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Author: Halls, Joanne N.

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A Spatial Sensitivity Analysis of Land Use Characteristics and Phosphorus Levels in Small Tidal Creek Estuaries of North Carolina, USA

Joanne N. Halls

Department of Earth Sciences
University of North Carolina, Wilmington
601 S. College Rd.
Wilmington, NC 28403

ABSTRACT

Small tidal creek estuaries provide important ecological habitats that are increasingly under pressure from urban expansion. In south-eastern North Carolina these coastal counties are among the fastest growing counties in the state. In New Hanover County alone, urbanized land use has increased by 100% between 1976 and 1999. This urbanization has led to an encroachment and loss of these valuable resources. To study the impacts of urbanization, five tidal creeks were analyzed for land use characteristics and phosphorus compounds in sediments. The goals of this study were: a) identify the land use characteristics of the five tidal creek watersheds within New Hanover County; b) compare and contrast these watershed land use characteristics with concentrations of phosphorus measured from sediment samples taken at various locations within these watersheds; and c) perform a spatial sensitivity analysis of the contributing area to these sample locations to determine the relationships between land use and concentrations of inorganic phosphorus. The tidal influences and minimal topographic relief within these watersheds made it impossible to accurately map the drainage area for each sampling site and therefore a spatial sensitivity analysis method was developed to analyze the land use adjacent to each sampling site. The land use potentially contributing to each sampling site was calculated using three radius measurements (0.25, 0.5, and 0.75 mile). Results indicate that the there is no significant statistical relationship between the various types of land use development (e.g. commercial, industrial, transportation, etc.) and the percentage of inorganic phosphorus in the tidal creeks. In comparing simply developed versus undeveloped land, there is a nonlinear relationship between the percentage of developed land and the percentage of inorganic phosphorus. In comparing the buffer sizes, the level of geographic analysis is most closely related to the percent inorganic phosphorus at the 0.25 and 0.5 mile radii and less at 0.75 mile radius. Results from this study illustrate the usefulness for careful geographic scrutiny and robust spatial analysis.

ADDITIONALINDEXWORDS: *geographic information systems, phosphorus, tidal creeks*

INTRODUCTION

Human modification of the natural environment has been documented as a significant factor contributing to coastal environmental change. The attractiveness of the coastal zone for a high quality of life is evidenced by the large population increase along the coastal areas of the United States. It is estimated that 3,600 people are moving to the coasts every day and over 40 percent of new commercial and residential development is occurring along the coasts (HAINES and WILLIAMS, 2000). Conversely, the habitats of the coastal zone are biologically diverse, provide breeding grounds for threatened and endangered species, buffer the uplands from storms, and drain storm-water runoff, to name just a few functions. Understanding the anthropogenic influences on the quality of this environment will help guide planners to utilize appropriate land use development strategies.

Whether it is tidal marsh deterioration and shoreline retreat (KENNISH, 2001), sediment load (ROONEY and SMITH, 1999), water quality (WINTER and DUTHIE, 2000; SMART *et al*., 2001; MCMAHON AND CUFFNEY, 2000; YOUNG and THACKSTON, 1999; TUFFORD, MCKELLAR, and HUSSEY, 1998; FISHER *et al*., 2000; RHODES, NEWTON, and PUFALL, 2001) or sediment contamination (SANGER, HOLLAND, and SCOTT, 1999a, 1999b; VAN METRE, MAHLER, and FURLONG, 2000) most studies have concluded that urbanization has led to deleterious impacts, including increased levels of phosphorus, to the surrounding watershed. Therefore, it was hypothesized that urbanization leads to higher percentages of phosphorus in small tidal creek estuaries. To assess this hypothesis an investigation into the spatial complexity of land uses surrounding sediment sampling sites was conducted using GIS.

