# The North Carolina Geographer

## Volume 15, 2007

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# FROM THE EDITORS

Dear Geographers,

In this volume of *The North Carolina Geographer*, we are excited to have research articles pertaining to mapping of flood extent with DEM-Inundation models, the North Carolina Global Transpark, and the North Carolina's Inner Banks. This will be the last volume produced by the UNC Wilmington editorial staff. We would like to thank all of the individuals that have offered their time towards the success of this journal, especially all manuscript referees and previous NCGS Secretaries Bill Graves and Selima Sultana. Michael Lewis of UNC Greensboro has been selected as the new journal editor and this editorial staff is confident he will maintain and increase the quality of the journal. As always, we encourage submissions of both research articles and Carolina Landscapes entries to the journal. Only through submission of manuscripts will our journal remain vital and sustainable. Remember, the goal of the journal is to highlight research on the geography of North Carolina, and topics of interest to geographers in North Carolina. Submit a manuscript yourself or encourage your colleagues and students to submit. Submissions for the 2008 issue are currently being accepted.

Thanks for your continued support of *The North Carolina Geographer!*

Sincerely,

Mike Benedetti (editor for physical geography)
Doug Gamble (editor for Carolina Landscapes)
Joanne Halls (editor for applied geography)
Liz Hines (editor for human geography)

**About the Cover:** The image on the cover is an artist's rendition of the North Carolina Transpark included on brochures produced by the Global Transpark Marketing Division, North Carolina Department of Commerce. (Image provided by Liz Hines, UNC Wilmington).

Authors alone are responsible for opinions voiced in this journal. Please direct inquiries concerning subscriptions and availabilty of past issues to the Editors. Back issues of the *North Carolina Geographer* are available for $6 per copy.

# DEPARTMENT of GEOGRAPHY

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# The North Carolina Geographer
# Volume 15, 2007

## Research Articles

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# Mapping Flood Extent Using a Simple DEM-Inundation Model

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A grid-based one-dimensional digital elevation model (DEM)-inundation model has been developed as a tool for flood extent mapping on floodplains. The validity and accuracy of the model have been assessed through comparison of modeled results with those derived from the widely used standard and complex 1-D Hydrologic Engineering Center–River Analysis System (HEC-RAS) model and verification against the September 1999 flood on the lower Tar River floodplain, North Carolina. The two models are comparable in accuracy. With its simple implementation and ease of parameterization, the DEM-inundation model is a potential alternative to the HEC-RAS model.

## Introduction

Floods are one of the most significant natural hazards, costing lives, serious damage to property, and disruptions to social and economic activities. The ability to map the flood extent accurately and timely can provide critical information for immediate flood relief activities, and pre- and post- flood mitigation efforts (Mileti 1999, Colby et al. 2000, Yang and Tsai 2000, Al-Sabhan et al. 2003). To this end, hydraulic models have been developed and used for mapping flood extent (Hydraulic Engineering Center 1997, Correia et al. 1998, Ackerman et al. 2000, Chang et al. 2000, Dobson and Li 2000, Al-Sabhan et al. 2003, Hunter et al. 2005, Bates et al. 2006). Over the years, both two- and one-dimensional hydraulic models have been developed. The 2-D models include those that employ sophisticated full finite-element approaches or that take grid-based approaches. For instance, Galland et al. (1991) developed a 2-D finite element numerical model, the TELEMAC-2D. Nicholas and Mitchell (2003) also developed a finite-element 2-D model that solves the depth-averaged shallow water form of the Navier-Stokes equations. The 2-D models are generally capable of achieving high mapping accuracy, especially for hydraulic processes at fine spatial resolution, but they require digital elevation models (DEMs) of high resolution and accuracy, as well as other geophysical model inputs. They all are computationally intensive. To avoid the drawbacks of the finite-element models, Bates and De Roo (2000) developed a raster-based model, the LISFLOOD-FP, which takes a storage cell approach to simulate flood hydrologic and hydraulic process. The LISFLOOD-FP has been subsequently improved and validated for the January 1995 flooding on the River Meuse, the Netherlands (Hunter et al. 2005, Bates et al. 2006).

Unlike 2-D models, 1-D hydraulic models are typically characterized by a series of cross-sections of channel and floodplain topography. Validation tests have reported that 1-D models, such as the Hydraulic Engineering Center–River Analysis System (HEC-RAS), are capable of reaching high accuracy in flood extent mapping (Horritt and Bates 2002). Investigations have been also conducted on how the accuracy of the model can be affected by various factors, such as mesh resolution, topographic representation, and spatial resolution (Horritt and Bates 2001, Horritt et al. 2006).

In short, the existing 1-D and 2-D models can map a flood extent accurately, but they are difficult to be parameterized. Among others, the estimation of Manning's coefficient of friction as input to the models, which is also referred to as Manning's *n* (Chow 1959), is highly uncertain and unreliable. For instance, laboratory experiments have reported higher values for Manning's *n* than those recommended in the well-established tables by V. T. Chow in 1959 (Wilson and Horritt 2002). Although different values have been recommended (Acrement and Schneider 1989) and extensive studies have been conducted to derive the coefficients (Werner et al. 2005, Wilson et al. 2006), there is still no proven way to estimate the *n* with a high level of confidence and accuracy. Additionally, the implementation of the existing models requires advanced levels of hydrologic and hydraulic knowledge and expertise, which is often lacking among prospective users, therefore hindering the use of the models. Thus, there are clear needs for a hydraulic model that is simple in parameterization and implementation. Such a simple model, if capable of reaching comparable accuracy of the complex model, can serve as an alternative. In addition, a simple model can provide initial and preliminary analysis, and the result can help the complex model for in-depth study.

To meet the needs for simple flood-extent mapping models, Wang et al. (2002) developed a model that maps flood extent by linearly interpolating the surface water height of a river between two neighboring gauging stations using the heights measured at the stations. In this article, an improved version of Wang et al. (2002)'s model is developed. The newly developed model is a 1-D DEM-inundation model that features three major improvements. First, Wang et al. (2002)'s model did not identify the central channel of the river; this model does. Second, Wang et al. (2002) represented distance between gauging stations with a straight line, whereas this model traces the distance along the central channel line between two neighboring gauging stations. Lastly, the changes in elevation of a river channel and banks along a river, which are important geometric factors affecting a river's water surface height at different flow conditions, were not modeled (Wang et al. 2002). This DEM-inundation model accounts for these factors in the water surface height interpolation. In summary, the objectives of this paper are to detail the development of a DEM-inundation model, to compare the model with the HEC-RAS model to assess their accuracy in flood extent mapping, and to validate the DEM-inundation model against a real flood event.

## Methodogy: HEC-RAS Model

To meet the needs for flood extent mapping, the Hydraulic Engineering Center (HEC) of the US Army Corps of Engineers developed a series of GIS-based hydraulic models, from the Arc/HEC2 to HEC-RAS (Hydrologic Engineering Center 1997, Kraus 2000, Ackerman et al. 2000, USACE 2007). HEC-RAS is one of the most popular 1-D hydraulic models. Compared with its predecessors, HEC-RAS comes with some major improvements. It facilitates the use of digital datasets such as DEM and TIN (triangular irregular network) (Correia et al. 1998, Dobson and Li 2000, Yang and Tsai 2000), and features an enhanced graphical user interface that simplifies the flood extent modeling processes.

The HEC-RAS model is designed to perform 1-D hydraulic calculation for a full network of natural or constructed water channels. In the model, surface profiles of a steady flow in which changes in flow depth and velocity occur gradually over a considerable length of channel are solved by using a 1-D energy equation and energy head loss equation (Hydraulic Engineering Center 1997). The steady flow's water surface profiles are computed from downstream to upstream at cross sections for a given discharge rate at upstream and water surface height value at downstream. In the solving of the water surface profile along a river channel, HEC-RAS requires geometric and hydraulic input parameters. The geometric parameters include the river system schematics, cross section profile, reach length, energy loss coefficient, and stream junction information. The schematic parameters define how river reaches are connected. Cross section profiles are required at locations where changes in discharge, slope, shape, and roughness occur along the river channel between the up- and down- stream. The reach length refers to the measured distance between cross sections. The reach lengths for the left overbank, right overbank, and channel are required. To evaluate energy losses, HEC-RAS uses energy loss coefficients including a) Manning's *n* value for friction loss (Chow 1959), b) contraction and expansion coefficients to evaluate transition loss, and c) bridge and culvert loss coefficients to evaluate losses related to weir shape, pier configuration, pressure flow, and entrance and exit conditions. The hydraulic inputs include flow regime, peak discharge information, and boundary conditions that include known water surface elevation, critical depth, normal depth, and rating curve.

## Methodology: One Dimensional DEM-inundation Model

Compared with the complex HEC-RAS model, the 1-D DEM-inundation model calculates an artificial water height surface using surface water height of a stream and compares the artificial surface with the DEM to determine water/non-water or flooded/non-flooded areas. The surface water height measurements are available at gauging stations. Because the distance between two neighboring gauging stations may be quite large, surface water heights between stations must be interpolated to create the artificial water height surface. This is accomplished in four major steps, the delineation of the stream centerline, derivation of surface water height along the centerline, estimation of the reach of the centerline's surface water height for locations off the centerline, and finally creation of the surface water height grid for different flow conditions. To delineate the centerline of a river section, we

a) Overlay co-located aerial photographs or remotely sensed images over the DEM covering the stream section in question. Then, a tentative centerline is drawn in such a way that it is positioned approximately equidistant between the left and right banks.

b) Identify the first DEM pixel on the upstream end of the tentative centerline, and use it as the center for searching the pixel with lowest elevation value within a certain radius. Our experiment indicated that a radius of 300 m is sufficient for most cases, which is equivalent of 10 pixels on 30 x 30 m USGS DEM. This pixel with the lowest elevation is then the actual location of the delineated centerline. Move one pixel downstream along the tentative centerline, and perform the similar searching until the downstream end of the tentative centerline is reached. Thus a lowest-elevation pixel is identified for each corresponding pixel on the centerline.

c) Manually draw a new centerline by tracing through all the pixels with the lowest-elevation values from the upstream to downstream ends.

d) Verify the centerline created in the step 3 with the DEM, aerial photographs or satellite images. If needed, repeat steps a), b), and c) until a satisfactory result is achieved. A satisfactory centerline should be continuous with each pixel positioned at the lowest point of its corresponding cross-section.

Typically, the delineated centerline is a curved line composed of the deepest pixels along a river stream.

Second, the water surface height at each location or pixel along the centerline is calculated. An assumption used for this calculation is that water surface height decreases from upstream to downstream and that the decrease depends on the changes of location and elevation long the centerline. Figure 1 illustrates the calculation. Let $A$ be the upstream end and $B$ the downstream end where the channel's elevations ($E_A$ and $E_B$) on river's centerline and surface water height ($H_A$ and $H_B$) are known. Let $X$ be a location between A and B. At $X$, elevation ($E_X$) is derived from DEM and water surface height ($H_X$) is computed using

$$\begin{cases} H_x = H_A \\ \qquad If\ \Delta E\cdot\Delta D = 0 \quad and\ E_X + D_X = 0 \\ H_x = H_A - \Delta H.\dfrac{E_X D_X}{E_X + D_X}\left(\dfrac{1}{\Delta E}+\dfrac{1}{\Delta D}\right) \\ \qquad If\ \Delta E\cdot\Delta D \neq 0 \quad or\ E_X + D_X \neq 0 \end{cases} \tag{1}$$

where $H_A$ = water surface height at location $A$,
$\Delta$H = water surface height difference between gauging stations $A$ and $B$,
$\Delta$E = elevation difference between $A$ and $B$,
$\Delta$D= distance between $A$ and $B$ along the stream centerline,
$H_X$ = water surface height at point $X$,
$E_X$ = stream channel's elevation at location $X$, and
$D_X$ = distance between $A$ and $X$ along the stream centerline.

In general, one should select locations $A$ and $B$ where gauging stations are located. Thus, $H_A$ and $H_B$ as well as $E_A$ and $E_B$ are known.

Third, with water surface heights at each pixel along the centerline calculated, one is ready to compute water heights at pixels off the centerline. With the assumption that water surface at a cross section is level, calculation of the surface water height at an off-centerline pixel is boiled down to finding the on-centerline pixel to which the off-centerline pixel shares a same cross-section. This is achieved by finding the on-centerline pixel with shortest straight line distance to the off-centerline pixel in question. There are four steps involved in this procedure:

a) Identify all the on-centerline pixels that are within a specified radius of the off-centerline pixel.

b) Calculate the straight line distance between the off-centerline pixel and each on-centerline pixel using the equation:

$$D = ((x_c - x_p)^2 + (y_c - y_p)^2)^{0.5} \quad (2)$$

where $x_c$ and $y_c$ are x and y coordinates of pixel $C$, $x_p$ and $y_p$ are x and y coordinates of pixel $P_i$. $i$ = 1, 2, 3, …, n and represents the series of on-centerline pixels that lie within the search radius (Figure 2). The x and y coordinates are relative to the origin located at the lower left corner of the study area as covered by the DEM, assuming the DEM used is of a square or rectangular shape.

c) Identify the on-centerline pixel $C$ that has the shortest straight line distance to the off-centerline pixel.

d) Assign the surface water height to the off-centerline pixel according to the assumption of level water surface at stream cross-sections.

e) Repeat the process for all off-centerline pixels. (Note: A C program was written to accomplish this step.)

Lastly, once all of the surface water heights are calculated, both on-centerline and off-centerline, a surface water height layer (a grid) is created with same spatial resolution as underlying DEM. It should be pointed out that if the size of the search radius for the nearest on-centerline pixel to offline-pixel is difficult to determine, searching the entire study area could be an alternative; it can, however, be very time consuming. There are other methods available for interpolating water surface height based on known water surface height at nearest points. For example, Werner (2001) used the inverse distance weighted interpolation.

## Methodology: Modeling Flood Extents by Using DEM-inundation and HEC-RAS Models

In the delineation of the flood extent, the 1-D DEM-inundation model superimposes the calculated surface water height layer over the DEM layer. Because both layers are grids with the same spatial resolution, the values of surface water height and ground elevation at each pixel are known. To delineate water/non-water (regular flow) or flooded/non-flooded (flood flow) areas, one needs to have two sets of a stream's surface water heights (a regular one and a flood one). Thus, two surfaces of the water heights are calculated. At a location $X$, let $H_{X\text{-regular}}$ be the regular height and $H_{X\text{-flood}}$ be the flooded height on the two surfaces, respectively. Then,

· if a location's elevation (on the DEM data) is $\leq H_{X\text{-regular}}$, then the location is classified as regular stream area,

· if its elevation is $> H_{X\text{-regular}}$ and $\leq H_{X\text{-flood}}$, then the location is a flooded area, or

· if the elevation is $> H_{X\text{-flood}}$, then the location is non-flooded or dry.

The HEC-RAS model simulation with regular and flood river surface height will also classify

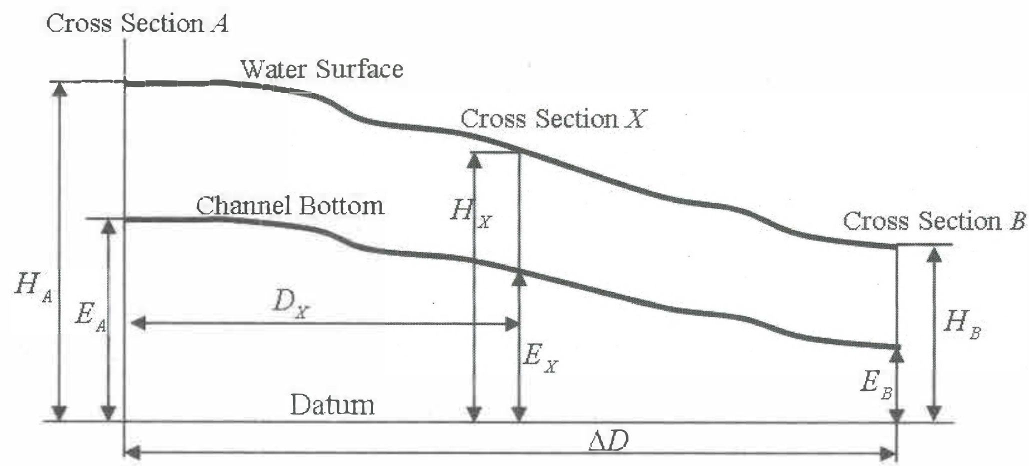


**Figure 1.** Illustration of the interpolation of water surface height, $H_X$ at a given location $X$ on the stream centerline.

