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# Examining the relationship between development patterns and total phosphorus in the Galveston Bay Estuary

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ABSTRACT

Understanding how the pattern of urban development affects the nutrients level in streams and rivers is particularly important for planners and policymakers working to maximize stream and river water quality. This study focuses on the Galveston Bay Estuary in Texas, where rapid population growth and development are increasing the nutrient loads in nearby water bodies. Specifically, this study examines multiple development metrics of both high and low intensity development across 99 watersheds adjacent to the estuary and how these development metrics relate to total phosphorus as an indicator of water quality. Spatial lag models were used to determine the statistical impacts of high intensity and low intensity development on total phosphorus levels. Results indicate that less fragmented, more connected, patches of urban development (specifically low intensity development) lead to lower total phosphorus levels. In addition, as the proportion of low intensity development increases within a watershed, total phosphorus levels are increased potentially due to runoff from fertilizer. The findings from this study can provide guidance to local planning and policy makers on how to effectively reduce the amount of and potential adverse impacts of total phosphorus entering Galveston Bay.

## 1. Introduction

High levels of nutrients from anthropogenic sources can have adverse effects on water ecosystems, such as eutrophication and hypoxia. Hypoxic zones are considered areas that have lower than 2 mg/l of oxygen (Diaz and Rosenberg, 2008; Dodds, 2006). Some hypoxic zones are caused by increased levels of nutrients and lead to phytoplankton blooms and subsequent low oxygen levels in the water, which can be detrimental to ecosystem health (Dodds, 2006). Anthropogenic factors, such as urban development are drivers of nutrient loading and polluted stormwater runoff. According to an EPA study, these factors were the primary reason why 40% of the surveyed U.S. bodies of water did not meet EPA water quality standards in 2005 (Hogan et al., 2014; Paul and Meyer, 2001; USEPA, 2005).

The impact of urbanization on the amount of nutrients in streams and rivers has been previously studied through various methods in locations including North Carolina (Carle et al., 2005), New York (Halstead et al., 2014), Maryland (Hogan et al., 2014), Washington (Alberti, 2005; Alberti et al., 2007), New Jersey (Zampella et al., 2007) and others (Carpenter et al., 1998; Lenat and Crawford, 1994; Paul and Meyer, 2001). To our knowledge, there are no studies of this nature in the Houston/Galveston region, and more specifically within the Galveston Bay Estuary. The Houston/Galveston region has a fast growing population, sprawling development, and economic importance making it an important area to study. The area is growing rapidly which in turn is increasing development and potential adverse impacts on the natural ecosystem. This rapid growth is accentuated by the sprawling development, which can decrease water quality (Sun et al., 2014). Runoff and fertilizers from sprawling urban development is correlated with increased nutrient levels in streams (Moore et al., 2003).

This study examines the relationship between one specific nutrient, total phosphorus, and the spatial patterns of two categories of urban development: low intensity and high intensity within Galveston Bay Estuary. Given the lack of research on the impacts of development patterns on water quality in the Galveston Bay Estuary, this study fills an important niche in better understanding how to reduce adverse impacts on water quality.

## 2. Literature review

### 2.1. Nutrient loading and eutrophication

Excessive amounts of nutrients entering into a rivers can be detrimental to ecosystem health and result in algal blooms, loss of sensitive invertebrates and nekton, and decreases in fish populations (Walsh et al., 2005). Algal blooms sometimes result in eutrophication and

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**Table 1**
FRAGSTATS landscape metrics equations and descriptions. Equations are derived from the FRAGSTATS manual from McGarigal (2015).

| Patch Metrics | Description | Equation |
|---|---|---|
| Patch Density | number of patches/watershed area | $PD = \frac{n_i}{A}(10{,}000)(100)$ |
| Largest patch index | % Largest Patch | $LPI = \frac{\max(a_{ij})_{j=1}^{a}}{A}(100)$ |
| Patch Size | Sum of all patches of corresponding landscape type divided by the number of patches | Mean Patch Size $= \sum_{j=1}^{n} aij$ |
| Number of patches | Total number of patches | $NP = n_i$ |
| Percent of like adjacencies | Number of like adjacencies between pixels of same class based on double count method/ number of adjacencies between pixels of classes summed then multiplied by 100 to obtain percent. | $PLADJ = \frac{g_{ii}}{\sum_{k=1}^{m} gik}(100)$ |
| Contiguity | Average contiguity value for the cells in a patch 1/ sum of the template values -1 | $CONTIG = \frac{\left(\frac{\sum_{r=1}^{z} c_{ijr}}{a_{ij}}\right)}{v-1} - 1$ |

hypoxia. In the 2001 National Oceanic and Atmospheric Administration (NOAA) State of the Coast Report, 45% of the Gulf of Mexico estuaries including the Galveston Bay Estuary were categorized as having a high level of eutrophication (Clement et al., 2001). The Trinity River/Galveston Bay watershed also has some of the highest total phosphorus loadings compared to other watersheds in the region (Rebich et al., 2011). Urban-related runoff/stormwater is one of the top five largest contributors to the impairment of river and stream water quality in Texas (U.S. EPA, 2010) and urban development contributes about 80% of the total phosphorus export from the Trinity River/Galveston Bay watershed (Rebich et al., 2011).