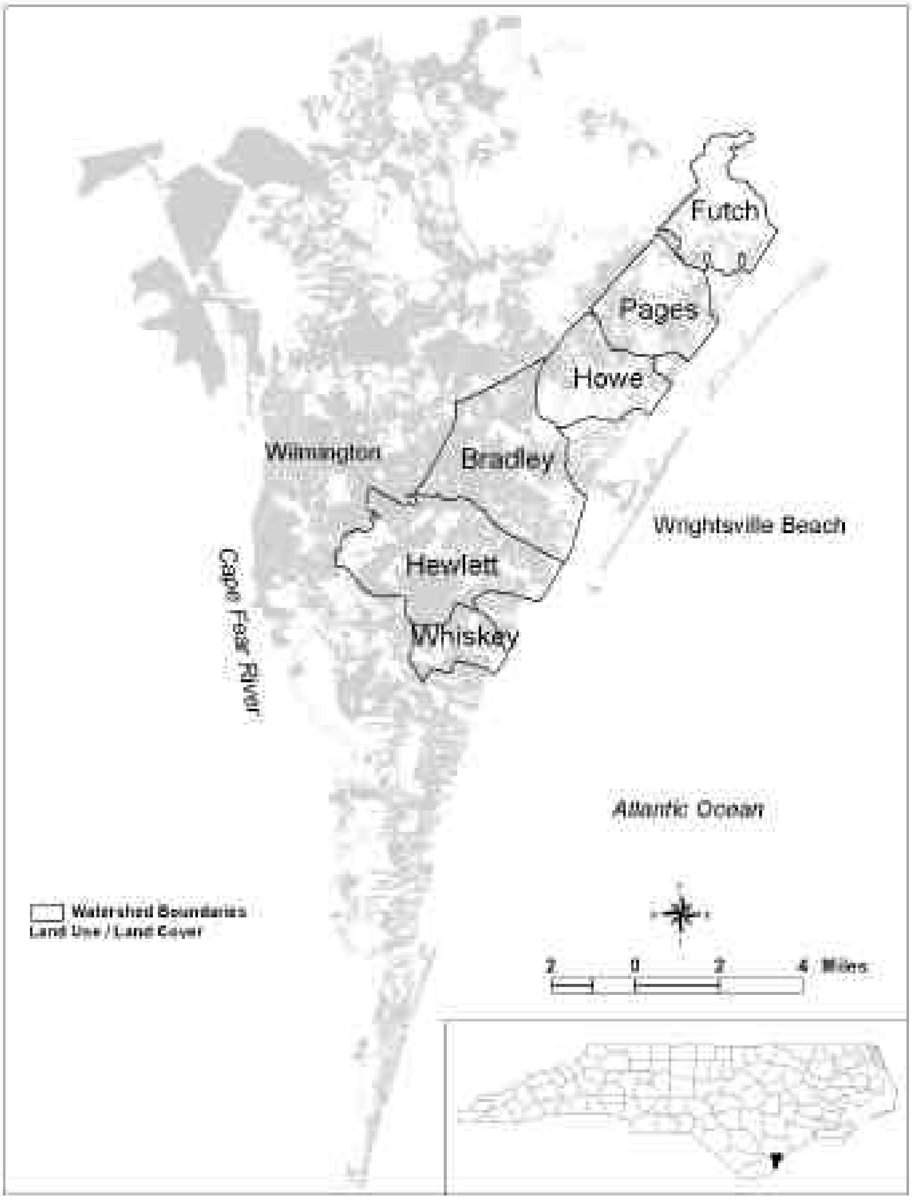

Figure 1. The distribution of developed land in New Hanover County and the location of the six tidal creek watersheds that drain to the Intracoastal waterway. The inset map identifies the location of New Hanover County in the southeastern coast of North Carolina.

Study Area

New Hanover County is a relatively small county located in southeastern North Carolina. The county is bounded with the Atlantic Ocean and the barrier islands to the east, the Northeast Cape Fear River and Pender County to the north, and the Cape Fear River and Brunswick County to the west (Figure 1). Several small tidal creek watersheds in the county have varying land uses and degrees of urbanization. These small coastal watersheds are investigated for land use and degree of phosphorus loadings at various locations within these watersheds.

The County has undergone rapid and consistent population growth. According to the national Census of Population and Housing, New Hanover County has increased from 20,717 housing units in 1950 to an estimated 80,218 in 1998 (Figure 2). The degree of new residential construction on the landscape has progressed rapidly in the past decade with a substantial increase in activity during the mid 1990's. However, there are land use development differences between the tidal creek watersheds (Table 1). The following section describes each watershed progressing from north to south.

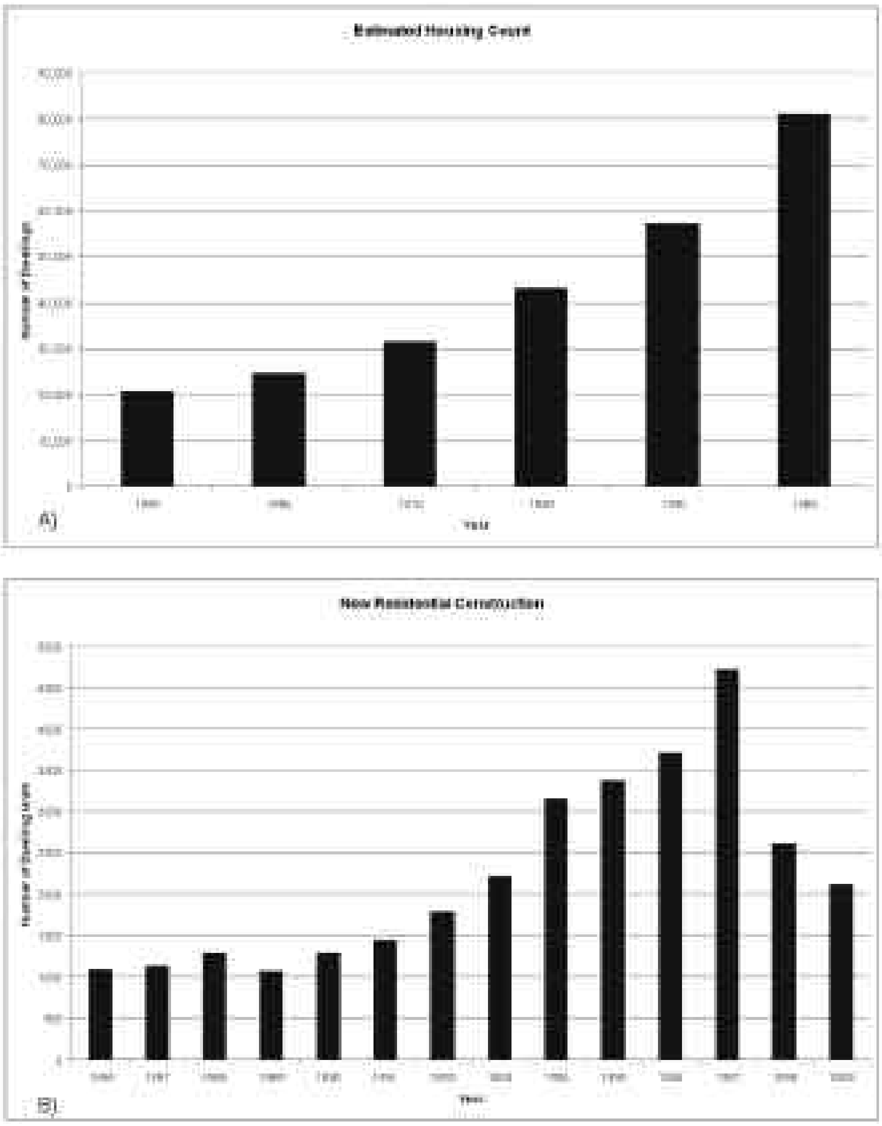

Figure 2. Residential growth in New Hanover County has steadily increased over the past several decades (A). Additionally, the number of new residential dwellings being constructed has increased over the past several years and in particular the 1990's saw a dramatic increase in subdivision development (B). (Adapted from New Hanover County Planning Department, 1999).

Tidal Creek Watersheds

In Futch Creek, suburbanization is occurring, but there remains a substantial amount of undeveloped land (Figure 3). This watershed crosses into Pender County and therefore not all of the watershed has land use / land cover data available. Therefore, sampling site FU-2 is not included in the spatial analysis. Futch Creek is furthest from the central city of Wilmington and is now undergoing rapid expansion. Overall, the watershed has a variety of land uses but is predominantly undeveloped land (48 percent), single-family residential (14 percent), forested areas (almost 9 percent), and recreation land dominated by a golf course (9 percent).