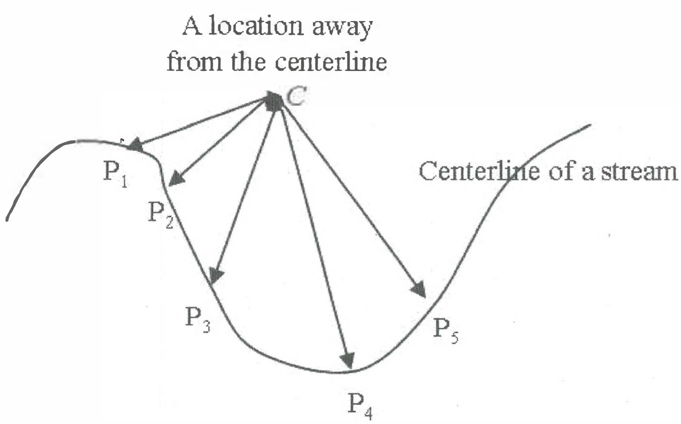


**Figure 2.** Interpolation of water surface height for an off-centerline location, $C$. Five points, $P_1, P_2, P_3, P_4,$ and $P_5$ on the central channel are shown as an example. Distances between $C$ and all points on the channel are calculated, so that the point(s) on the centerline having the shortest distance to $C$ will be identified.

each pixel within the study area as regular stream, flooded, or dry (non-flooded).

## Methodology: Comparison and accuracy assessment of flood extents derived by both models

To compare the inundation extents from both models, first we summarize descriptive statistics of the regular stream area, flooded area, and non-flooded area. Next, spatial comparison analysis of the extents at the same flow condition is carried out to quantify the amount of agreement between the two models on a pixel-by-pixel basis. If a pixel is classified as same category (regular stream, flooded, or non-flooded area) by the two models, there is an agreement; otherwise, there is a disagreement.

The water/non-water or flooded/non-flooded boundaries delineated by the DEM-inundation and HEC-RAS models can differ so to understand the variation of the boundaries statistically, we used the matched-pair *t*-test of the boundaries on both sides of the river channel. Figure 3 shows two sets of boundaries, one centerline, and nine channel cross-sections. (The centerline is depicted as straight line for simplicity.) Neighboring cross-sections are roughly 400 m apart in this study. Along each cross-section, two interception points with the boundaries are obtained; the distances between the two points and the centerline are calculated. Once the distance measurements for all cross-sections are computed, there are two sets of distance measurements: one from the DEM-inundation model and the other from the HEC-RAS model. The null hypothesis ($H_0$) for the *t*-test is that there is no difference between the distances from the two models (i.e., the boundaries are statistically identical), and the alternative hypothesis ($H_A$) is that a significant difference exists between the two models. A significant level of $\alpha = 0.05$ is chosen to test whether $H_0$ should be rejected. Similarly, distance measurements and *t*-test was be carried out for the boundaries on the other side of the centerline (e.g., Figure 3).

Finally, to validate the 1-D DEM-inundation model as well as HEC-RAS model, we evaluated modeled flood extents at a record-high flood flow on 23 September 1999 against remotely sensed data and *in situ* measurements obtained at several sites. The date and site selection are based on available ancillary datasets detailed in the next section. Error matrices are used to quantify the mapping accuracy

## Methodology: Study Area and Datasets

The study area is on the lower floodplain of the Tar/Pamlico River (drainage area ~ 157 km$^2$), North Carolina. It covers part of Pitt County on the west and Beaufort County on the east (Figure 4). The Tar River flows into Pitt from the northwest and exits to Beaufort to the east. After passing the bridge of Highway 17, it is called the Pamlico River. There are two USGS gauging stations, one at Greenville and the other at Washington (Figure 4). Greenville is the largest city in Pitt County, and Washington is the largest city in Beaufort County. There are three major reasons for choosing this particular study area: floods triggered by heavy precipitation, tropical storms and hurricanes occur frequently in the study area; the two river gauging stations provide the real-time measurements for water surface height and daily mean discharge; and on-going flood research in this area has resulted in several in-house geo-spatial and remote sensing datasets (Colby et al. 2000, Wang et al. 2002, Wang 2004, Wang and Zheng 2005).

Based on the statewide land use and land cover layer created by the North Carolina Center for Geographic Information and Analysis, there are fifteen land use and land cover types within the study area (Wang 2004). Bottomland forests/hardwood swamps and cultivated areas were dominant land cover types (about 73% of the study area). The bottomland forests/hardwood swamps are areas of deciduous and woody vegetation taller than 3 m, where crown density is at least 25%. Tupelo (*N. aquatica*) and cypress (*Cupressus*) are the major species. The cultivated lands are areas occupied by crops of cotton, corn, tobacco, and soybeans. In addition, there are developed areas, which count for about 3% of the study area and are mainly concentrated in the vicinity of the cities

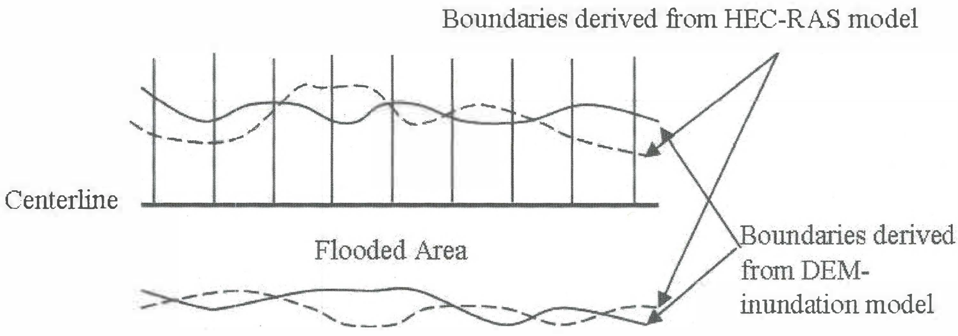


**Figure 3.** Hypothetical boundaries derived from the HEC-RAS and DEM-inundation models. Nine cross-sections are plotted at evenly-distributed intervals.

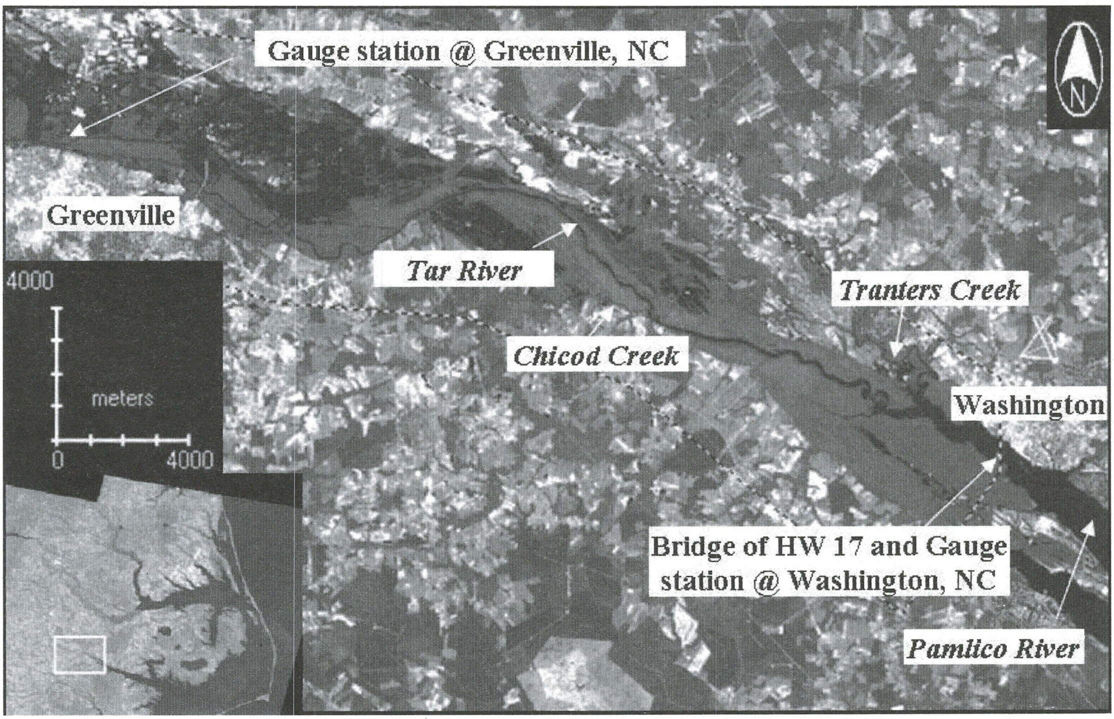


**Figure 4.** Landsat 7 ETM+ data of band 8 on 23 September 1999 (path/row 14/35). The study area outlined by the dotted lines covers the Tar/Pamlico River floodplain, North Carolina.

of Greenville and Washington (Wang 2004). The statewide land use and land cover data are used to estimate the Manning's *n* coefficient of roughness at each cross-section along the river channel, which is one of the most important input parameters to the HEC-RAS model.

The surface water height and discharge data collected at the gauging stations of Greenville and Washington are given in Table 1. The DEM-inundation model only uses the water surface height, whereas HEC-RAS model requires both height and discharge along with other previously discussed inputs. Inundation extents are modeled at two representative flooding flow conditions: a flood-stage flow on 28 February 2003 and a record-high flood flow on 23 September 1999. The flow condition on 28 July 1999 is used as the regular flow (because of the availability of Landsat ETM+ data). Thus, comparisons of the modeled results under the two distinct flood-flow situations as referenced to the regular flow condition can be performed.

DEM data for the study area were obtained from the USGS National Elevation Dataset. The DEM has a 30 m by 30 m horizontal spatial resolution and a vertical accuracy of $\pm$1m (USGS NED 2007). The terrain within the study area is flat with a minimum elevation of 0.0 m, a median of 3.5 m, a maximum of 22.5 m, a mean of 4.7 m, and a standard deviation of 4.0 m. Thus, any significant increase of river's surface water height could inundate a large area. Also, it should be noted that the south side of the Tar River has considerably more relief than the north side. Conceivably, the accuracy of DEM has a significant impact on flood mapping and the availability of higher accuracy DEM will improve floodplain modeling assessment. On the other hand, because DEM accuracy should similarly impact both models, the NED DEM is considered as a reasonable choice for comparing the two models under the same set of conditions.

Remotely sensed imagery and aerial photography were used to identify flooded and non-flooded areas to aid the validation of inundation extents resulting from the two models. These datasets include Landsat 7 ETM+ data acquired on 28 July 1999 and 23 September 1999, and oblique aerial photographs taken on 23 September 1999. These datasets, combined with *in situ* observations made in October 1999, were used to identify twenty-five flooded sites, twenty-five regular river sites, and twenty-five non-flooded sites. Thus, the accuracy of the modeled flood extents at the record-high flood flow can be evaluated at the seventy-five sites. The areas covered by the sites and by categories are: regular river area of 4.63 km$^2$, flooded area of 4.41 km$^2$, and non-flooded area of 5.32 km$^2$, for a total of 14.36 km$^2$ or 9.1% of the entire study area. Since there is no other remotely sensed or *in situ* datasets on 28 February 2003, no verification of the modeled results were performed. It should be noted that the USGS Digital Orthophoto Quarter (DOQQs) acquired in 1998 were used to aid the initial identification of the steam centerline (on the DEM) and landuse categories for sites where ground access is impossible. Finally, all digital datasets used for this study have been re-projected into the Universal Transverse Mercator (UTM) coordinate system using the World Geodetic System–1984 (WGS84) models for the spheroid and datum.

## Results and Discussion

Two layers consisting of water and non-water categories covering the entire study area were first created at the regular river flow condition (Table 1) using DEM-inundation and HEC-RAS models, respectively (Figure 5). In the figure, the water area is shown in black and non-water area in white. The main channel of the Tar River is clearly delineated, and two tributaries (Chicod and Tranters creeks, Figure 5b) are identified. Visual examination of the modeled results indicates that the water areas may be similar. However, in the upstream section there is more area classified as water by the HEC-RAS model than by the DEM-inundation model (Figure 5). At the regular flow, water areas are 11.85 km$^2$ and 16.95 km$^2$, according to the DEM-inundation model and HEC-RAS model, respectively (Table 2).

Four additional layers were modeled for water and non-water categories for the flood-stage flow and record-high flood flow conditions using the two models. The water areas on all these four layers include the regular river surface area (e.g., Figure 5),

**Table 1.** River data measured at the Greenville and Washington gauging stations.

| | Regular | Flood-stage | Record-high |
|---|---|---|---|
| Date | 28/07/1999 | 28/02/2003 | 23/09/1999 |
| Discharge ($m^3/s$) | 4.39 / NA | 302.99 / 311.49 | 1846.26 / 2152.08 |
| Water height (m) | 0.37 / 0.27 | 3.30 / 0.31 | 7.96 / 1.60 |

**Table 2.** Modeled extents of regular river, flooded, and non-flooded areas ($km^2$) at three flow conditions.

| | | Regular | Flooded | Non-flooded |
|---|---|---|---|---|
| Regular flow | DEM-inundation | 11.85 | XXX | 145.12 |
| | HEC-RAS | 16.95 | XXX | 140.02 |
| Flood-stage flow | DEM-inundation | 11.85 | 56.10 | 89.02 |
| | HEC-RAS | 16.95 | 45.67 | 94.35 |
| Record-high | DEM-inundation | 11.85 | 77.80 | 67.31 |
| | HEC-RAS | 16.95 | 74.35 | 65.67 |

which should be excluded in order to map the flooded area. This exclusion is done through recoding and overlaying operations. Thus four inundation maps representing the flood extents when the Tar River was at a flood-stage flow (Figure 6) and at a record-high flood flow (Figure 7) were generated. In these figures, the regular river areas are shown in black, the flooded area in gray and non-flooded area in white.

At the flood-stage flow on 28 February 2003 (Figure 6), there are large flooded areas surrounding the regular river area, and more flooded areas to the north of the river than to the south. The lower relief on the north bank than south bank is a factor contributing to this difference. Comparison of both inundation maps indicates that more disagreements occur within the upper half of the study area (northwest) than at the lower half (southeast). There are non-flooded islands (surrounded by flooded area). For example, there is an island in the middle of the flooded area on the inundation map derived from the DEM-inundation model (Figure 6a), and an island of much larger size exists at the corresponding location on the flood map derived from the HEC-RAS model (Figure 6b). Both islands are identified using black arrows in the figures.