Multiple nutrients contribute to nutrient loading including nitrate, nitrite, ammonium, and total phosphorus. This paper looks solely at total phosphorus due to high data availability in the study area and it's importance in both fresh and salt water phytoplankton growth (Withers et al., 2009). Future research of other parameters including nitrogen-based nutrients is important based on data quality and availability. Seasonal variability within nutrients can also be high and can occur due to rising water levels, precipitation, salinity, and other factors. To remove this inter-annual hydro-climatic variability, others in the past have used temporal averages (Sliva and Williams, 2001).

### 2.2. Impacts of development patterns

Urban development has been shown to have negative effects on aspects of the ecosystem including stream water quality. Urban development is also one of the major factors driving fragmentation of landscapes (Alberti, 2005; Alberti et al., 2003; Matte et al., 2015). Fragmentation of a landscape occurs when alteration to the natural ecosystem (including forest, wetlands and grasslands land covers) disrupts the flow of the landscape (Matte et al., 2015; Su et al., 2014). When there is high ecosystem fragmentation due to urban development (for example, roads and urban centers), the natural ecosystem is broken into multiple patches. Consolidating/clustering of development is a way to ensure the greatest portion of the natural ecosystem is preserved.

There is an overall consensus of a negative relationship between urban land cover and water quality; studies suggest that this research may vary when examining different types of land cover or specific water quality indicators. For instance, Tong and Chen (2002) and Ahearn et al., (2005) both found a positive relationship between total nitrogen (TN) and total phosphorus (TP) levels in water and urban land cover. In Williams et al., (2005), however, no significant correlation was found between TN, TP, and urban land. Zampella et al., (2007) found conflicting results that align with portions of both Tong and Chen (2002) and Williams et al. (2005) stating no relationship between TP and urban land use but a significant positive relationship between TN and urban land use. The difference in these studies highlights the potential for spatial variation in the relationship between development and nutrients as well as differences in methodology, nutrient parameter, and type of development measured.

Overall, a thorough understanding of these relationships in a specific study area can help planners minimize the effects on streams. The general consensus from existing literature concludes that increasing urban land cover increases impervious surface areas and subsequently decreases nearby river water quality (Chang, 2008; Chang et al., 2014; Hogan et al., 2014; Paul and Meyer, 2001).

### 2.3. Other factors

There are multiple other factors that influence the development patterns and total phosphorus relationship. According to Dudley and May (2007) septic systems can contribute to riverine phosphorus loadings on average 12% (based on the catchments reviewed, with a range of 3–58%, and utilizing the middle value when a range is given for a catchment). Other factors include precipitation and other land cover types including crops, forests, wetlands, and development. Forests can act as a filtration system and reduce the amount of nutrients that run off into the stream. However, if a forest becomes too fragmented then the forest can potentially become a detriment to the streams quality (Lee et al., 2009). Wetlands can also serve as a filtration system for nutrients meaning an increased amount of wetlands will decrease the nutrients in surrounding rivers (Reddy et al., 1999). Agricultural land can be a large contributor of nutrient input into rivers due to high levels of fertilizer runoff from crops or residential land (Hart et al., 2004 & Lenat and Crawford, 1994). Other factors potentially include physiological variables and soil characteristics. Due to the flat nature of the landscape in this study these variables were not included. In future research these variables could be utilized to determine further relationships.

### 2.4. Landscape metrics

There are many landscape metrics that have been used in literature. This paper utilizes 7 metrics that are calculated in either ArcMap or FRAGSTATS. Table 1 shows each metric calculated in FRAGSTATS and corresponding description and equation. Proximity to development patch was calculated in ArcMap10.2 using the distance of the patch centroid to the nearest river. Proximity is utilized because of the small nature of the patches in the study area.

Patch number is a simple way to measure fragmentation of development. The limiting factor with this metric is that there is no information about the area, distribution, or density of the patches. Since the area of the watershed is not held constant, patch density is a way to better understand the number of patches in the landscape. Patch density is the number of development patches divided by the total watershed area and multiplied by a conversion factor to get the units in number per 100 ha. For both the patch number and patch density the 8 neighbor rule for delineating patches was used (Carle et al., 2005; McGarigal, 2015).

Mean patch area is a measure of fragmentation that measures the average patch size of a land cover type in the watershed. Contiguity measures the sum of all the development patches divided by the