Ecological Informatics 4 (2009) 243–253

Contents lists available at ScienceDirect

Ecological Informatics

journal homepage: www.elsevier.com/locate/ecolinf

Application of watershed analyses and ecosystem modeling to investigate land–water nutrient coupling processes in the Guadalupe Estuary, Texas

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ARTICLE INFO

Article history:
Received 3 April 2009
Received in revised form 3 July 2009
Accepted 7 July 2009

Keywords:
Nutrient loading
Land use/land cover
Ecosystem responses
Modeling
Estuary
GIS

ABSTRACT

Estuarine nutrient enrichment is thought to be controlled by land use patterns in coastal watersheds. Hence, the objective of this work was to conduct a watershed analysis in two adjacent river basins with different land use characteristics to determine their influence on estuarine ecosystem response in the Guadalupe Estuary, Texas, U.S.A. All data sources for this study were available electronically on the Internet; the data were mined, managed, analyzed and transformed to simulate the estuarine ecosystem response to watershed-derived nutrient loads. Between 1992 and 2001, developed land use/land cover increased the most while forest cover decreased the most in both basins. Two hydrologic units nearest the coast were responsible for the greatest change in land cover. Nutrient concentrations and loads were significantly higher in the San Antonio River Basin than in the Guadalupe River Basin. Both river basins exhibited the highest flows ever recorded in 1992, however the magnitude of difference in loads between the two coastal hydrologic units for a wet and dry year was much greater in the Guadalupe River Basin (GRB) than in the San Antonio River Basin (SARB); this difference supports the concept that the GRB is a nonpoint source dominated system and SARB is a point source dominated system. There was a strong correlation between developed land use and nutrient concentrations in river water; the GRB had less developed land use and lower nutrient concentrations while the SARB had more developed land use and higher nutrient concentrations. Estuarine ecosystem response differed in the timing, duration and magnitude of DIN, phytoplankton and zooplankton when nitrogen loads from the Lower Guadalupe River were used as opposed to the Lower San Antonio. The two basins studied differ in their fundamental characteristics, i.e. precipitation, flow, human population density, etc., resulting in different drivers of nitrogen loading, point sources in the San Antonio River Basin and nonpoint sources in the Guadalupe River Basin, therefore, differing estuarine ecosystem responses.

1. Introduction

Nutrient enrichment is the leading cause of degraded water quality in United States (U.S.) coastal waters (Howarth, 2004; Bricker et al., 2007). Increases in nitrogen flux to coastal waters have been linked to human-induced changes in coastal oceans world-wide (Vitousek et al., 1997; Boesch, 2000; Scavia et al., 2002). Sources of nutrient enrichment include discharges from municipal and industrial activities, atmospheric deposition derived from fossil fuel combustion and land-derived sources associated with runoff from various land use types, e.g., agriculture, residential, construction, and urban (Howarth et al., 2002; Bricker et al., 2007; Galloway et al., 2008). Human-induced sources of nutrient enrichment have been attributed to the degradation of water quality and the subsequent unbalancing of the nitrogen cycle (Cloern, 2001; Howarth, 2004).

Estimates place between 53 and 60% of the U.S. population living within 60 km of the coast with high population growth identified along the Texas Gulf Coast (Culliton, 1998; Crossett et al., 2004). Larger human populations result in increased human-induced sources of nutrients and concomitant environmental pressures. Nitrogen is the limiting nutrient in many estuaries, therefore the addition of nitrogen to estuaries stimulates algal growth and leads to eutrophication (Bricker et al., 2007). When eutrophication occurs, dissolved oxygen is consumed during algal decomposition resulting in faster rates of oxygen depletion than reaeration, creating hypoxic conditions which have been positively correlated with coastal population growth (Verity et al., 2006).

If human development leads to coastal nutrient enrichment, then watersheds with different land use characteristics should have different nitrogen loads. Further, increased development over time should alter nitrogen loads and estuarine ecosystem functioning. The Guadalupe and San Antonio Rivers are adjacent and flow into the Guadalupe Estuary, providing an ideal setting to test this hypothesis.

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doi:10.1016/j.ecoinf.2009.07.002

The hypothesis was tested by: 1) conducting a watershed analysis which included quantifying land use/land cover (LULC) change in the Guadalupe and San Antonio River Basins between 1992 and 2001, analyzing long-term (1987–2006) water quality data in both river basins, and comparing the relationship between LULC change and water nutrient concentrations in both basins, and 2) using results from the watershed analysis as model inputs to simulate potential temporal estuarine ecosystem responses to varying nutrient loads delivered by the contributing river basins.

2. Methodology

2.1. Study area

An estuary is a transition zone where salt water from the sea mixes with freshwater draining from the land. Freshwater inflow has a major influence on coastal ecosystems because it regulates salinity, nutrients, and sediments (Schubel and Kennedy, 1984). The Guadalupe Estuary is one of seven major estuarine systems located along the central Texas Gulf of Mexico coast in the U.S. The Guadalupe Estuary receives freshwater inflow from the San Antonio and Guadalupe Rivers, which converge about 16 km upstream prior to flowing into the estuary (Fig. 1). Mixing of salt and freshwater creates a salinity gradient in the west to east direction of the estuary. The estuary has a bay area of 579 km^2 and drains two basins, the Guadalupe River Basin (GRB) and the San Antonio River Basin (SARB) (Fig. 1) (TDWR, 1980). The basins differ in size, population density, urbanized area, precipitation, river flow, annual average runoff, and number of permitted discharges (Table 1).