Figure 7 shows the modeled inundation extents at a record-high flood flow condition. The extents are visually similar. The aerial digital photographs acquired on 23 September 1999 and ground truth collected in October 1999 indicate that the majority of flooding occurred on the north side of the river, where the elevation is much lower than the corresponding part on the south side. The slightly higher elevation on the south bank is one major factor to its smaller flooded area as compared to the north side. Two noticeable disagreements of the extents as pointed by two pairs of black arrows are observed: one occurs near the northwest corner and the other near the easternmost location. In addition,

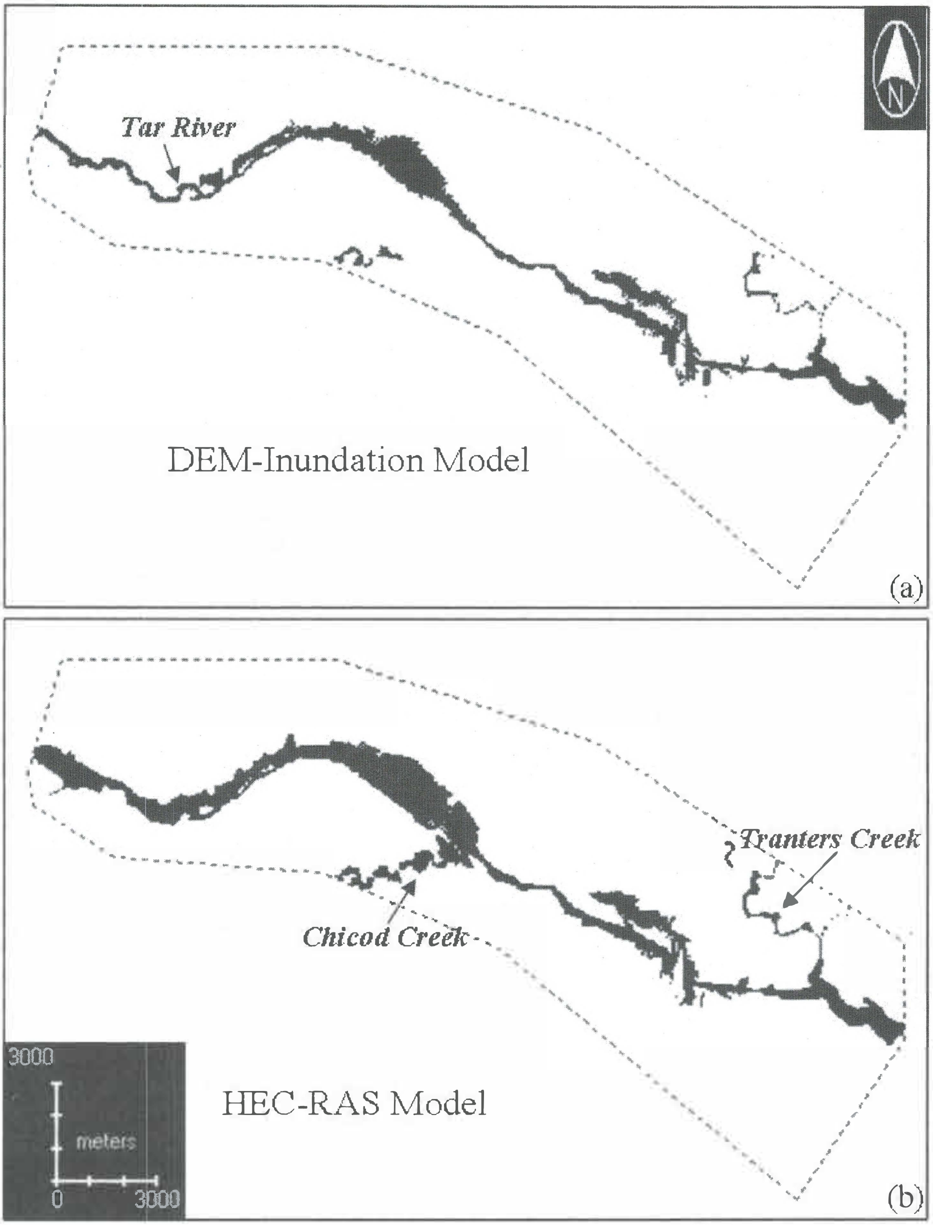


**Figure 5.** Regular river area (in black) and non-water area (in white) derived from a) DEM-inundation model and b) HEC-RAS model at a regular flow on 28 July 1999.

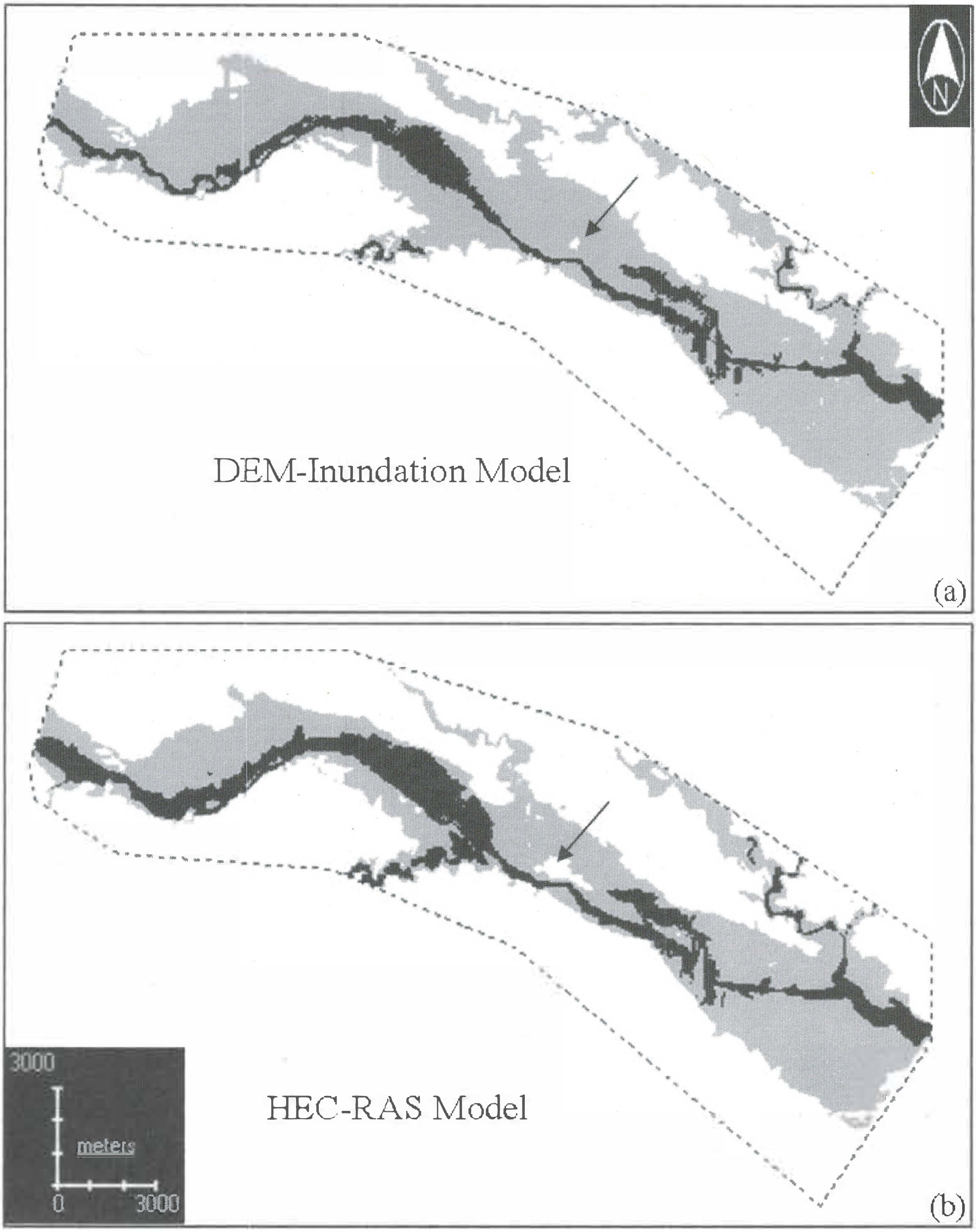


**Figure 6.** Inundation extents derived from a) the DEM-inundation model and b) the HEC-RAS model at a flood stage flow on 28 February 2003. The regular river area is in black, flooded area in gray, and non-flooded area in white. Unflooded islands exist, as pointed by black arrows as examples.

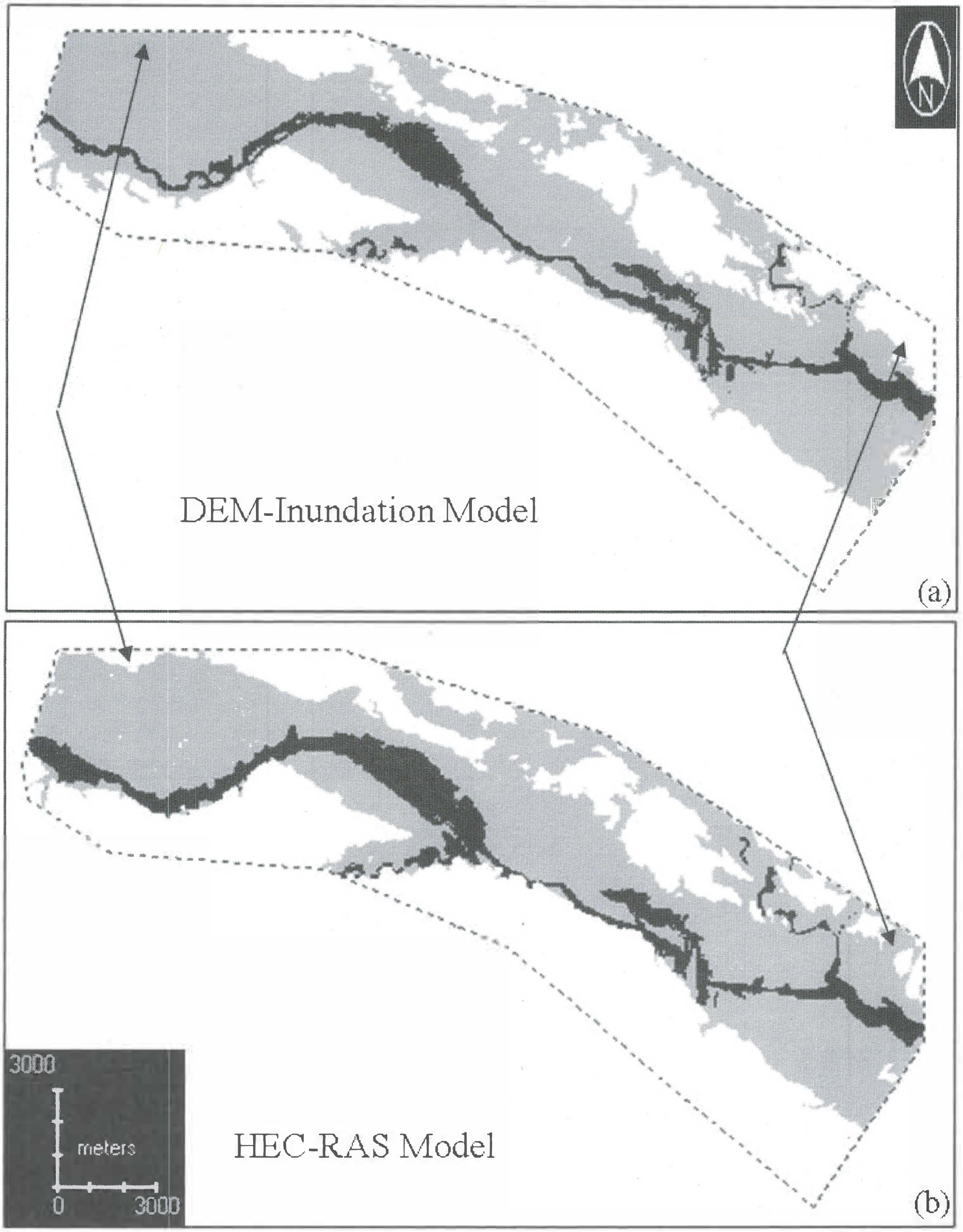


**Figure 7.** Inundation extents derived from a) DEM-inundation model and b) HEC-RAS model at a record-high flood flow on 23 September 1999.

in comparison with Figure 6, there is much greater flooded area in Figure 7, especially within the upstream section where the majority of non-flooded islands are now flooded. The increased flooded areas are attributed to the higher water surface level and discharge volume on 23 September 1999 compared to 28 February 2003 (Table 1). Table 2 summarizes the area of each category on each inundation extent map. As the river changes from its flood-stage to record-high flood flows, flooded areas increase from 56.10 to 77.80 $km^2$ (based on DEM-inundation model) and 45.67 to 74.35 $km^2$ (HEC-RAS model).

The spatial comparison analysis of the modeled inundation maps at the same flow condition quantified the degree of agreement on a pixel-by-pixel basis. The area classified as the same categories by the two models is $150.18^2$ km (of a total area of 157 $km^2$) or 95.7% on 28 July 1999 maps, 142.08 $km^2$ or 90.5% on the 28 February 2003 maps, and 140.34 $km^2$ or 89.4% on 23 September 1999 maps (Table 3). Table 3 also details the agreements and disagreements by the categories.

The results of the *t*-tests on the mean distance from the stream centerline to the water/non-water or flooded/non-flooded boundaries on both banks of the inundation maps are shown in Table 4. On 28 July 1999, $t$ and $p$ values for the water/non-water boundaries are 1.573 and 0.122 for the north bank and 1.633 and 0.109 for the south bank, respectively. The $p$ values at both banks suggest that the null hypotheses are not rejected, indicating that the water/non-water boundaries resulting from the DEM-inundation and HEC-RAS models are not statistically different. Because the $p$ values of the *t*-tests for the flood-stage flow and record-high flood flow are all greater than or equal to 0.103 (Table 4), we conclude that the flooded/non-flooded boundaries on the north and south banks are statistically the same.

Thus far, the DEM-inundation and HEC-RAS models have comparable results in this study area. The findings are very encouraging. Next, the DEM-inundation model and the HEC-RAS model were put to the final test. The accuracy of the modeled flood extents at the seventy-five selected sites were validated against the ancillary datasets collected during and after the 1999 flood, as described in the previous sections. The results indicated that both models reached high accuracy (Table 5). Based on the DEM-inundation model, the producer's accuracies are between 88.3% and 99.3% and user's accuracies 93.1% and 94.6%. The overall accuracy is 95.1%. Similar high accuracies are also obtained by using the HEC-RAS model (Table 5).

## Conclusion

A hydraulic 1-D DEM-inundation model, which is simpler than the standard complex 1-D HEC-RAS model, has been developed. Compared with the HEC-RAS model, the DEM-inundation model requires fewer input parameters that are readily available. The DEM-inundation model is also easier to implement than the HEC-RAS model. Furthermore, comparisons between inundation extents from the models and accuracy evaluation for a flood event on the floodplain of the Tar/Pamlico River, North Carolina have shown that the results from the two models are very similar and both reached overall accuracy greater than 93%. Thus, the DEM-inundation model can be an effective alternative to the more complex HEC-RAS model.

Before concluding, we would like to mention three recent developments: the creation of the DEM for the state of North Carolina, implementation of more river gauging stations by the USGS, and availability of real-time gauge data. All of these developments positively impact the application of the DEM-inundation model. After the 1999 flood in eastern North Carolina, the state of North Carolina initiated a statewide flood mapping program (NC Floodplain Mapping Program 2007). One of the products downloadable for free from the program is the statewide light detection and ranging (LIDAR) derived DEM. The DEM is of 15 x 15 m (50 x 50 ft.) resolution, and has a vertical accuracy of approximately 0.2 m. One distinct feature of the new LIDAR-derived DEM, as compared with other DEMs (e.g., NED DEM), is that the LIDAR-derived DEM has been hydro-corrected, i.e., all the channels of streams

**Table 3**. Spatial comparison of the inundation extent maps derived from both models at three flow stages. The area is in km$^2$, and the percentage within the [] is computed out of the total study area.

(a) A regular flow (07/28/1999)

| | HEC-RAS model: Non-water area | Water |
|---|---|---|
| DEM-inundation model | | |
| Non-water area | 139.17 [88.7%] | 5.95 [3.8%] |
| Water | 0.84 [0.5%] | 11.01 [7.0%] |

(a) A flood-stage flow (02/28/2003)

| | HEC-RAS model: Non-flooded area | Flooded area | Regular river area |
|---|---|---|---|
| DEM-inundation model | | | |
| Non-flooded area | 87.94 [56.0%] | 1.07 [0.7%] | 0.00 [0.0%] |
| Flooded area | 7.02 [4.5%] | 43.13 [27.5%] | 5.94 [3.8%] |
| Regular river area | 0.04 [0.0%] | 0.80 [5.1%] | 11.01 [7.0%] |

(a) A record-high flood flow (09/23/1999)

| | HEC-RAS model: Non-flooded area | Flooded area | Regular river area |
|---|---|---|---|
| DEM-inundation model | | | |
| Non-flooded area | 62.67 [39.9%] | 4.64 [3.0%] | 0 [0.0%] |
| Flooded area | 4.34 [2.8%] | 67.09 [42.7%] | 6.37 [4.1%] |
| Regular river area | 0.00 [0.0%] | 1.27 [0.8%] | 10.58 [6.7%] |

**Table 4**. Matched-pairs *t*-tests on the water/non-water or flooded/non-flooded boundaries derived from DEM-inundation and HEC-RAS models at three flow conditions.