Page's Creek is a relatively developed watershed with largely single-family residential housing (33 percent), a comprehensive transportation network (more than 7 percent), and a moderate amount of undeveloped land (45 percent) (Figure 4). In comparing Page's Creek to Futch Creek the residential development is located closer to the sampling sites in Page's Creek and this may have an influence on the measured levels of phosphorus at these sites.

Howe Creek is a more densely developed watershed with single-family residential (22 percent), recreation land including a large golf course (7.5 percent), a large

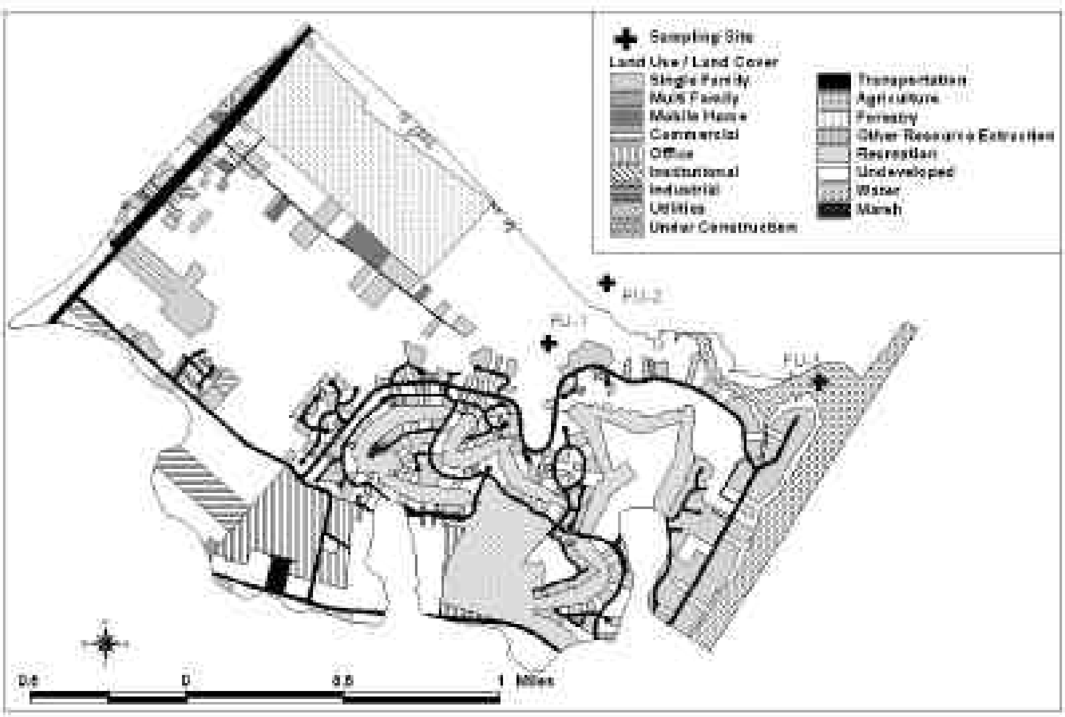

Figure 3. Land use / land cover for Futch Creek watershed. This watershed crosses into Pender County which does not have land use or land cover data. Therefore, sampling site FU-2 will not be used in the analysis of land use data.

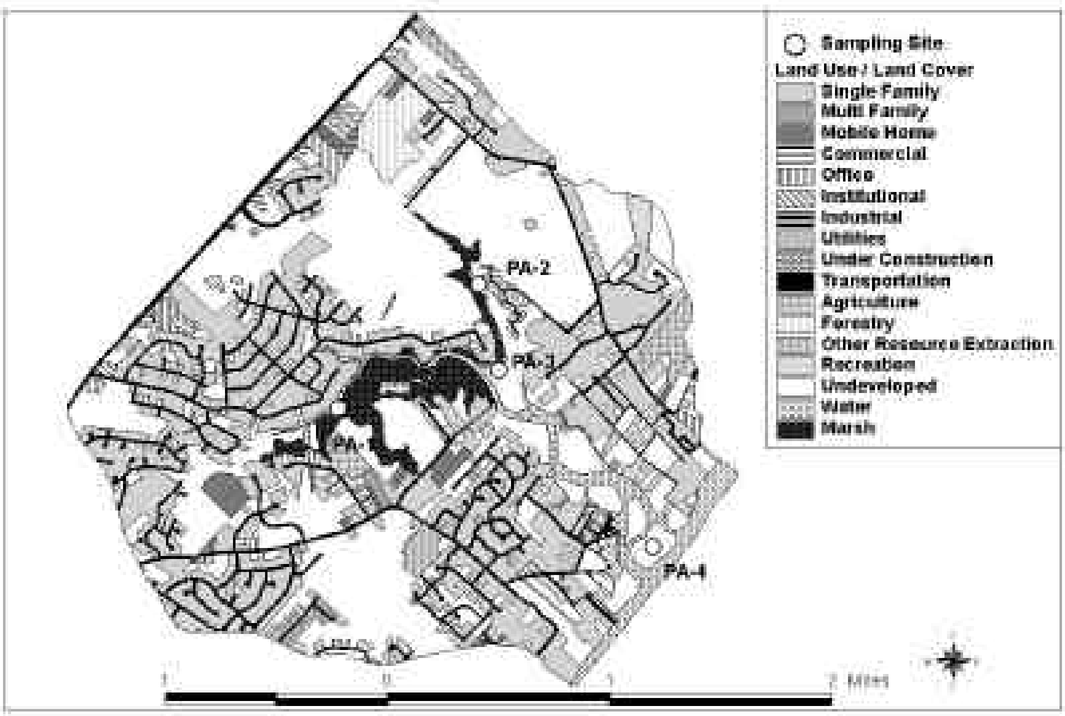

Figure 4. Land use / land cover for Page's Creek watershed. Note the expansive single family residential development, accompanying extensive transportation network, and relatively large amount of land still open for development.