Table 1
Characteristics of Guadalupe and San Antonio River Basins.

Characteristic	Guadalupe River Basin	San Antonio River Basin
Area (km^2)	15,151	10,826
Population[a,b]	400,000	1,800,000
Urbanized area (%)[a,b]	2	8
Precipitation (cm $year^{-1}$) [a,b]	76–94	66–97
Annual average river flow (m^3/s)[c]	56.76 (1936–2007)	22.61 (1925–2007)
Annual average runoff (m^3/ha)[d]	848	714
Number of permitted discharges[a,b]	51 industrial	83 industrial
	19 municipal	34 municipal

[a] GBRA (2006).
[b] SARA (2003).
[c] Calculated at the pour point of each coastal HUC (USGS, 2008).
[d] TDWR (1980).

2.2. Watershed analysis

The watershed analysis is comprised of two major components, the spatial and water quality analyses. A spatial analysis was performed to determine land use/land cover (LULC) changes in the study area. Categories of LULC from the Multi-Resolution Land Characteristics Consortium (MRLC, 2008) were used to perform the change analysis at the basin and hydrologic unit code (HUC) scales. HUCs which consist of hydrologic units are defined by hierarchical water management units that have the capacity to represent the spatial hydrological variability in the U.S. (Seaber et al., 1987). Spatial data layers used for the analysis were integrated into a geographic information system (GIS) using ArcGIS v9.3™ software. Analyses were performed with both raster and vector models in the GIS using the Albers Equal Area

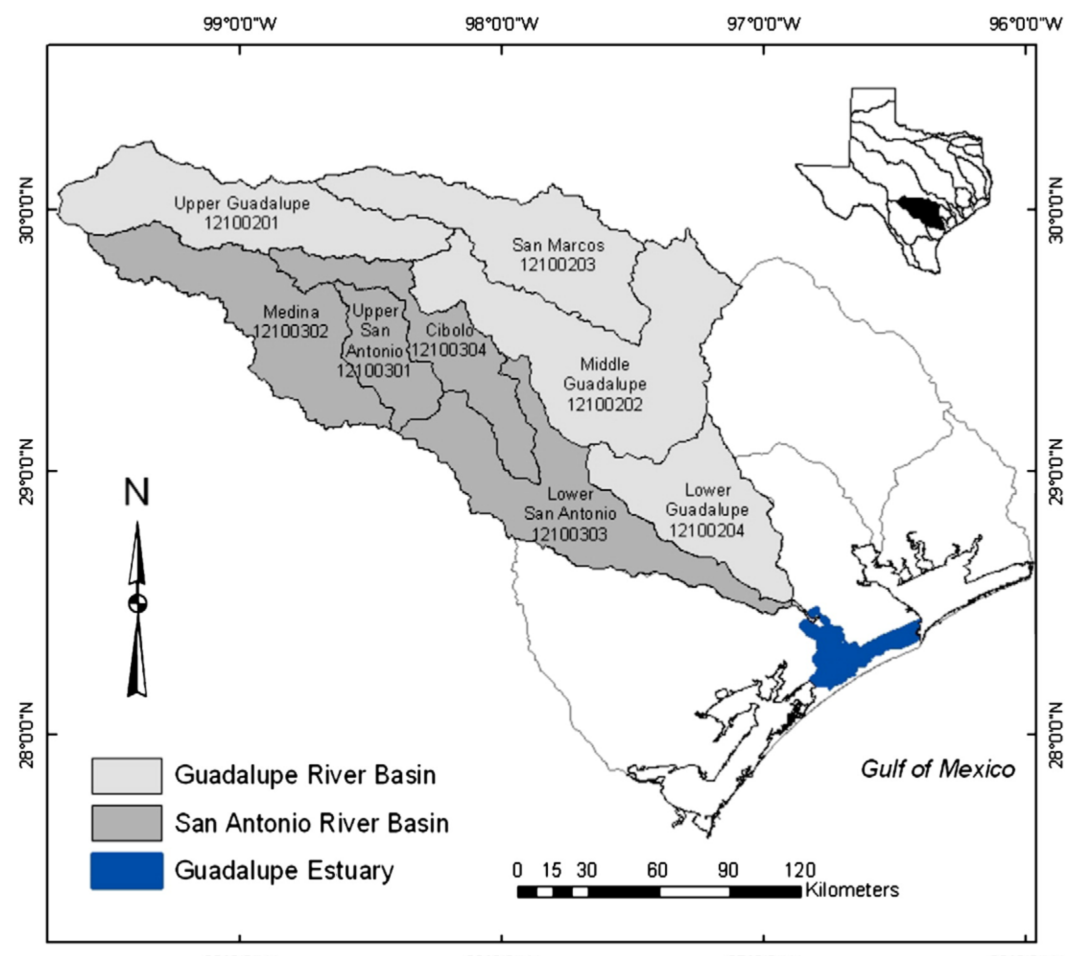

Fig. 1. The Guadalupe Estuary and the two contributing basins, the Guadalupe and San Antonio River Basins with 4 8-digit hydrological unit codes (HUCs) delineated in each basin.