(a) A regular flow condition (07/28/1999)

| Water/non-water boundary | *t* | *p* |
|---|---|---|
| On north bank | 1.573 | 12.2% |
| On south bank | 1.633 | 10.9% |

(b) At the flood-stage and record-high flood conditions.

| | The flood-stage flow (02/28/2003) | | The record-high flood flow (09/23/1999) | |
|---|---|---|---|---|
| Flooded/non-flooded boundary | *t* | *p* | *t* | *p* |
| On north bank | 1.620 | 11.1% | 1.612 | 10.3% |
| On south bank | 1.490 | 14.3% | 1.648 | 10.6% |

have been manually and clearly delineated by analysts, and portions of bridges and overpasses have been removed from the DEM (Figure 8). For example, streams clearly depicted by the LIDAR DEM (Figure 8a) are barely noticeable in the NED DEM (Figure 8b). Since the airborne LIDAR sensor measures surface elevation, surface elevations of bridges and overpasses will appear on the uncorrected DEM instead of that of the underlying surfaces. The hydro-correction is necessary to ensure the flow continuity of water in streams under bridges and on road surfaces beneath overpasses. Thus, because of the hydro-correction, the delineation of the center line of a steam becomes easy or may already be done; this simplifies the implementation of the DEM-inundation model (within the state of North Carolina).

The DEM-inundation model is designed to be used on a stream section between two gauging stations where preferably no major inflow from tributaries exists. With the inflow (from the tributaries into the main steam) the surface water height at the downstream gauging station will be augmented. Thus, the inflow can affect the model output. Although this may limit the applicability of the model, the ever increasing number of gauging stations in the United States is making this less of a problem. For example, in the study area, three additional gauging stations (between the Greenville and Washington stations) have been recently added (USGS NWIS 2007). The surface water heights measured at the new Chicod Creek and Tranters Creek stations (e.g., Figures 4 and 5) will help address the influence of the tributary inflows (to the Tar River) and estimation of the surface water heights at the meeting points of the Tar River/Chicod Creek and Tar River/Tranters Creek. The new gauging station (SR1565) near Grimesland at Tar River not only divides the stream

**Table 5.** Error matrix and classification accuracy derived from both models at sites of regular water, flooded, and non-flooded areas. The date is 23 September 1999. The area is in $km^2$.

(a) DEM-inundation model

| | Reference data | | | |
|---|---|---|---|---|
| Model output | *Flooded area* | *Non-flooded area* | *Regular water area* | *Total* |
| *Flooded area* | 4.17 | 0.31 | 0.24 | 4.72 |
| *Non-flooded area* | 0.24 | 4.98 | 0.08 | 5.30 |
| *Regular water area* | 0.00 | 0.03 | 4.31 | 4.34 |
| *Total* | 4.41 | 5.32 | 4.63 | 14.36 |

| | Producer's accuracy (%) | User's accuracy (%) |
|---|---|---|
| Flooded area | 88.3 | 94.6 |
| Non-flooded area | 93.9 | 93.6 |
| Regular water area | 99.3 | 93.1 |

Overall Accuracy 95.1%

(b) HEC-RAS Model

| | Reference data | | | |
|---|---|---|---|---|
| Model output | *Flooded area* | *Non-flooded area* | *Regular water area* | *Total* |
| *Flooded area* | 4.22 | 0.23 | 0.18 | 4.63 |
| *Non-flooded area* | 0.19 | 5.04 | 0.06 | 5.29 |
| *Regular water area* | 0.00 | 0.05 | 4.39 | 4.44 |
| *Total* | 4.41 | 5.32 | 4.63 | 14.36 |

| | Producer's accuracy (%) | User's accuracy (%) |
|---|---|---|
| Flooded area | 91.1 | 95.7 |
| Non-flooded area | 95.2 | 94.7 |
| Regular water area | 98.9 | 94.8 |

Overall Accuracy 93.1%

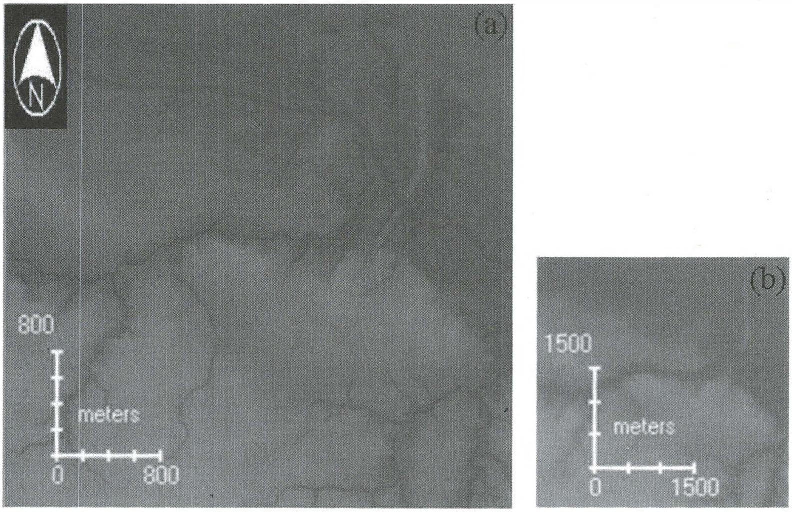


**Figure 8.** Streams or centerlines are clearly delineated in the hydro-corrected LIDAR DEM (a) as compared to the USGS DEM (b). The DEMs cover areas near (east of) Greenville, NC.

segment between Greenville and Washington into two segments, but also provides another independent measurement of the surface water height. Furthermore, the USGS currently maintains a network of nearly 18,000 gauging stations across the country. The high density of gauging stations has made it more likely that there is no major tributary between two stations. Finally, using real-time surface water height measurements available at gauging stations, one can use the model to simulate a range of flood-extent scenarios in an event of a flood. Therefore, the DEM-inundation model will be capable of meeting the needs for quick implementation in urgent situations by the flood management and mitigation agencies at different government levels, especially in situations where there is a lack of sufficient hydrologic/hydraulic knowledge and limited resources to implement the more complex models (e.g., HEC-RAS, TELEMAC-2D, and LISFLOOD-FP).

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# The North Carolina Global Transpark: A Brief History from the Regional Planning Perspective

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The North Carolina Global TransPark (GTP) recently attracted Spirit AeroSystems, contracted to build the fuselage panels for the Airbus A350, to the underutilized facility at Kinston. With it 11,500-foot runway, access to the North Carolina State Ports by rail, the 2,000 acres of land, and training facilities, the GTP proved to be the appropriate site for the company. Its location between several military air bases is an additional advantage. For seventeen years, it has been the source of frustration for the state, and many have called it a "boondoggle." Recently developments appear to suggest a promising future, if somewhat different from its original purpose. It is appropriate at this point, to review the theoretical foundations of the GTP concepts and the history of its implementation. The facility was plagued from the outset with public relations missteps, intersectional discord, and unrelenting criticism. However, demographic factors associated with the thirteen counties of the former Global TransPark Development Zone (now North Carolina's Eastern Region) have made the site less attractive to the type of manufacturers the planners intended to attract. These factors include a low percentage of resident college graduates in proportion to those with less than a high school education, and low population density compared to the state's metropolitan counties. Regardless of the potential success of the GTP, the region requires greater access to educational opportunities for its overall preparation for future economic development.

## Introduction

In early May of 2008, Governor Mike Easley announced that the Global TransPark in Kinston had finally attracted a significant client. Spirit AeroSystems will be manufacturing fuselage panels for the Airbus A350. The company received a substantial incentive package worth more than $125 million from the State of North Carolina, however the TransPark's lengthy runway, its 2,000 acres of available land, the facilities training center, and rail access to the ports of Morehead City and Wilmington led the company to select this site. Governor Easley believed the TransPark was the best thing going in North Carolina at this time (*Wilmington Star- News*, 15 May 2008). Aircraft related manufacturing seems a very appropriate activity for the facility, not only for its unique manufacturing capabilities, but also for its central location near East Carolina University, Seymour Johnson Air Force Base, New River Marine Corps Air Station, and Pope Air Force Base, near Fort Bragg, which is about one hundred miles to the southwest. Each of these places train people who become qualified for aircraft related manufacturing.

Does this change of fortunes vindicate the planner of the TransPark? When the facility is paid for, it is likely that researchers in the field of transportation geography and regional planning will need to take a second look at the state's infamous "boondoggle." It is appropriate at this point, to review the history of the TransPark, and to identify the problems that plagued its first seventeen years. This study examines the history of the GTP project from its conception, and indentifies the regional concerns associated with it.

North Carolina's Global TransPark (GTP) plan began with a one-hour meeting in 1990 between Governor James Grubbs Martin and John D. Kasarda of UNC-Chapel Hill's Kenan-Flagler Business School. Kasarda, a sociologist, proposed a technologically advanced industrial complex centered at a cargo airport with highway and rail connections. Like similar airport-centered cities that he had observed in China, this facility would serve as a connecting node in the emerging global economy. He used the word "Aerotropolis" to describe his vision (*Wall Street Journal*, 2 December 1992). In a number of empirical studies and professional publications, Kasarda and his colleagues established a strong argument for organizing geographically dispersed manufacturers, suppliers, and clerical services linked by a sophisticated telecommunication network to an airport-centered multi-model hub.

From such a facility, air transport would provide a rapid link to the national and global markets. Nearby highway and railroad connections would deliver product components to a dedicated site within the core of the hub for final assembly and disperse finished goods into the distribution network as the market required. Kasarda referred to this as "agile manufacturing," with unified telecommunications networks, transportation systems, and support services. He and his colleagues advocated the integration of sophisticated computer programs into the management of industrial logistics (Irwin and Kasarda, 1991; Vastag, Kasarda and Boone, 1994; Kasarda, 1998; Kasarda and Rondinelli, 1998; Kasarda, 2001; Greis, Olin, and Kasarda, 2003). Economic geographers and others have labeled this method of industrial production "just-in-time" production, a term subsumed under the economic philosophy of Post-Fordism. This appeared to be the emerging economic revolution in the closing years of the twentieth century, and the progressive minded in North Carolina government embraced the idea of building such a facility to counter the decline in the state's traditional manufacturing of textiles, furniture, and tobacco products.

The planners of the North Carolina Global TransPark (GTP), a 2,400-acre business park/cargo airport north of Kinston built with an 11,500-foot runway designed to accommodate heavy airfreight traffic, estimated that the project would create 55,000 jobs. By 2007, the facility had instead become the home of a few small companies that also served some passenger aircraft. While the facility appeared to be making progress in attracting business, it was not able to operate without the aid of the state. The burden of a $32 million debt, due the state in 2009, would have had to be renegotiated (Raleigh *News and Observer*, 31 January 2007, 3 January 2008). Many North Carolinians had accepted it as a failed venture, while others now anticipate that the time will come when the TransPark develops its niche in the state's economy. A similar logistical concept, the Inland Ports, a cooperative initiative between the State Ports Authority, the railroads, Charlotte/Douglas and Piedmont/Triad airports, has proven profitable. What geographic factors have contributed to the difficulties of the former and the success of the latter, and perhaps the ultimate attractiveness of both? Finally, what are the demographics of North Carolina's Eastern Region and how have they worked against the TransPark's success on the scale of Research Triangle Park or the Piedmont Triad?

### *Outsourcing and Post-Fordism*

The decline of eastern North Carolina began with the outsourcing of traditional jobs, such as textile manufacturing, during the latter decades of the twentieth century. The term *outsourcing* refers to a cost-cutting strategy that has become central to the corporate canon during the last few decades, facilitated in part by advances in telecommunication and computer technology. Corporations seeking cheap labor, limited or no environmental policy constraints, and lax government oversight can relocate part of their manufacturing process to underdeveloped nations. While the practice is recent, it resembles similar arrangements under European imperial capitalism during the nineteenth century (Stearns, 1998, 150-156). It has become a politically contentious issue in the United States because of its destabilizing effect on regional and state economies when factories relocate. On an individual level, displaced workers must enter the academic environment to enhance their education to acquire a different profession or else resign themselves to lower paying jobs in the service sector. By extension, it creates a type of degree inflation where by the demands of the emerging job market require a college education and/or specialized certification. The university is increasingly adjusting its mission to the demands of the market (Delanty, 2002). On the other side of the outsourcing argument, the class dynamics in an earlier industrial economy, which have historically led to economic and social reforms, are now geographically and culturally displaced from "first world" consumers (Kester, 1993, 75-76). However, the apparent benefits of outsourcing initially manifested in lower product cost to the consumer and high dividends to shareholders are transitory. Its net result is the creation of trade deficits and ubiquitous debt as traditional industrial economies retool to accommodate the new paradigm. This, unfortunately, is the starting point for discussing the more elegant aspects of Post-Fordism.

Post-Fordism is a communication based, time dependent method of industrial organization that reduces the need to maintain large inventories of production material and finished products, eliminates redundant facilities, and locates the diverse functions of the company in geographically advantageous places. This production paradigm evolved in parallel with downsizing and outsourcing of certain industries and in response to the emerging global economy. Yet, there is nothing in this organization of manufacturing that requires the locating parts of the process outside national boundaries. Fordism, named for Henry Ford and his assembly line production methods, organizes all the functions of an industrial process in one location. Raw materials are fashioned into components in one division, assembled in another, and warehoused for distribution. Administration, accounting, sales, research and development, and production are centrally located. Labor in the Fordist manufacturing paradigm divided into single task specialties. In contrast, Post-Fordist labor is flexible. Workers, trained in multiple tasks and production processes, can adapt to manufacturing different products to meet specific and changing demands.

Post-Fordist production responds to specific time-based market demands. By extension, the Post-Fordist industrial paradigm leads to a reorganization of the socioeconomic landscape. Facilities for the final assembly of products are located at multimodal nodes, preferably with interstate highway access, rail service, and airfreight service. Facilities or separate companies involved in manufacturing parts, preassembled units, or packaging and shipping are located in close proximity to the manufacturing plant. The multi-modal network can supply the basic material from remote providers and ship out the final product. Self-sufficient communities, replete with their own service economies, form clusters of interrelated manufacturing centers along the access routes to the shipping facilities. Corporate headquarters can be remotely located in a financial metropolis near banking and government, while research and development facilities are located near sources of intellectual expertise, such as universities. Clerical and account activities are dispersed or outsourced, and telecommunications link all divisions of labor.

The new production paradigm also places demands on transportation. Transportation of goods and labor must constantly adapt to changing origins and destinations determined by the demands of the market. The synchronizing of transportation terminals facilitates the integration of transportation modes, rather than the competition between modes (Rodrique, 1999, 256-257, 259). The study of logistics in transport geography is an expansion of the concept of space/time convergence to include the structure and flow of goods through nodes and networks. The concept of *logistical friction* is a central concept in transport geography, including variables beyond the cost of transportation, such as inefficiencies in the organization of the supply chain, the sources of delays caused by the nature of the transportation system's connecting facilities, and elements of the intervening physical geography between locations that contribute to transportation time and cost. Contemporary corporate site location strategy for certain facilities is directed towards seeking those places with the best access to market areas and a capacity for handling large volumes of freight. Large ports, major airports, and the intersection of interstates highways offer potential market access (Hesse and Rodrique, 2004, 176, 179). Reducing the delays from urban congestion cuts the operator's delivery costs. The proximity of rail and marine transport relieves pressure on existing roads as well as demands for road development (Dinwoodie, 2006, 309, 318-318).

However, facilities and infrastructure alone do not make for the ideal environment for Post-Fordist industrial strategies. A multi-modal alliance between airlines, ports, trucking companies, and railroads improves efficiency and maximizes the benefits of existing infrastructure. Zhang and his colleagues have identified strategic components for the establishment of a multi-modal airfreight network that serves the global economy. First are the *integrators* engaged in web-based transportation logistical management. These services coordinate the flow between carriers. Second are the *forwarders* that accumulate and distribute freight, such as the trucking companies and railroads. The airlines, railroad, and trucking companies that enter into multimodal alliances or merge can improve their profits and increase the efficiency of air cargo transport by diminishing the need for specialized outside logistical services contractors (Zhang *et al.*, 2007, 234-237, 239, 244-245).