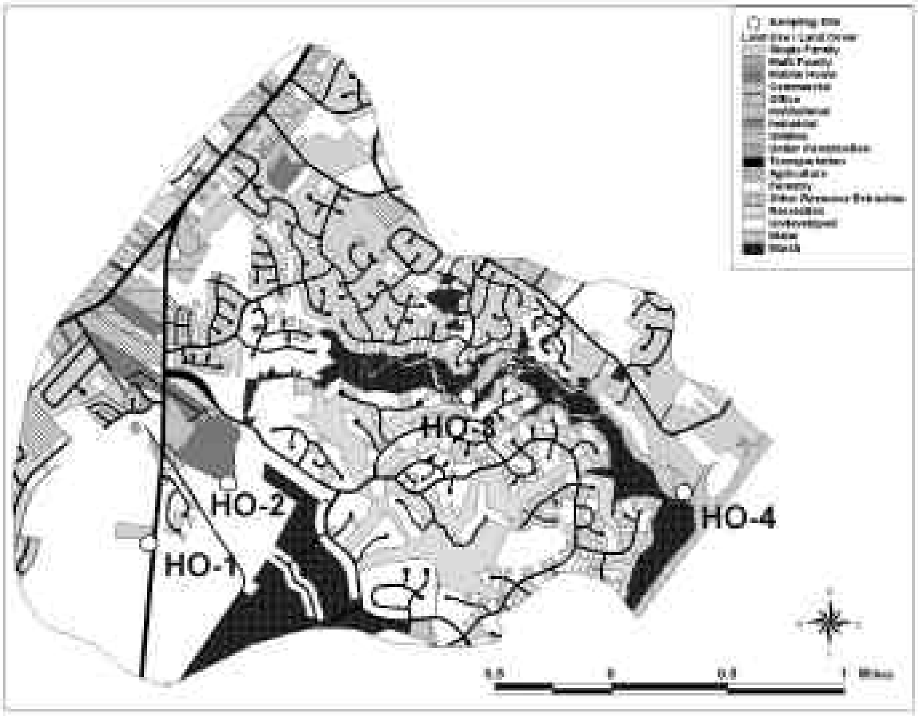

Figure 5. Howe Creek is dominated by residential areas, marshes, a large golf course, and higher intensity land uses (mostly commercial and institutional).

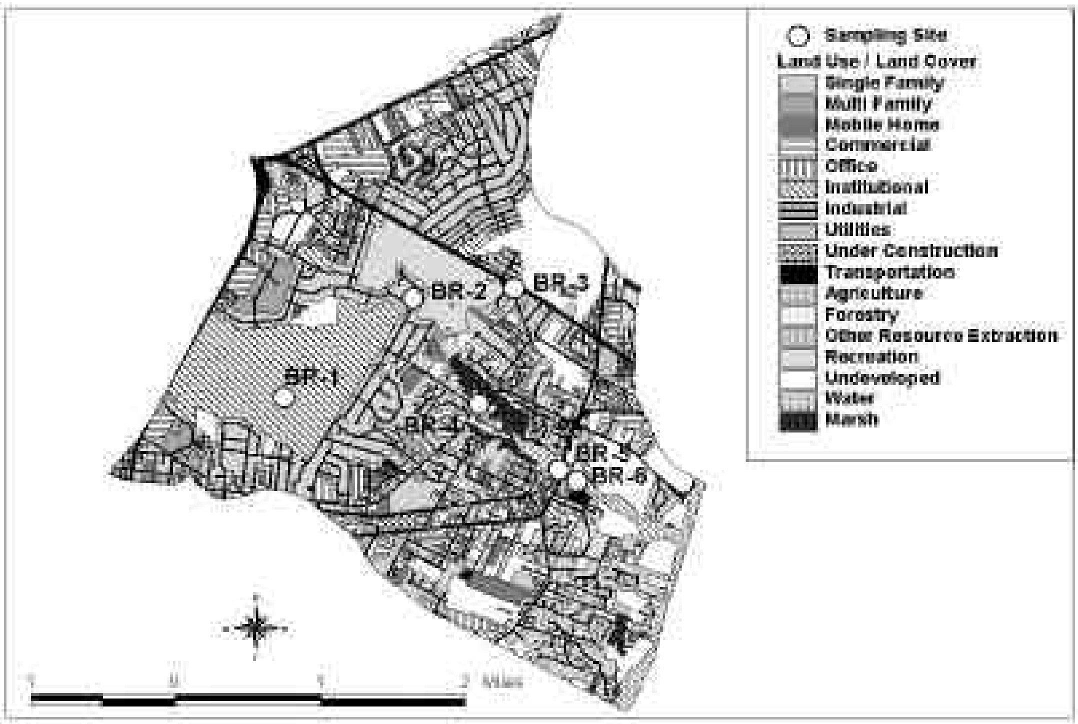

Figure 6. Bradley Creek watershed is a fully developed watershed with a variety of land uses. This watershed includes the University of North Carolina at Wilmington campus which contains a variety of cover types including building, parking lots, roads, and large tracts of undeveloped land

transportation network (8 percent), and commercial and institutional development along a main road (more than 4 percent) (Figure 5). The amount of undeveloped land in Howe Creek is 41 percent and located primarily away from the creek itself. Additionally, the amount of marsh land is greater in Howe Creek watershed than the other watersheds at just more than 9 percent.

Bradley Creek is a fully developed watershed with only 20 percent of undeveloped land (Figure 6). Included in this watershed is the campus of the University of North Carolina at Wilmington with cover types including roads, parking lots, buildings, and large tracts of undeveloped land. A variety of land uses are spread across the watershed including single family residential (32 percent), recreation land consisting of parks and golf courses (almost 6 percent), transportation (11 percent), and commercial areas (more than 5 percent).

The Hewlett's Creek watershed is a highly developed watershed dominated by single-family residential land (more than 47 percent), multiple recreation areas including several golf courses (more than 6 percent), and the highest amount of transportation corridors (12 percent) (Figure 7). Hewlett's Creek is densely developed with very little undeveloped land remaining (21 percent).

Lastly, the Whiskey Creek watershed is dominated by single-family residential development (50 percent), a dense transportation network (11 percent), and undeveloped land adjacent to the creek (28 percent) (Figure 8).

SPATIALANALYSIS

To test the hypothesis that the percentage of urban development land uses is correlated with the percentage of inorganic and organic phosphorus, sediment samples were analyzed and compared with the land use / land cover data. The sediment samples were collected from a variety of locations (both tidal and nontidal) within the watersheds during June and July of 1998.

