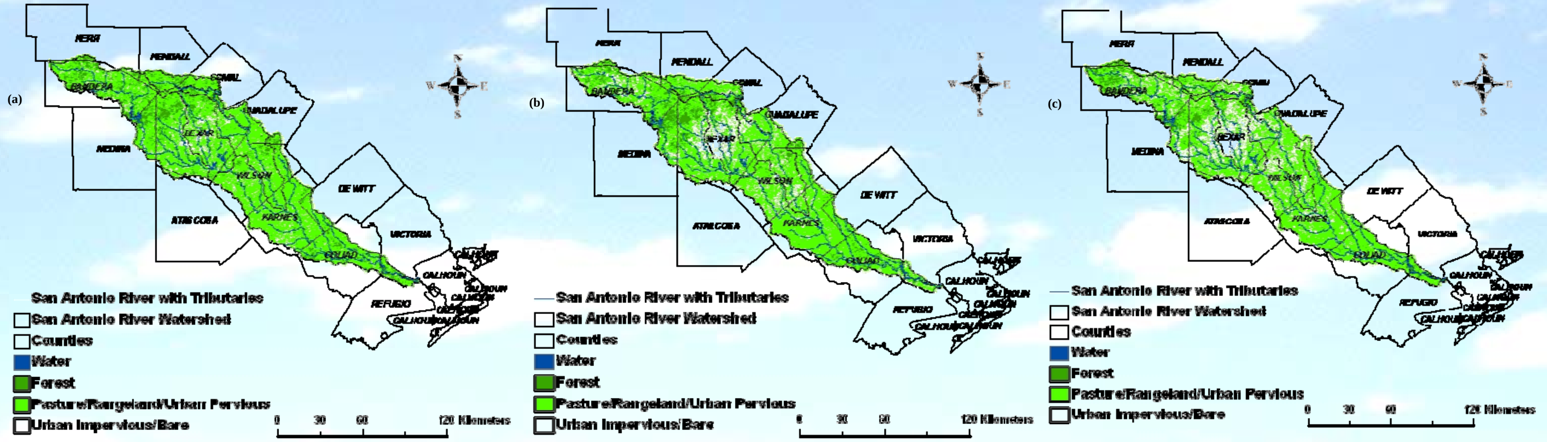

Figure 2: Land use land cover in San Antonio Watershed; (a) 1987, (b) 1999, and (c) 2003

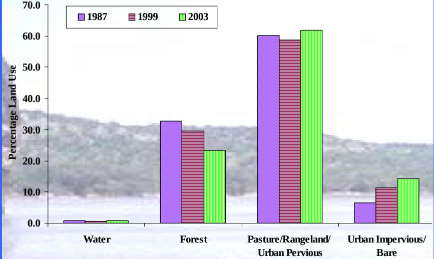

Figure 3: LULC percentage in San Antonio Watershed

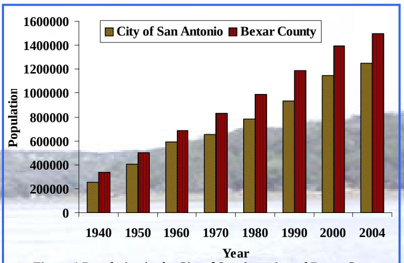

Figure 4:Population in the City of San Antonio and Bexar County

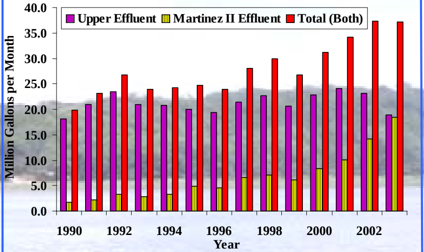

Figure 5: Two WWTPs discharge in San Antonio River Basin

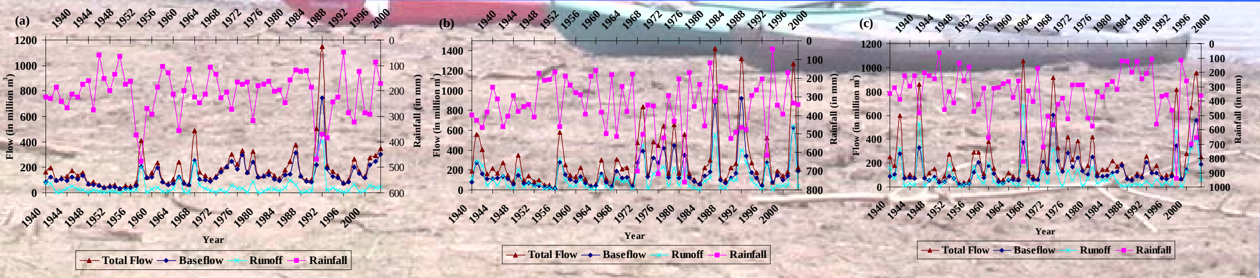

Figure 6: Comparison of seasonal Total flow, Baseflow, Runoff, and Rainfall (a) Dec-Mar, (b) Apr-Jul, and (c) Aug-Nov

Results and Discussion:

LULC analysis suggested Pasture/Rangeland/Urban impervious to be the dominant land use in all the three years (Figure 2). Forest area decreased in the analysis period (Figure 3). Decrease in forest area could be attributed to an increase in urban impervious/bare land (Figure 3). Population has also increased in last two decades, particularly in Bexar County (Figure 4). Urban impervious/bare cover increased in Bexar County from 9% in 1987 to 21% in 2003.

With increase in population, increase in impervious surface, there has been an increase in WWTPs discharges (Figure 5). Analysis of environmental flow suggested an increasing trend in total seasonal flow (Dec-Mar, Apr-Jul, Aug-Nov), and total seasonal baseflow (Figure 6) (Sahoo and Smith, unpublished). Also analysis of these variables suggested presence of dominant frequency in 8 years cycle (Sahoo et al., unpublished). However, no increasing trend was observed in seasonal rainfall or seasonal runoff. Analysis of similar rainfall events from 1950s and from 1990s and corresponding seasonal total flow, baseflow and runoff suggested seasonal total flow increased substantially in 1990s. Baseflow contributed more to total flow than runoff. Increasing trend in baseflow could be attributed to WWTPs discharge (Figure 1 and Figure 5).

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