**A History of the GTP from Primary Sources**

The history of the North Carolina Global TransPark is a compilation of press reports, legislative documents, and official reports. Solid research and practical observations appear to support the concepts behind the facility. However, the nature of the planning problems surrounding its early existence constitutes a mix of managerial missteps and public relations blunders that have agitated long-standing urban and regional rivalries.

The name "Global TransPark" did not appear until 1991 when it was created in North Carolina's Department of Economic and Community Development as part of a marketing plan to draw a favorable comparison with the successful Research Triangle Park. The General Assembly approved the expenditure of $117,000 for an ad campaign for the project (Greensboro *News & Record*, 4 November 1991). The term "Global TransPark" became confusing when it was overused in the titles of several related, yet discreet, administrative entities. These included the N.C. Global TransPark Development Zone (Figure 1), N.C. Global TransPark Development Commission, and N.C. Global TransPark Authority.[1]

The plan attracted early criticism in 1991 when Robert W. Poole, Jr. of the John Locke Foundation, a North Carolina conservative think-tank, attacked the idea of such a facility as explained in Governor Martin's published essay on the project. Poole noted problems with existing cargo airports in Texas and Alabama, and argued that a new airport "must meet real needs and be located where the market dictated – not simply where a planner would like it to be." Citing a 1991 Federal Aviation Administration study, he noted that the passenger airlines carried sixty percent of the nation's air cargo.

Charlotte/Douglas International Airport, Raleigh-Durham International Airport, and Piedmont Triad International, as well as a site near Seymour Johnson Air Force Base in Goldsboro, were among the initially recommended sites for the GTP (Figure 2). Limited space between Pope Air Force Base and Fort Bragg worked against placing the site near Fayetteville. The editor of the Fayetteville *Observer* noted that the Laurinburg/Maxton Airport, one of the sites under consideration, had scant infrastructure and was located near sensitive wetlands (Fayetteville *Observer*, 12 February 1992). Charlotte sent city officials to Raleigh before the 19 May 1992 selection date in an effort to convince officials that Charlotte/Douglas was well equipped and had sufficient land to expand (Charlotte *Observer*, 21 April 1992). The selection committee, headed by Governor Martin, favored less developed sites with more growth space. The finalists were Laurinburg/Maxton Airport and Kinston Regional Jetport (Charlotte *Observer*, 11 May 1992). Officials selected Kinston Regional Jetport. John Kasarda observed that the 30,000 acres of surrounding land were suitable for industrial use (Charlotte *Observer*, 20 May 1992). The Fayetteville *Observer* immediately editorialized the opinion that the project was likely to fail if located in such a depressed region and that the projected $156 million cost of the facility would serve the state

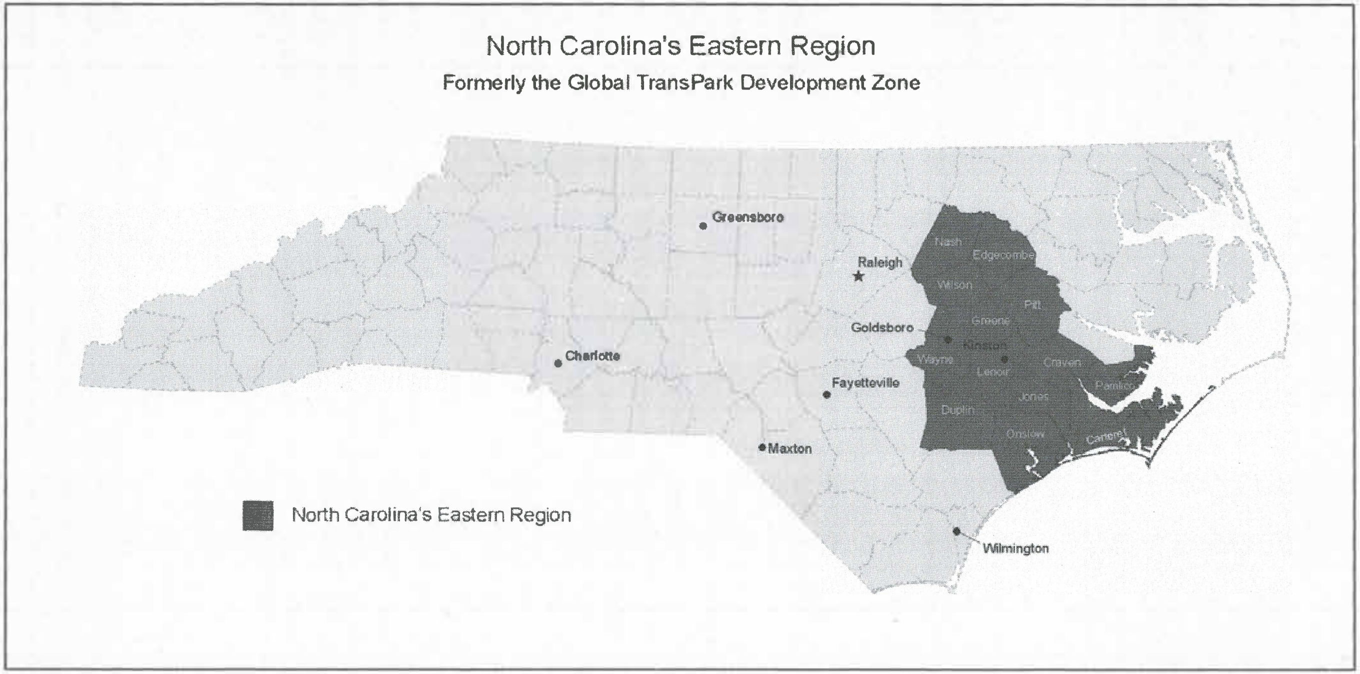


**Figure 1.** North Carolina's Eastern Region, Formerly the Global TransPark Development Zone. Source: Map by Leanne Sulewski

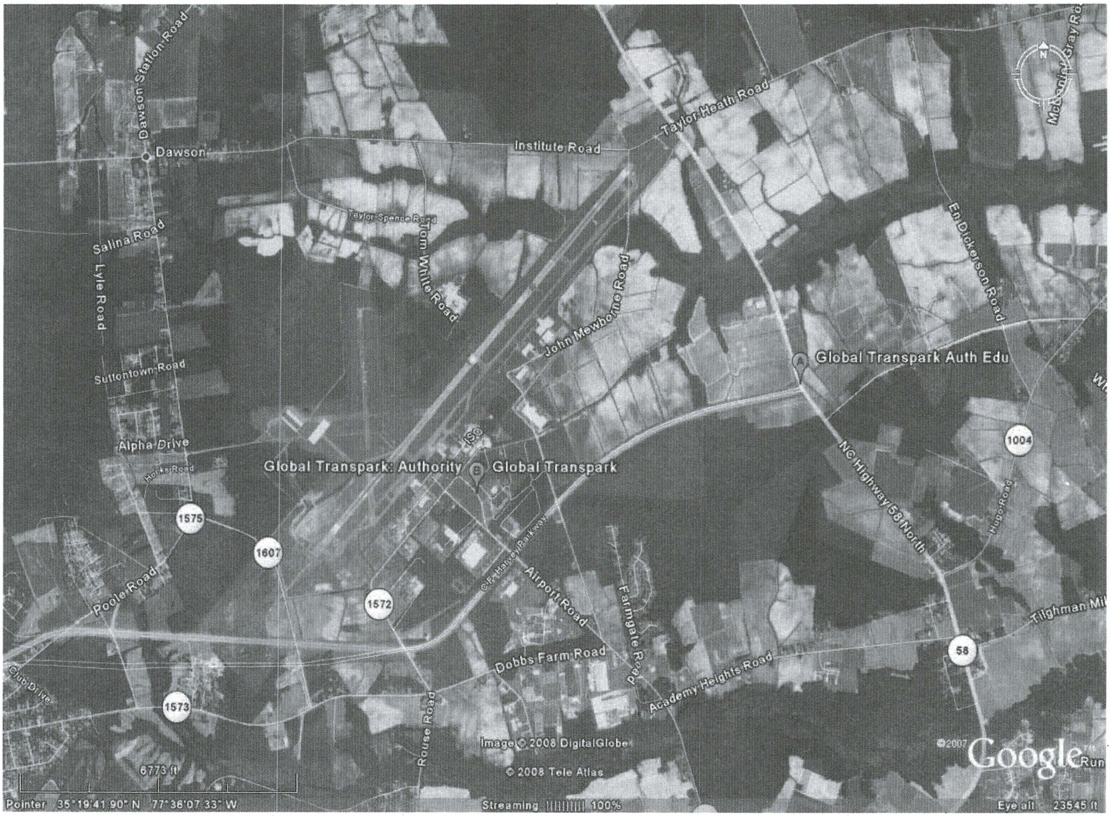


**Figure 2**. This Google Earth image shows the North Carolina Global TransPark runway, road network, and growth space. Most of the land surrounding the TransPark site appears to be agricultural. Source: GoogleEarth

better if applied to education and repairing existing infrastructure. In addition, the owners of the supposedly vacant land at Kinston organized against the plan (Fayetteville *Observer*, 6 December 1992). In 1994, New Hanover County declined the invitation to join the Global TransPark Development Zone. The county, asked to pay more into the project than the other counties of the zone, saw no benefit in supporting Kinston and Goldsboro when the old competition from Norfolk and Morehead City remained unchanged. The New Hanover County Airport Authority endeavored to build its own industrial complex. This plan evolved in improvement in runway and facility improvements as well as the acquisition of more land for future growth (Wilmington *Star News*, 26 May 1994, 11 August 1994, 18 October 1994, 9 September 1998).

Small things also set people in the region against the facility. The Global TransPark Development Commission irritated the commissioners of bordering counties when they erected their "Entering" and "Leaving Global TransPark Development Zone" signs along I-40, US 17, and other major highways. The North Carolina Department of Motor Vehicles and the Kinston license plate agency offended many residents of Eastern North Carolina by having special "GTP" license plates for all drivers in the TransPark Development Zone counties when they purchased new plates. When the TransPark Development Commission offered to spend public money to build a special school for the children of employees of the Japanese automotive firm, AMSO, so the students would not fall behind their counterparts in Japan, a member of the commission representing Carteret County resigned in protest (Wilmington *Star-News*, 24 September 1994; Charlotte *Observer*, 31 August 1994; Wilmington *Star-News*1995). Other elements of the Japanese affair are amusing.

> At a meeting with a Smithfield Foods Inc. representative last month, Gov. Hunt pitched the idea of TransPark flying fresh cuts of prime pork to Japan from the company's hog-slaughtering plant in Tar Heel, about 100 miles from TransPark. ... Raoul Baxter, president of Smithfield's international unit, shares the governor's enthusiasm about the potential of selling fresh, North Carolina pork in Japan. He predicts the Smithfield, Va. company's newly launched "flying pig program" — which is in the testing stages — ultimately could grow to five plane-loads a week.
> (*Wall Street Journal*, 15 March 1995)

GTP officials also contemplated using the TransPark for developing a global market for North Carolina tobacco products. Governor Hunt noted a Department of Health and Human Service task force concluded that "American cigarettes in foreign markets does not increase the number of smokers in those markets" (Durham *Herald-Sun*, 29 November 1995). At the end of 1995, the TransPark Development Commission approved a $22,500 grant to study the impact of the proposed IBP hog processing plant in Edgecombe County (Durham *Herald-Sun*, 29 November 1995; Greensboro *News and Record*, 9 December 1995).

Support for the TransPark in Charlotte and Raleigh was waning by 1996, and Governor Hunt advised the TransPark Authority to "rein in some of its spending practices." In 1998, North Carolina offered $100 million in incentives to Federal Express to locate a new $300 million package sorting hub at one of the state's airports. Additional packages were offered by Charlotte, Greensboro, Raleigh-Durham, and the TransPark. Charlotte and Raleigh-Durham were the only airports to meet the company's exact requirements, but Piedmont Triad International Airport, the TransPark, and two South Carolina airports (Columbia and Greenville-Spartanburg) were also among the finalists. Kinston, thirty miles from I-95, was deemed to be too far out of the way. [Erskine Bowles noted in a *Wall Street Journal* interview in 2000, that there were 105 stoplights on US 70 between Kinston and Raleigh. A company such as Federal Express, that selected Greensboro as its hub, would never locate to the TransPark because of so many stoplights.]

Other attempts to attract large corporations to the TransPark were also unsuccessful. An attempt to lure Lockheed Martin to the TransPark to build a new spacecraft named VentureStar failed in the late 1990s, a wasted effort that produced disparaging headlines (Charlotte *Observer*, 7 April 1996; Wilmington *Star-News*, 2 April 1998; *Wall Street Journal*, 4 February 1998, 26 August 1998, 5 January 2000). In addition, other agencies began to compete with GTP. Charlotte/Douglas International Airport and Norfolk Southern began planning a $90 million global cargo complex in 1999. They were also trying to bring the CSX Rail Line in on the deal. Their proposals were similar to the TransPark, but their infrastructure was already in place (Charlotte *Observer*, 12 April 1999).

By the time the TransPark runway (Figure 2) was officially opened in December of 2002, the General Assembly had cut the facility's annual budget to $1.6 million, pushing the TransPark authority to begin to develop its passenger, rather than cargo, airport options and drawing swift opposition from the region's other airports – New Bern, Greenville, and Jacksonville. Their existence depended on the 300,000 passengers using their combined services annually. They had supported the TransPark's construction as a cargo airport, but were not about to nurture a rival in their own backyard. To their dismay, many passengers did fly from Kinston. In 2006, 65,000 passengers used the jetport to make connection to Atlanta through Delta Airlines and the Atlantic Southern Airline (Charlot*te Observer*, 25 July 2002, 27 December 2002; Raleigh *News and Observer*, 31 January 2007).

The combination of delays from concerns "over environmental impacts, engineering problems, and the sheer immensity of constructing an 11,500-foot runway," and its poor prospects for success led the 2002 North Carolina General Assembly to consider ending funding for the Global TransPark. TransPark officials tried to thwart this by warning the General Assembly that the state would have to repay FAA grants if funding was terminated. This turned out it be inaccurate, because the funds would not have to be returned as long as the facility remained in public hands.

The term "buffalo hunting" refers to incentive packages offered to corporations to locate their facilities in a particular location. Taxpayers ultimately pay for these in some form, and local governments often augment these packages. In 2003, the hopes of Transpark "buffalo hunters" were high that Boeing would select the Global TransPark for a new facility to build its 787 passenger jet. After Boeing selected Seattle for the new site, the Fayetteville *Observer* expressed the opinion that Boeing had used the incentives offered by North Carolina as leverage to get a better offer from the state of Washington. This might or might not have been accurate, but it made the "buffalo hunters" appear as hapless rubes that "were played" by the large corporation. Such a disappointment directed fault towards the TransPark and reinforced the public's impression that the project was a waste of public funds and that the state needed to "try something else" (Fayetteville *Observer*, 23 December 2003; Wilmington *Star-News*, 27 December 2003).

In a 2004 "buffalo hunt," North Carolina offered an incentive package to the computer manufacturer Dell. The company was attracted to the Piedmont International Airport in Greensboro, where Federal Express had already located. They passed over the "almost-empty" TransPark. The Fayetteville City Council, working with county leaders and lobbyists, the Ferguson Group, set out on their own to seek federal funding to attract business. State Senator Larry Shaw expressed frustration that Raleigh "overlooks the East and Cape Fear, and these regions should make a point of finding out about new opportunities as soon, or before, Raleigh becomes aware of them" (Fayetteville *Observer*, 24 December 2004). Raleigh promoted the Kinston facility, neglected Fayetteville, and in the process rekindled the perennial sectional rivalries of the past.

Newspaper articles about the TransPark in 2005 and 2006 reflect both a need to make the site useful and its long legacy of futility and embarrassment. During 2005-06, the General Assembly considered a proposal to merge the NC State Ports Authority, the North Carolina Railroad, and the Global TransPark Authority into one agency. The annual revenue generated by the railroad and ports amounted to $43.4 million dollars in 2006, and the TransPark received a $1.6 million appropriation from the state. The TransPark falls under the authority of the NC Department of Transportation, the ports are under the NC Department of Commerce, and the North Carolina Railroad – incorporated in 1849 – is a private corporation in which the state owns all the shares and leases the corridor to the Norfolk Southern Railroad. Such a merger was difficult to imagine (Wilmington *Star-News*, 24 April 2006). For the various carriers to act in concert while being responsible to different state agencies with different mission statements seemed almost impossible. The railroad and ports were moving vast quantities of bulk products, profitably. The TransPark was a liability. Although the TransPark had been attracting more clients recently, it remains heavily indebted to the state. This brings the history of the TransPark to its recent change of fortune.