The percent of inorganic phosphorus in sediment cores was determined using 31P nuclear magnetic resonance (NMR) spectroscopy. Sediment core samples were collected in the upper 10 cm of each marsh site. Phosphorus was base-extracted by vigorously shaking the sediments for 12 h in a solution of 0.5 M NaOH and 0.1 M EDTA at room temperature. The extract was filtered, lyopholized and rehydrated in 10% D_2O (deuterium oxide). This procedure has been shown to extract 71-90% of total P without hydrolyzing phosphodiester bonds (Cade-Menun and Preston 1996), which has been reported to be a source of

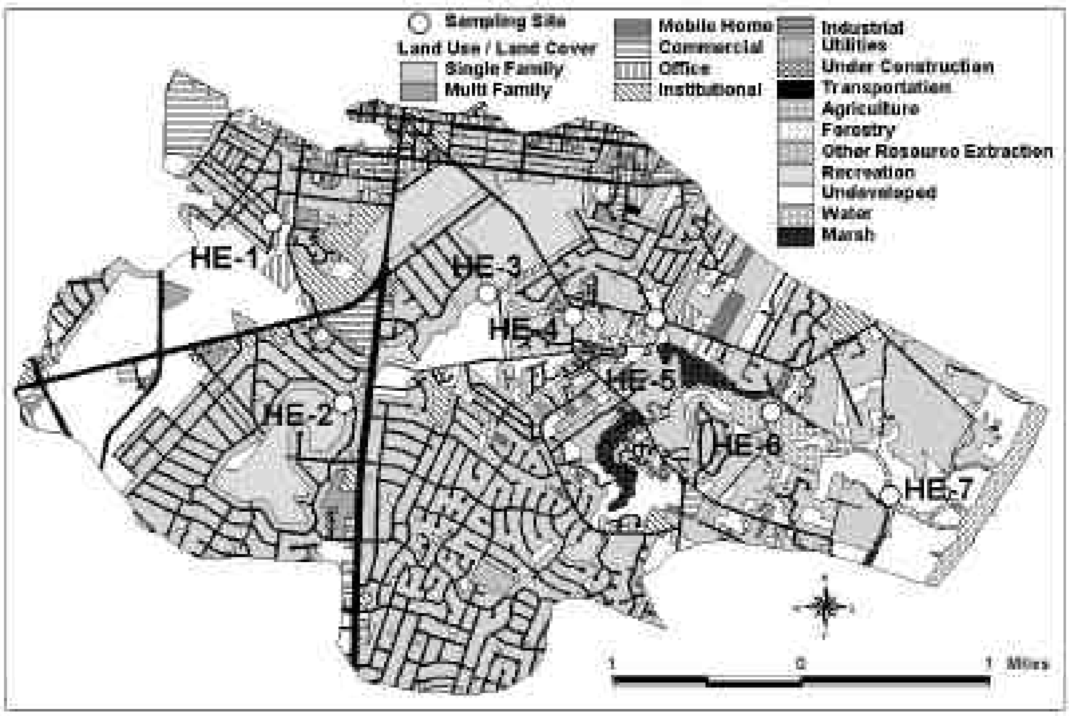

Figure 7. Hewlett's Creek watershed is a highly developed watershed dominated by single-family residential areas, multiple recreation areas including several golf courses, and transportation corridors.

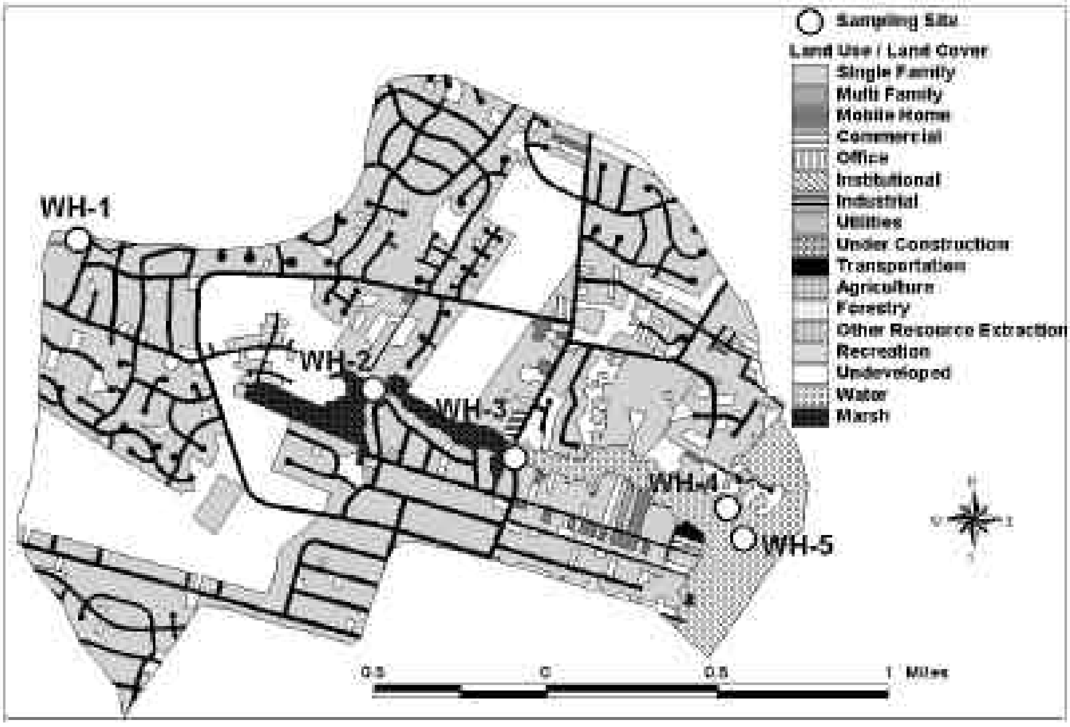

Figure 8. Whiskey Creek watershed is a smaller watershed dominated by single-family residential areas, transportation network, and undeveloped land adjacent to the creek.

bias using other protocols (Adams and Byrne 1989; Ingall *et al.*, 1990; Hupfer and Gächter 1995). 1H-decoupled 31P-NMR spectra were collected at a frequency of 162 MHz using a Bruker 400 DMX spectrometer located at UNCW. All of the spectral peaks were integrated, and the relative amount of inorganic phosphate was determined from its fractional peak area relative to the total integral area of the organic phosphorus peaks.