**The Obstacles to the GTP's Success**

Many missteps seem to have contributed to the TransPark's image as a failure. The press accounts of the early years of the North Carolina Global TransPark give the impression that the project went forward without proper planning. The action of officials in Raleigh as well as the Global TransPark Authority led to public contempt for the project and eroded corporate confidence in its success. Funding for the project was premature, allocated by the General Assembly before securing any commitment from potential clients. The TransPark Authority inflamed resentment within the Eastern Region and across the state with its public relations campaigns and it became a sink of consultant fees without producing any profits or debt service. Some of the proposed usages of the TransPark were absurd, pork exports to Japan and cigarettes for the global market being the most extreme examples. The TransPark drew passenger service away from airports, creating the resentment of nearby airport authorities, rather than developing as a cargo airport as originally touted. When North Carolina was recommended as a prime site in the "buffalo hunts," overlooked cities adopted a "go it alone" strategy to counter Raleigh's perceived neglect. These serious flaws beg an examination of the state's regional planning policy.

Several questions must be asked regarding North Carolina's economy and the concept of "just-in-time manufacturing." How does the "knowledge class" of college graduates determine regional economies? What are North Carolina's homegrown regional industries? Are they traditional industries, Post-Fordist, or a mix? Does GTP's disappointing performance point to a failure of the educational system, is it the result of poor location, or is the whole Aerotropolis concept a modern internal improvements fad that gave way to more diversified applications?

In *Improving North Carolina's Economic Development Delivery System, A Report to the North Carolina General Assembly*, Michael I. Luger and Leslie S. Stewart of the Office of Economic Development of the Kenan Institute at UNC-Chapel Hill identify education as the primary attractor for new business.

> When the number one factor in business site selection is well-trained and/or well-educated labor, a low college attainment rate alone – which one can discover on a first-pass web search of a community – will take the place off the site selection list without anyone ever making the first inquiry. All the "marketing" or incentives in the world are not going to drive a company needing Ph.D. engineers to a remote area where few residents attend college.
> (Luger and Stewart, 2003, Section 2, 6)

Of the thirteen counties of North Carolina's Eastern Region, originally the Global TransPark Development Zone, the percentage of individuals with undergraduate degrees in twelve of these counties is less than twenty percent (Figure 3). The counties of North Carolina's Eastern Region, formerly the GTP Development Zone, had a significantly higher percentage of individuals that had not completed high school than most of the top seven counties having the highest percentage of college graduates (in gray). Pitt County is the home of East Carolina University, and Watauga County has a small population and is home to Appalachian State University. The population per square mile in the counties of North Carolina's Eastern Region is significantly lower than the urban counties. The percent of unemployed people and those living below poverty level is also higher in the Eastern Region, as compared to the urban counties of Mecklenburg, Guilford, Wake, and New Hanover. As expected, the median household income for the Eastern Region is lower than the counties with high percentages of college graduates and greater population density (Table 1). When the complete Census data from Table 1 is analyzed using Pearson Correlation Coefficient, it not surprising that there are negative correlations between median household income and the unemployed, people living in poverty, and high school dropouts. Conversely, there should be a positive correlation between college graduates and median household income. The most interesting correlation is that between population per square mile, median household income and a college education. This suggests that the division between the college educated and high school dropout are more pronounced in the low population density counties (Table 2). This is not a favorable recommendation for the counties of the former GTP Development Zone. Has the low population density been the result of outward migration? Jones County is only now beginning to regain its 1960 population level. The population of Edgecombe County has fluctuated by thousands over

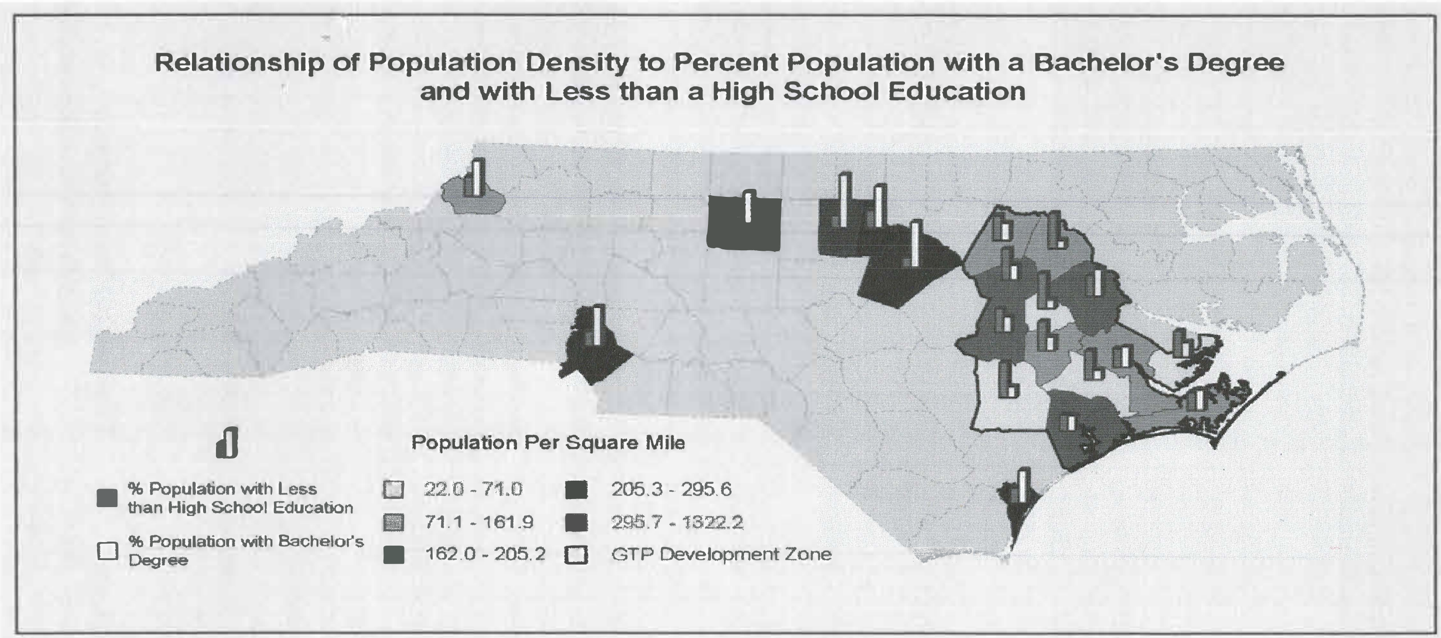


**Figure 3**. Relationships of Population Density to Educational Attainment in North Carolina, Map by Leanne Sulewski. Source: U.S. Census Bureau. (2000). Census 2000; (2004) Median Household Income http://censtats.census.gov

the entire period. Lenoir County gained fewer than four hundred people over sixteen years. Duplin County experienced recent growth after four decades of stagnation, perhaps the result of the construction of I-40 through the county in the 1990s. Onslow and Wayne, both the sites of military bases, have experienced steady growth. The population of Carteret, a coastal county, has doubled. Nash County has grown by a third. The remaining counties have experienced steady grown (Table 3). The rural east appears to be losing its college educated work force to the metropolitan centers of the Piedmont. Although the region has attracted well-to-do retirees and seasonal tourists, the chasm between the affluent and impoverished in the east continues to expand (Raleigh *News and Observer*, 22 March 2007). Statistics from the 2000 US Census and other official sources indicate that all the counties of North Carolina's Eastern Region, formerly the Global TransPark Development Zone, have few residents with at least a bachelor's degree.

The technically oriented jobs of a facility such as GTP require a well-educated and technologically sophisticated work force to attract corporations that offer good salaries. Ironically, the Global TransPark offers facilities designed for the current Post-Fordist industrial economy in a depressed region that has been losing its educated population because of a lack of employment opportunities. Although the several military bases in the region offer the facility the potential for an alternative work force, the low number of college graduates in the region limit GTP's potential for attracting clients.

The extreme disparity between the educational percentages and ranking of the counties of North Carolina's Eastern Region and the key counties of the Piedmont have placed the region in the condition of "contingent marginality." That is, the region is not well prepared to negotiate the present market place because of inadequate labor skills (Mehretu, *et al*, 200, 90-91). Traditional Fordist jobs, such as those in the former textile industry of the eastern counties, require a minimal education to accomplish what is termed "low trust" tasks, such as attending a machine. These are the jobs that are often outsourced to the third world. The Post-Fordist work model, driven by "market flux, global competition, and rapid technology," redesigned jobs to fit an autonomous "high trust" model with a focus on mental skills (Vallas, 1999, 77-80). A "knowledge class" became the center of such a work force, and the role of the domestic unskilled laborer is now limited. Indeed, information in itself is a commodity (Kester, 1993, 77, 83). Universities have responded to the needs of the information-based capitalism of the global market, and as a result, they are central to the economic health of the state (Delanty, 2002, 185, 187-188).

The impact of these changes in the work model has serious implications for North Carolina's Eastern Region. Improvements to the infrastructure of a region and the building of state of the art industrial complexes like the Global TransPark will not attract corporations that need a large pool of skilled, flexible-tasking workers. The "One North Carolina Image" that the state wants to promote cannot be achieved when whole blocks of counties become marginalized by educational disparities, as has been the case in eastern North Carolina.

In a recent UNC Tomorrow Listening Forum held at Rocky Mount, residents attending the meeting concurred that only education can provide the bridge between the old and new economies, and that the out-migration of the region's bright students must end. The University of North Carolina needs to be accessible and affordable as it was originally mandated. The connections between K-12, community colleges, and the university should be seamless, and the UNC system needs to reach into rural communities through distance learning resources and satellite campuses to bridge the gap between a Fordist and Post-Fordist labor force (University of North Carolina, 2007).

## The Inland Port Success

Charlotte and Greensboro are inland ports, a concept pioneered by the North Carolina State Ports Authority in the 1980s. These Piedmont cities,

**Table 1.** Demographics of the counties of North Carolina's Eastern Region, formerly the GTP Development Zone. Source: US Census Bureau

| County | % Bachelor Degree | % Persons below poverty | % Unemployed | % Less then HS | Pop. Per Sq. Ml. | Median Income '04 |
|---|---|---|---|---|---|---|
| Greene | 8.2 | 20.2 | 7.3 | 34.6 | 71 | 32203 |
| Edgecombe | 8.5 | 19.6 | 9.6 | 34.4 | 110.1 | 32193 |
| Jones | 9.5 | 16.9 | 5 | 27.8 | 22 | 33326 |
| Duplin | 10.5 | 19.4 | 7.4 | 34.2 | 60 | 31893 |
| Lenoir | 13.5 | 16.6 | 8 | 28.1 | 149.1 | 32123 |
| Pender | 13.6 | 13.6 | 5.7 | 23.2 | 47.2 | 37394 |
| Pamlico | 14.7 | 15.3 | 5.7 | 24.8 | 38.4 | 35200 |
| Onslow | 14.8 | 12.9 | 6.9 | 15.7 | 196 | 34995 |
| Wayne | 15 | 13.8 | 6.3 | 22.8 | 204.9 | 35018 |
| Wilson | 15.1 | 18.5 | 7.2 | 30.6 | 199 | 34649 |
| Nash | 17.2 | 13.4 | 5.5 | 24.4 | 161.9 | 38394 |
| Craven | 19.3 | 13.1 | 5.3 | 17.9 | 129.1 | 39141 |
| Carteret | 19.8 | 10.7 | 5 | 17.9 | 114.2 | 40423 |
| Pitt | 26.4 | 20.3 | 6.8 | 20.1 | 205.2 | 35444 |
| Guilford | 30.3 | 10.6 | 5.5 | 17 | 648.8 | 42545 |
| New Hanover | 31 | 13.1 | 5.7 | 13.7 | 805.6 | 42579 |
| Watauga | 33.2 | 17.9 | 8.2 | 18.4 | 136.4 | 34165 |
| Mecklenburg | 37.1 | 9.2 | 5.2 | 13.8 | 1322.2 | 49683 |
| Durham | 40.1 | 13.4 | 5.1 | 17 | 770 | 44048 |
| Wake | 43.9 | 7.8 | 3.9 | 10.2 | 754.6 | 57846 |
| Orange | 51.5 | 14.1 | 3.7 | 12.4 | 295.6 | 46621 |

Counties of the former GTP Development Zone had a significantly higher percentage of individuals that had not completed high school than most of the top seven counties having the highest percentage of college graduates (in gray). Pitt County is the home of East Carolina University. Watauga County, home of Appalachian State University, has a small population. The population per square mile in the counties of North Carolina's Eastern Region is significantly less, with the percentage of unemployed and person living below poverty higher, than most of the counties with the highest number of college graduates. The median household income estimate in 2004 for North Carolina's Eastern Region is lower than the counties with high percentage of college graduates and higher population density per square mile.

**Table 2.** Correlation analysis of North Carolina Eastern Region county demographic data (from Table 1).

| | | % Bachelor Degree | % Persons below Poverty | % Unemployed | % Less then HS | Pop/mi$^2$. | Median Income '04 |
|---|---|---|---|---|---|---|---|
| % Bachelor Degree | *r* | 1 | -0.525(*) | -0.581(**) | -0.820(**) | 0.682(**) | 0.826(**) |
| | *p* | | 0.015 | 0.006 | 0.000 | 0.001 | 0.000 |
| | *n* | 21 | 21 | 21 | 21 21 | 21 | |
| % Persons below Poverty | *r* | -0.525(*) | 1 | 0.723(**) | 0.777(**) | -0.624(**) | -0.808(**) |
| | *p* | 0.015 | | 0.000 | 0.000 | 0.003 | 0.000 |
| | *n* | 21 | 21 | 21 | 21 | 21 | 21 |
| % Unemployed | *r* | -0.581(**) | 0.723(**) | 1 | 0.676(**) | -0.401 | -0.747(**) |
| | *p* | 0.006 | 0.000 | | 0.001 | 0.072 | 0.000 |
| | *n* | 21 | 21 | 21 | 21 | 21 | 21 |
| % Less then HS | *r* | -.820(**) | 0.777(**) | .676(**) | 1 | -.620(**) | -.793(**) |
| | *p* | 0.000 | 0.000 | 0.001 | | 0.003 | 0.000 |
| | *n* | 21 | 21 | 21 | 21 | 21 | 21 |
| Pop. Per mi$^2$ | *r* | .682(**) | -.624(**) | -0.401 | -.620(**) | 1 | .770(**) |
| | *p* | 0.001 | 0.003 | 0.072 | 0.003 | | 0.000 |
| | *n* | 21 | 21 | 21 | 21 | 21 | 21 |
| Median Income '04 | *r* | .826(**) | -.808(**) | -.747(**) | -.793(**) | .770(**) | 1 |
| | *p* | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | |
| | *n* | 21 | 21 | 21 | 21 | 21 | 21 |

* Correlation is significant at the 0.05 level (2-tailed).

** Correlation is significant at the 0.01 level (2-tailed).

When the complete Census data from Table 1 is analyzed using Pearson Correlation Coefficient, the most interesting correlation is that between population per square mile, median household income and a college education. This suggests that the division between the college educated and high school dropouts are more starkly defined in the low population density counties.

linked to the ports at Wilmington and Morehead City by rail, attract commerce from industries located in the interior and to the west. For these inland ports, the volume of international trade has increased since the 1980s, and they are now examples of the "large distribution-center business model," in which companies create large distribution facilities to serve a larger market and which is now the business standard. Cargo arrives and leaves the ports rapidly in containers that are off-loaded onto rail cars and trucks. True, large corporations, such as Lowe's and QVC, have located their distribution centers in the eastern counties of Northampton and Edgecombe (North Carolina State Ports Authority, 2007). The actual extent of the market influence of the ports extends to the Piedmont and beyond. Imports and exports at Morehead City and Wilmington represent a greater share of the state's economy than the output and consumption of their respective regions.

Manufacturing in North Carolina is diverse, divided between cutting-edge technology, durable goods, and traditional bulk commodities, such as phosphate. The export market for agricultural products, especially tobacco and cotton, persists. The significance of the ports is magnified by their connection to big inland distribution centers and high value manufacturers. The North Carolina Department of Commerce's *Profiles of Industry* features six key industries other than agriculture. They are "Biotechnology, Pharmaceuticals, and like Science, Business and Financial Services, Chemicals, Plastics and Rubber, Information and Communication Technologies, Motor Vehicles and Heavy Equipment, Textiles, Apparel, and Textile Machinery" (North Carolina Department of Commerce, 2008). Most of these contribute to the top twenty-five export categories.

An examination of the tonnage statistics for the Port of Morehead City from 1997 to 2006 shows that the major export from the port has been phosphate. Scrap metal, sulfur, rubber, and other bulky raw materials were consistently included in the top five commodities that were imported. The Port of Wilmington imports and exports more general merchandise. In 2006, the port exported 167,280 tons and imported 241,065 tons of general merchandise (North Carolina State Ports Authority, 2006). The US Census Bureau lists tobacco and related products as North Carolina's numbers one and two exports for the years 2003 through 2006. Between 2005 and 2006, leaf tobacco exports increased 60 percent from $419 million to $670 million. The number three export was turbo-aircraft parts, followed by blood products, integrated circuits, cotton, chemicals and wood pulp, enriched uranium, and machine parts. The remainder of the list includes a mix of items such as mechanical shovels, pharmaceuticals and motor vehicle parts (US Census Bureau, 2008). North Carolina has a mixed economy ranging from agriculture to the manufacturing of high value durable goods to biotech. It contributes to the domestic market and the global economy.

## Just-In-Time Distribution

Just-in-time manufacturing is the making of goods as they are demanded, rather than storing parts and goods in warehouses and filling orders from them. The nature of the just-in-time economy appears to have evolved into a concentration of inventory in geographically strategic locations within the existing transportation network. Consumer goods are sent to retail distributers to meet the specific demands for a product within a region or at a specific location. Items reach the shelves "just-in-time." The integration of a distribution center, parcel service, and a cargo airport appears to be more compatible with the "large distribution-center business model" for specific markets such as individual consumers, and special conditions like time sensitivity, low weight, and high value. Manufacturers serving a national or global market may increase efficiency by adjusting production to specific market demands, but the distribution center is more integrated into the multimodal transportation network.

The Aerotropolis mystique is based upon the reality that cargo aircraft can overcome the logistical friction of land and ocean and deliver goods as quickly as possible. However, there is little reason to believe that the existing regional airports of North Carolina, such as Charlotte/Douglas, Piedmont/Triad, Raleigh/Durham and smaller facilities in the eastern and western counties, are less able to handle an increase in the time sensitive goods of the global

Table 3. Population statistics for the counties of North Carolina's Eastern Region prior the construction of the GTP, and the most current population estimates. Source: Forstall, R. (1995). *North Carolina, Population of Counties by Decennial Census: 1900-1990*; US Census Bureau. (2008). *USA Counties*. http://censtats.census.gov

| County | Census 60 | Census 70 | Census 80 | Census 90 | Est. 06 |
|---|---|---|---|---|---|
| Jones | 11005 | 9779 | 9705 | 9414 | 10204 |
| Pamlico | 9850 | 9467 | 10398 | 11372 | 12785 |
| Greene | 16741 | 14967 | 16117 | 15384 | 20157 |
| Nash | 61002 | 59122 | 67153 | 76677 | 92312 |
| Duplin | 40270 | 38015 | 40952 | 39995 | 52790 |
| Edgecombe | 54226 | 52341 | 55988 | 56558 | 53964 |
| Lenoir | 55276 | 55205 | 59819 | 57274 | 57662 |
| Carteret | 30940 | 31603 | 41092 | 52556 | 63584 |
| Wilson | 57716 | 57486 | 63132 | 66061 | 76624 |
| Craven | 58773 | 62554 | 71043 | 81613 | 94875 |
| Wayne | 82059 | 85408 | 97054 | 104666 | 113847 |
| Pitt | 69942 | 73900 | 90146 | 107924 | 145619 |
| Onslow | 82706 | 103126 | 112784 | 149838 | 150673 |

economy than a dedicated facility like the Global TransPark. In the decade that the state searched for clients for the cargo airport, the existing regional airports upgraded their services and attracted business. Air transport does not supplant rail, highway, and ocean transport. The economy of the state is not based upon the production of high-value, low weight, time-sensitive items exclusively. There is still a global demand for traditional agricultural products, bulky mineral and forest products, and heavy machinery. The ports, railroads, and trucking companies have established profitable alliances. The multimodal distribution based model has worked in practice and includes a broad range of products, whereas the dedicated airport city concept depends upon certain classes of manufactured items, such as those with high value and low weight. It is also dependent upon the presence of a large pool of a certain class of workers, the highly skilled and educated. The major manufacturing that will soon take place at the TransPark is unique. While the Piedmont can supply more than its share of trained individuals to assemble computers, dispatch parcels, manage records, develop software, and test pharmaceuticals, there is a high concentration of military facilities in the east and Cape Fear region training people to handle and maintain aircraft. There are universities in the region that graduate a sufficient number of highly trained professionals, even though most of the Ph.D. programs are located in the Piedmont. In addition, locating the Spirit AeroSystems facility in space-hungry Raleigh, Greensboro, or Charlotte would not have been advantageous.

## Conclusion

North Carolina's Eastern Region has few college educated residents, and unfortunately the demands of the present economy require workers that can perform "high trust" tasks. The press quickly identified the more obvious planning errors that plagued the Global TransPark during its early years. It is easy to speculate that had it been located in another region it might have fared better. However, the location, with its proximity to the ports and available growth space, is appropriate for a specific class of manufacturing, and might prove to be a resounding success against the odds in the future. The glaring fact remains that the time when a person could secure life-long employment with a high school education is past. All the superlatives bandied about by the planners of the TransPark – state of the art, high tech, just-in-time, agile manufacturing – depend on the "knowledge class." Politicians, planners, and educators frenquently refer to the nation's place in the global economy, but rarely cast a critical eye on its future development. There are no guarantee that the present economic landscape will remain stable. It is an experiment in so far as nothing like it has existed before.

In the early nineteenth century, every part of the state was enthralled by visionary schemes for canals and railroads. Nathaniel Macon, North Carolina's venerated elder statesman in its early years, steadfastly held to his conviction that the state would be better off if it applied its treasure towards advancing public education and its university rather than follow the commercial fads of the day (Dodd, 1903, 388). He was so right. In the present fast-paced world of global capitalism, commercial fads come and go rapidly. Yesterday it was the Aerotropolis, today it is the large distribution-center business model, and tomorrow the cost of petroleum products will lead to some other business paradigm. It is certain that agile minds will be required to meet the challenges. In addition, it is both ridiculous and socially unacceptable to promote conditions that accelerate the migration of college graduates from the east and west to the Piedmont. Recent experience has made it apparent that water resources in the Piedmont are becoming a serious weakness for industry in the region. The present drought has persisted, and if it is long term, as predicted, the limits of this critical resource will prompt planners to encourage growth elsewhere. From a political standpoint, the economic marginalization of any one section of the state will interfere with any state plan for economic improvements. North Carolina's one hundred counties are divided into four distinct regions with uneven population totals. The regions can align against state policy decisions that they perceive to benefit one region while the others pay for it. Slighted regional centers, like Fayetteville during the "buffalo hunts," might adopt the "go it alone" strategies that will undermine well-intentioned policy in the future. Finally, the recent developments with the TransPark indicate that North Carolina's Eastern Region is an appropriate location for certain high tech manufacturing.

Success or failure, the TransPark history cannot be removed from the region it was intended to improve. Without the aid of improvements in the access to education, the region will not provide workers for the economic landscape of today or tomorrow. The region needs "just-in-time" access to higher education. The University of North Carolina and the North Carolina Community College System will have to find a way of delivering it – with or without walls. Joseph Caldwell, first president of the University of North Carolina expressed similar thoughts in 1832 that are appropriate for the counties of the east today.

> How can we imagine that a people like ourselves, living in an age of knowledge everywhere distributed through a thousand channels, can continue indifference to its opportunities? (Coon, 1908, 557)

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# North Carolina's Final Coastal Frontier: Land Cover Change in the Inner Banks, 1996-2001

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North Carolina's coastal region has a long history of development that is most concentrated in oceanfront regions such as the Outer Banks and other barrier island beach communities. As land becomes scarce in oceanfront regions, interior coastal zones have the potential to act as outlets to absorb development pressure related to amenity, retirement, and working-age in-migrants. A recent news article published in 2006 claims that this process is already underway and that the interior coast is experiencing an inland "coastal boom". I define the Inner Banks as a new regional entity and examine the inland coastal boom theme by addressing two questions: (1) What are the patterns of net land cover change?, and (2) What are the most important types of land cover change?. Using 1996 and 2001 NOAA land cover data, I employ change analysis techniques involving analysis of the land cover transition matrix. Results indicate a small net gain in developed land area. However, of this gain, there is a strong signal of conversion from forest and scrub in 1996 to developed by 2001. Results are disaggregated from the entire Inner Banks region to the county level to map and report results which demonstrate substantial geographic variation with highest gains in developed area occurring in Carteret, Craven, Hertford, Chowan, and Pasquotank counties. If the Inner Banks is indeed North Carolina's final coastal frontier, then population growth and land development during the next decades have the potential to dramatically alter the region's land cover, ecosystems, economy, and cultural sense of place.

## Introduction

A recent headline regarding land use and development in coastal North Carolina proclaimed that the "coastal boom moves inland" (Price 2006). The news article continued to describe a region undergoing tremendous change along the state's 3,000 miles (approximately 4,800 km) of estuarine waterfront. This inland coastal region historically has been lightly populated and economically lagging compared to neighboring barrier island oceanfront communities and large metropolitan areas located in the piedmont such as the Triangle (Raleigh, Durham, Chapel Hill), Triad (Greensboro, Winston-Salem, High Point), and metropolitan Charlotte. Intensive development has been present in North Carolina's barrier islands, including the Outer Banks, for decades resulting in land scarcity and high property prices. The proclaimed inland coastal boom, though certainly of lower magnitude than Outer Banks development, arguably represents a new and final frontier of coastal development in North Carolina with potential impacts on the region's rich natural resource base, economy, and sense of place. The objective of this paper is to characterize land cover change for North Carolina's inland estuarine region, defined here as the "Inner Banks", over the years 1996 to 2001 thereby providing a baseline analysis of inland coastal change that can be tracked during subsequent years to help monitor the magnitude and effects of the "coastal boom".

Land use and land cover change research is situated within the context of an emergent land change science that has matured as a fundamental element of global environmental change and sustainability science (Rindfuss et al. 2004). Geospatial information technology, GIS and remote sensing approaches underpin much of land change science. A common initial approach is to map land cover pattern at two or more time periods via classification of satellite imagery and to quantify net amounts and rates of change. The land cover transition matrix is the fundamental starting point that is used to identify patterns of net change. For example, what was the net gain or loss of developed, agriculture, forest, wetland or other land classes? Moving beyond net change, inspection of inter-category change (e.g. agriculture-to-developed, forest-to-wetland, etc.) can reveal more detailed information regarding specific from-to trajectories, or signals, of change. A danger with this approach is that researchers may fail to distinguish between random signals and the more important systematic signals of change that suggest key processes responsible for landscape dynamics. A methodological advance towards analysis of the transition matrix introduced by Pontius et al. (2004) and described in more detail below enables such discrimination (see also Braimoh 2006).

This paper introduces a regional definition of the Inner Banks and characterizes land cover change within the Inner Banks by analyzing a transition matrix derived from a multi-temporal land cover product obtained from NOAA and by employing a GIS-based methodology to answer the following research questions:

1. What was the net areal change for defined land cover classes in the Inner Banks during the period 1996-2001?

2. What were the most important systematic signals of conversion from non-developed to developed land?

## Study Area

The study area is comprised of parts or the whole of 16 counties that border North Carolina's estuarine shoreline (Figure. 1) comprising the Inner Banks. Barrier island portions for 4 of the 16 counties, Carteret, Currituck, Dare, and Hyde, were excluded in order to focus analysis specifically on the interior coastal region. The non-profit corporation Foundation for Renewal of Eastern North Carolina (FoR ENC) is actively marketing and promoting this region as the "Inner Banks" through a recent branding campaign. As part of this campaign, For ENC markets an "IBX" window sticker and has produced promotional public service announcements and videos to promote the Inner Banks as a regional entity. Local communities are beginning to self-identify with the Inner Banks. For example, the town of Washington's web site encourages visitors to "Return to the Heart of the Inner Banks" (Washington Visitor Information, 2008).

In addition to regional branding, a goal of FoR ENC is to promote entrepreneurial and economic growth by highlighting the "creative economy" (Florida, 2002) and the attraction interior coastal amenities. Part of FoR ENC's mission statement states:

> The Foundation of Renewal for Eastern North Carolina (FoR ENC) is a vehicle for change in one of America's most underserved regions, a non-profit "merchant bank" that trades in intellectual capital as much as in financial capital. FoR ENC is designed to serve as a catalyst for economic and entrepreneurial growth in Eastern North Carolina. FoR ENC blends the best practices of the for-profit and non-profit sectors to facilitate the process of renewing the economy across the region. This process includes identifying, developing, and energizing citizens and organizations across Eastern North Carolina and challenging our disparate parts to work as a whole to build a leadership base for the future of the region. (FoR ENC, 2008)

Preliminary data exploration and regional familiarity suggest that counties located north of the Albemarle Sound are functionally connected to the Virginia Beach-Norfolk-Newport News MSA located nearby in southeastern Virginia. This north-