The spatial sensitivity analysis used three buffer sizes around each sampling site. Buffer sizes of 0.25, 0.5, and 0.75 mi radii were chosen because this compares well with similar studies, is representative of the size of these watersheds, and because the environment is tidal (flow direction is both upstream and downstream). Within each watershed, each sampling site was buffered at the three distances (0.25, 0.5, and 0.75 mile), intersected with the land use data, and compared with the sediment phosphorus data. To compare the land use data with the phosphorus data each site was geometrically computed independently from each other in order to avoid merging overlapping buffers (Figure 9). Table 2 contains the percent of land use class by buffer size (0.25, 0.5, and 0.75 mi radius) at all of the sampling sites.

Watershed Analysis

To compare the results of each sampling site, differences among the watersheds, and differences in the land uses at each buffer size, multiple regression statistics were performed. Although the multivariate analysis revealed no significant relationships among the land use variables and phosphorus at each of the sampling sites, there are small differences between the watersheds, the buffer sizes, and the resulting percentage of land uses. To compare the land uses across watersheds only a few of the land uses had sufficient representation to enable a comparison. One of these is single family residential land use which is prevalent across all of the watersheds. The other land uses did not show any correlation with inorganic phosphorus. Table 3 contains the R-squared values and correlation coefficients of percent single family residential and percent inorganic phosphorus. Interestingly, when the intracoastal waterway sampling sites are removed from the analysis the corresponding R-squared and correlation coefficients improved dramatically. The following is a summary of the findings at each watershed:

- Hewlett's creek watershed shows a positive relationship between residential land use and

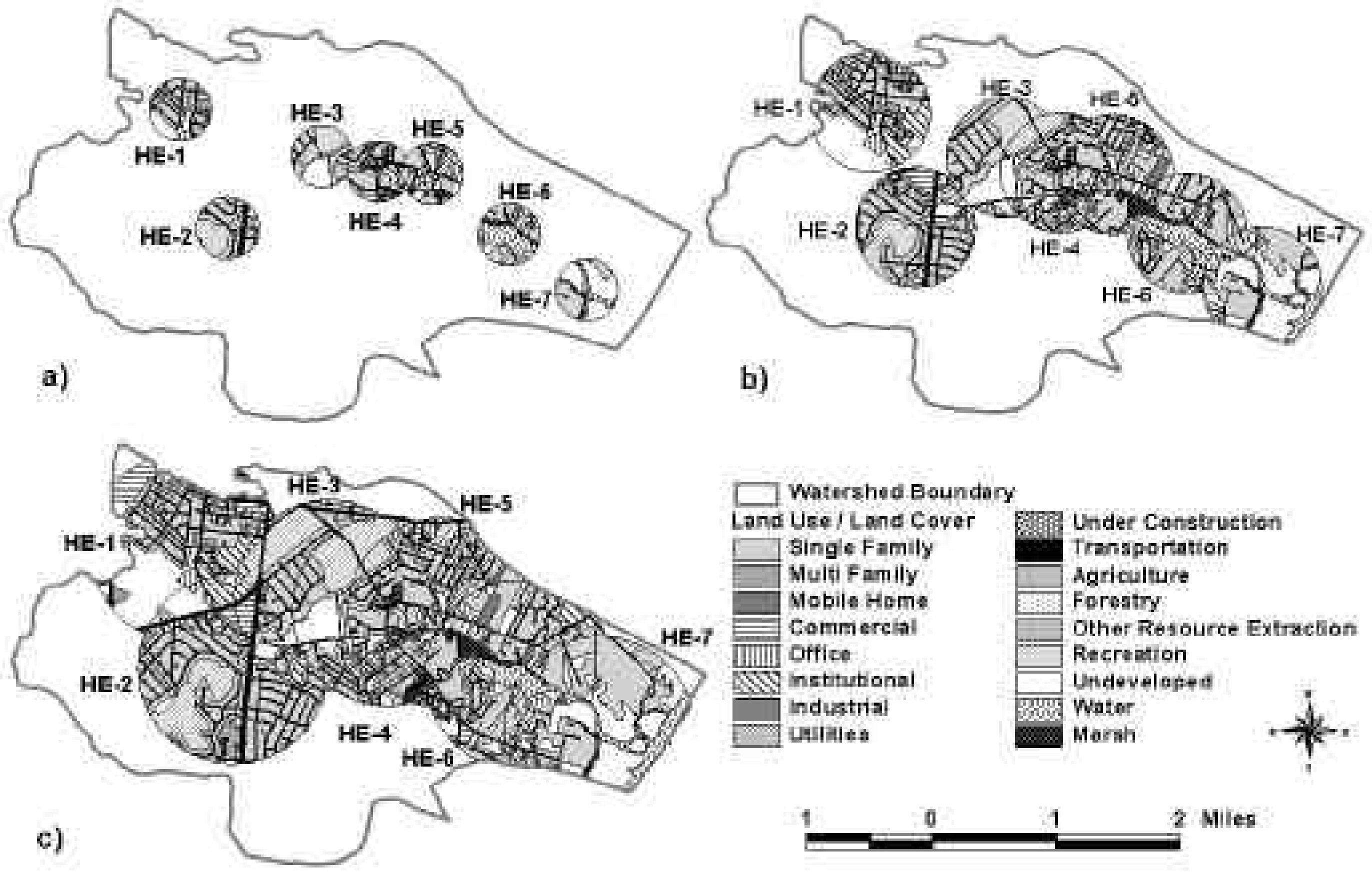

Figure 8. Spatial sensitivity analysis of Hewlett's Creek watershed using a) 0.25 mile buffer, b) 0.5 mile buffer and c) 0.75 mile buffer.

inorganic phosphorus at the 0.25 mile buffer size (R-squared = 0.6505 and correlation coefficient = 0.8065).

- Bradley creek has a strong negative relationship between residential land use and inorganic phosphorus. The only buffer size of any significance was the 0.25 mile buffer size with an R-squared value of 0.9405 and a correlation coefficient of -0.9698.
- Howe creek watershed also has a negative relationship between residential land use and inorganic phosphorus but this is demonstrated at all buffer sizes (R-squared = 0.6614, 0.9351, 0.9236 and correlation coefficient = -0.961, -0.967, -0.813).
- Page's creek, unlike the other watersheds, showed no relationships at any buffer size.
- Whiskey creek has a positive relationship between residential land use and inorganic phosphorus at all buffer sizes but is strongest at the 0.25 mi radius (R-squared = 0.9892, 0.7018, 0.7993 and correlation coefficient = 0.994, 0.838, 0.894).

Generalized Land Use

Next, a more generalized approach was studied to determine if the percent of developed land (versus undeveloped) was related to the amount of inorganic and organic phosphorus at each site. Developed land uses included: commercial, industrial, institutional, mobile homes, multi-family residential, office, single family residential, transportation, under construction, and utilities. Undeveloped categories were: agriculture, forest, marsh, other resource extraction, recreation, and undeveloped land. To compare the watersheds and buffer sizes at each sampling site, each land cover class was recoded to either Developed or Undeveloped. These data were then spatially analyzed to determine the percentage of developed land within each buffer distance (0.75, 0.5, and 0.25 mile) around each sampling site. To accurately compare developed versus undeveloped land, open water areas were not included in the calculation of percent developed and

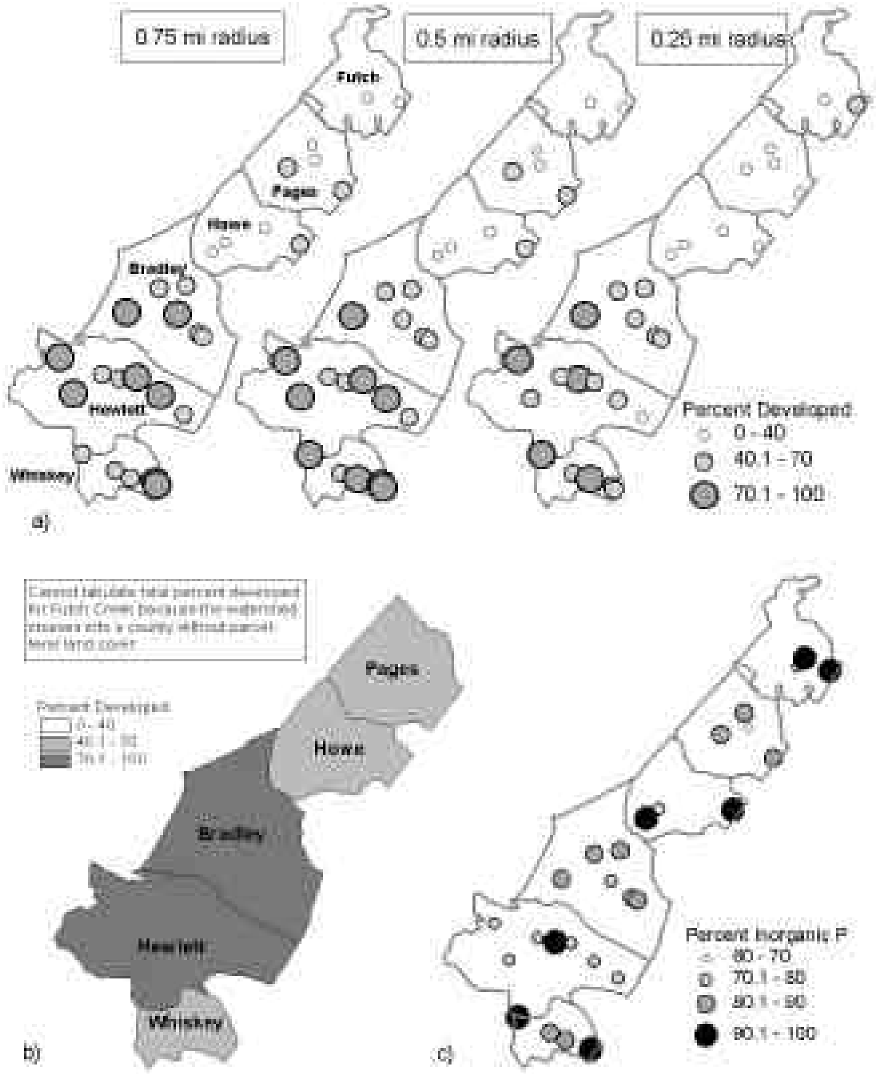

Figure 10. The percentage of developed land within each buffer (a), the overall percentage of developed land within each watershed (b), and the percentage of inorganic phosphorus at each sampling site (c). The two highly developed watersheds, Bradley and Hewlett creeks, have several sites that are less developed and do not correspond with the percent of inorganic phosphorus.

percent undeveloped. Because land use/land cover varies there are differences among the watersheds as a whole as well as the sites within each watershed when the buffer size results are compared (Figure 10). The two more highly developed watersheds, Bradley and Hewlett creeks, have several sites that are less developed than the others and the sites do not correspond with the percent of inorganic phosphorus. Futch and Howe creeks, the least developed watersheds, do not correspond with the relatively high percentage of inorganic phosphorus.

Due to a lack of a clear relationship between developed land and percentage of inorganic phosphorus a final analysis was conducted to examine the relationships of all sites, not by watershed, to the percentage of inorganic phosphorus. Linear regression statistics were computed first using all of the sites, which showed no relationships, and second removing the intracoastal waterway sites which did reveal some interesting trends (Figure 11). The nonlinear relation ship suggests that as land becomes developed (0-40) there is a decrease in the percentage of inorganic phosphorus. At the middle level of development (41-70) there is no relationship, and lastly at the densely developed stage there is a positive relationship between development and percent inorganic phosphorus. In comparing the three buffer sizes, buffer radii of 0.25 and 0.5 mi are similarly showing the nonlinear relationship with percent inorganic phosphorus where 0.75 mi does not show the same relationship and clearly has no relationship at the high density of development.

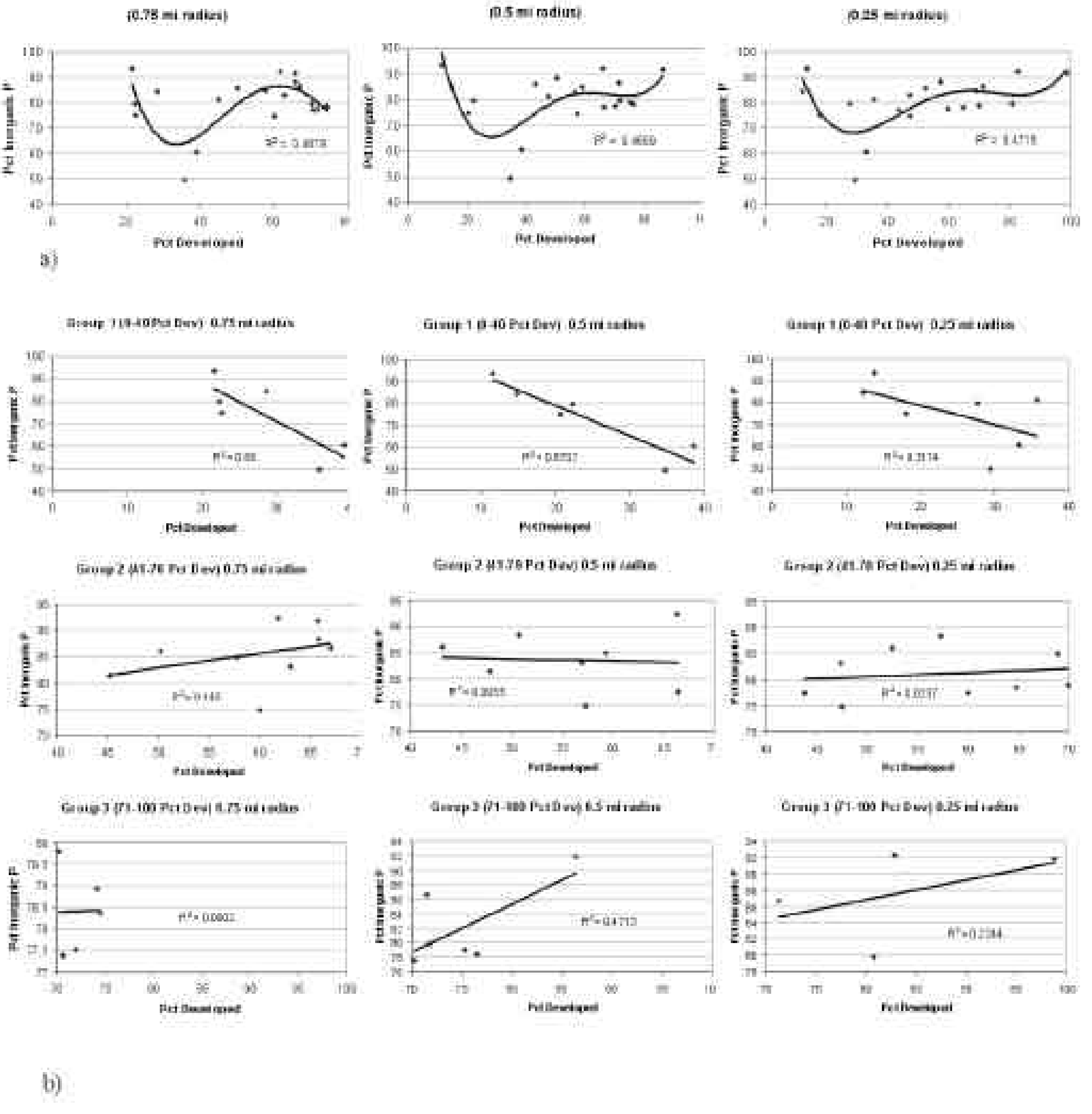

Figure 11. The relationship between percent developed land and percent inorganic phosphorus at each buffer radius (a) and the linear relationships at each grouped level of development (0-40, 41-70, and 71-100 percent) (b). The nonlinear relation ship suggests that as land becomes developed (0-40) there is a decrease in the percentage of inorganic phosphorus. At the middle level of development (41-70) there is no relationship, and lastly at the densely developed stage there is a positive relationship between development and percent inorganic phosphorus. In comparing the three buffer sizes, buffer radii of 0.25 and 0.5 mi are similarly showing the nonlinear relationship with percent inorganic phosphorus where 0.75 mi does not show the same relationship and clearly has no relationship at the high density of development.

CONCLUSIONS

Unlike previous studies that have identified urban development as directly related to water quality pollution, this study has demonstrated that in small tidal creek watersheds there is no clear relationship between urban land use and percent inorganic phosphorus. There were no significant statistical relationships when multivariate analysis was performed on the land use types and the percent inorganic phosphorus across all of the watersheds. Investigating land use patterns and inorganic phosphorus within each watershed, some watersheds showed clear positive relationships between single-family residential development and inorganic phosphorus (Hewlett and Whiskey), some were negative relationships (Bradley and Howe), and one showed no clear relationship (Page). This demonstrates that the watershed characteristics are unique and cannot be translated to trends for all watersheds.

Analyzing the sites across all of the watersheds, the 0.25 mi radius produced the strongest relationships between single-family residential and inorganic phosphorus. The 0.75 mile radius produced completed different results and this sensitivity analysis leads to the general geographic conclusion that the immediate areas surrounding the sampling sites have the best representation for contributing area.

In comparing a more generalized land use assessment of developed versus undeveloped land, there is a stronger relationship between developed land and inorganic phosphorus when the sites located nearest the Intracoastal waterway were removed from the analysis. There is a nonlinear relationship between the percentage of developed land and the percentage of organic and inorganic phosphorus. Using natural breaks in the data, the less developed sites (0-40 percent developed) showed a negative relationship with percent inorganic phosphorus and highly developed sites (71-100 percent developed) show a strong positive relationship with inorganic phosphorus. Preliminary analysis suggests that at a critical, maximum, threshold in urbanization (above 70 percent developed) the environmental parameters are revealing an impact through an elevated level of inorganic phosphorus. Future research is being conducted to test this relationship.

In comparing the buffer sizes, the 0.25 mile and 0.5 mile radius land use data is most closely related to the phosphorus data. The results from this study concur with other studies that have found varying and diverse results (FONG and ZEDLER, 2000).

This study analyzed one sediment sampling effort at each site. To improve the temporal aspect of the phosphorus data, a study is currently being conducted to analyze Hewlett and Page's creek watersheds in more detail by collecting monthly samples at more sites within each watershed. In a watershed in Australia, it was found that more sampling sites contributed more information regarding nonpoint and point sources (EYRE and PEPPERELL, 1999). This approach will hopefully reveal seasonal changes in sediment and water quality as well as geographically identify the locations contributing the greatest amounts of phosphorus.

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http://www.co.new-hanover.nc.us/GIS/GISmain.htm.

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