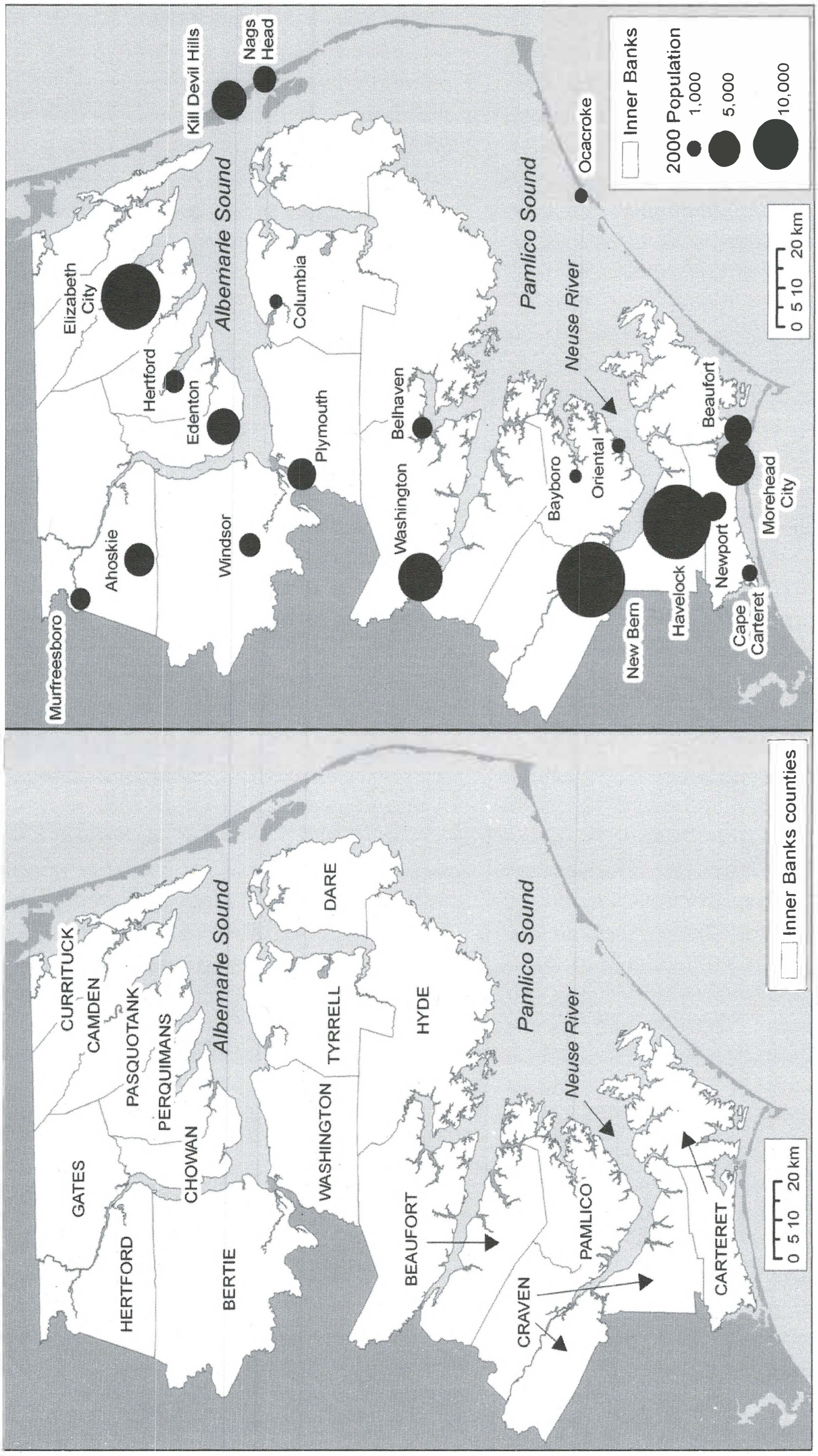


**Figure 1**. Inner Banks study area. Arrows by selected county names indicate county areal extents.

ern tier (Table 1) of the IBX is a destination for exurban working-age migrants who commute to the MSA and retirement age migrants from the MSA and elsewhere. Elizabeth City (Pasquotank County) is this tier's largest city. Population growth is exerting development pressure within these counties as land must be converted to accommodate new arrivals and as local governments work to provide required infrastructures and services. These pressures are evidenced by the fact that in 2007 Camden County enforced a temporary moratorium on new development due to exorbitant growth pressure. Also, during a field interview during the summer of 2006, the mayor of Hertford (Perquimans County) described challenges in regional planning related to in-migration specifically mentioning the large influx of "halfbacks" – a colloquial term for northeast retirement migrants who move initially to Florida and subsequently to North Carolina, or "halfway back". The apparent reason for such "halfback" moves is dissatisfaction with Florida as a residential location for selected retirement migrants. South of the Albemarle Sound, the central tier of the IBX borders the Albemarle and Pamlico sounds. This tier is the least populated, and counties include Washington, Tyrell, Hyde, the mainland portion of Dare, and the northern half of Beaufort. Washington (Beaufort County) is this tier's largest city. The southern tier borders the Neuse River and Pamlico Sound and counties consists of Craven, Pamlico, the mainland portion of Carteret, and the southern half of Beaufort. New Bern (Craven County) is its largest city, and its surrounding region is actively marketed and recognized as a retirement destination hotspot. Inland coastlines and waters act as amenity attractions. For example, Oriental (Pamlico County) is self-promoted as the "sailing capital of North Carolina" (Town of Oriental, 2008). The southern tier is also home to a substantial military population oriented towards Marine Corps Air Station Cherry Point in Craven County and Camp Lejeune (Marine Corps) in nearby Onslow County. Many Camp Lejeune personnel stationed in Onslow County locate residentially in the adjacent Carteret County.

Table 1 summarizes population growth patterns for 1990-2000 by regional tier and county. The highest population and growth is in the southern tier followed closely by the northern tier. The central tier has a substantially smaller population and growth rate. Population growth for the entire state of North Carolina during the same period was 21.4%. Large portions of this state-wide growth are concentrated in the large metropolitan regions such as Charlotte and the Triangle. Inner Banks growth is geographically uneven among the three tiers and collectively is lower than growth for the state a whole.

Ecologically, the Inner Banks forms the core of the Albemarle-Pamlico Estuary System, the second largest estuary system in the US after the Chesapeake Bay. It provides habitat for the largest population of black bear within North Carolina and the recently reintroduced red wolf. It is a major habitat for waterfowl and migrating birds. The annual bird migration is an important tourist attraction of the region. Much of the region is characterized by large low-lying areas (< 2 m elevation) with gentle slopes, low-gradient streams, and poorly drained soils (Moorhead and Brinson, 1995). In terms of area, wetlands is the largest land cover class and predominates in the eastern IBX and riparian zones, followed in magnitude by forest which is more prevalent in the west (Figures 2 & 3). While humans historically have made substantial modifications (naval stores industry, drainage projects, agriculture), the region houses a rich natural resource base whose environmental amenities act as an attraction for in-migrants, second home owners, and tourists. The developed built environment forms a small percentage of the IBX landscape (Figure 4) which has its highest levels in the southern Inner Banks associated with cities such as New Bern, Havelock, Morehead City, and Beaufort.

## Data and Methods

NOAA's Coastal Change and Analysis Program (C-CAP) is a nationally standardized database of land cover and land change information, developed using Landsat remotely sensed imagery (NOAA, 1995). Gridded land cover data (30 m resolution) were extracted from the 1996 and 2001 C-CAP land cover products (NOAA Coastal Services

**Table 1.** Population change, 1990-2000.

| County | 1990 | 2000 | % change |
|---|---|---|---|
| ***Northern Tier*** | ***125,455*** | ***135,518*** | ***8.0*** |
| Bertie | 20,388 | 20,044 | -1.7 |
| Camden | 5,904 | 6,885 | 16.6 |
| Chowan | 13,506 | 14,526 | 7.5 |
| Currituck* | 12,290 | 16,152 | 31.4 |
| Gates | 9,305 | 10,113 | 8.7 |
| Hertford | 22,317 | 21,533 | -3.5 |
| Pasquotank | 31,298 | 34,897 | 11.5 |
| Perquimans | 10,447 | 11,368 | 8.9 |
| ***Central Tier*** | ***45,881*** | ***69,069*** | ***4.8*** |
| Beaufort** | 42,283 | 44,958 | 6.3 |
| Dare* | 1,024 | 1,182 | 15.4 |
| Hyde | 4,721 | 5,057 | 7.1 |
| Tyrrell | 3,856 | 4,149 | 7.6 |
| Washington | 13,997 | 13,723 | -2.0 |
| ***Southern Tier*** | ***135,796*** | ***151,516*** | ***11.6*** |
| Carteret* | 42,811 | 47,146 | 10.1 |
| Craven | 81,613 | 91,436 | 12.0 |
| Pamlico | 11,372 | 12,934 | 13.7 |

Source: US Census, 1990 and 2000.
* Barrier island population excluded.
** Beaufort County counted entirely as Central Tier.

Center, 2007). Generalization of C-CAP's original classification scheme yielded the following land cover classes used for analysis: developed, agriculture, forest, scrub, wetlands, and other. The "other" class consisted largely of large inland lakes (e.g. Lake Mattamuskeet). The "scrub" class is defined as areas dominated by shrubs less than 5 meters tall with shrub canopy typically greater than 20 percent of total vegetation and includes tree shrubs, young trees in early successional stage, or trees stunted from environmental conditions. A raster combine function was then applied to the two generalized land cover grids to create a single "change" grid representing, on a per pixel basis, land cover categories for both dates with which patterns of change can be analyzed.

Analysis of change was conducted initially through construction of a traditional transition matrix (Table 2). Interpretation of the matrix is straightforward with elements $c_{ij}$ ($i$ does not equal $j$) indicating proportions (percents) of the landscape transitioning from class $i$ to class $j$, for example a change from forest ($i$) to developed ($j$) denoted by $c_{31}$. More simply, the $ij$ notation refers to a specific from-to land cover change magnitude reported as the percent of the total landscape area. Elements of the main diagonal, $c_{jj}$, indicate proportions of land classes that did not change, or *persistence*. Total percentages per class in 1996 and 2001 are indicated in the Total 1996 column and Total 2001 row respectively. Total losses per class in 1996 and gains per class in 2001 are indicated in the Loss column and Gain row respectively.

Following Pontius et al. (2004), identification of systematic inter-category transitions requires computing both expected gains and losses for each class pair assuming a random process of gain and loss. Expected gain for class pair $i$ and $j$ is defined as:

$$g_{ij} = \left(c_{+j} - c_{jj}\right)\left(\frac{c_{i+}}{100 - c_{j+}}\right), \forall i \neq j$$

This formulation assumes that the amount of class $j$ gain from a specified class $i$ and the study area's proportion of class $i$ during 1996 are empirically given. The empirically observed gain is then distributed to come from the other $j$ categories ac-

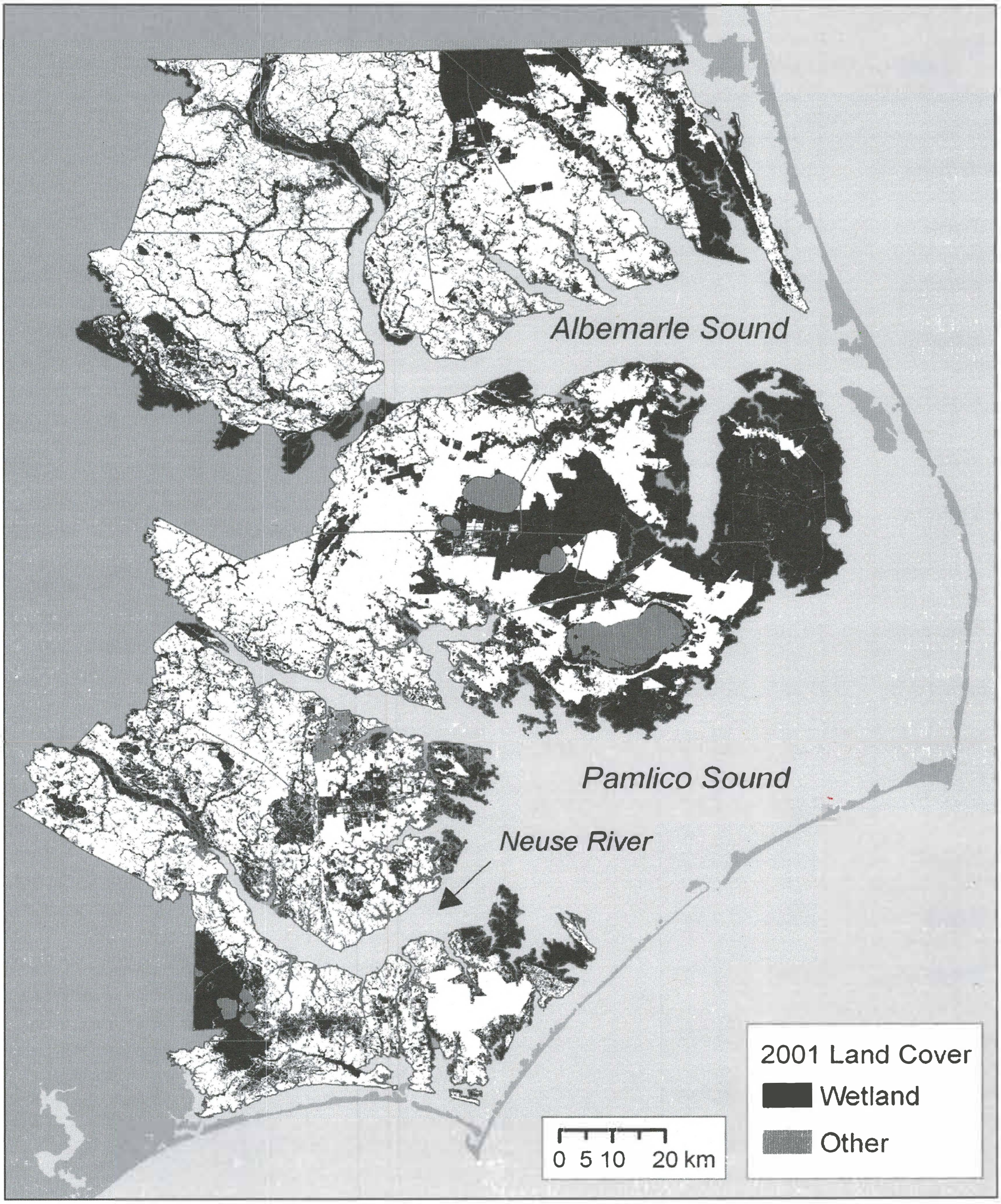


**Figure 2.** 2001 land cover: wetland and other. Source: derived from NOAA-CCAP.

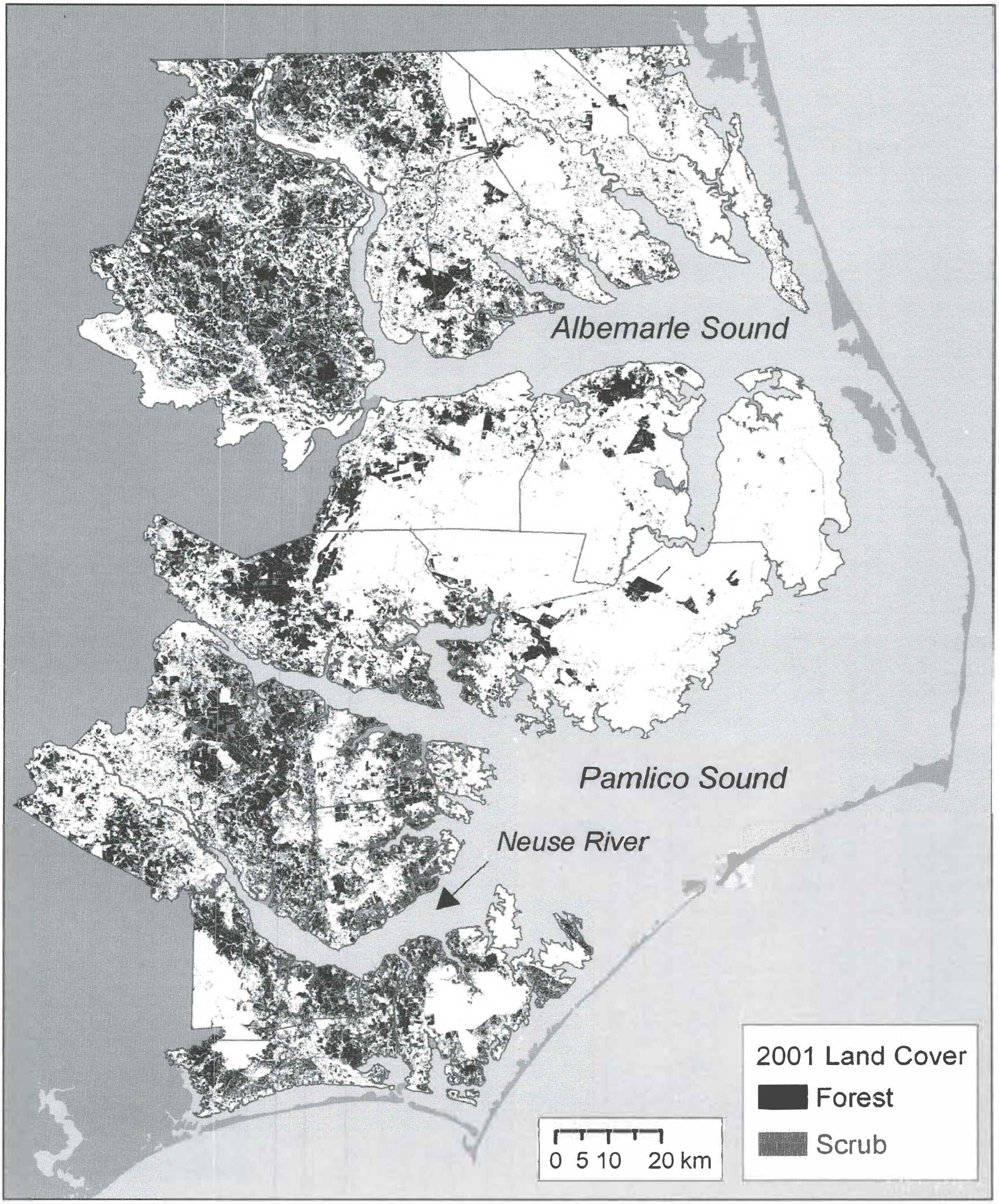


Figure 3. 2001 land cover: forest and scrub. Source: derived from NOAA-CCAP.

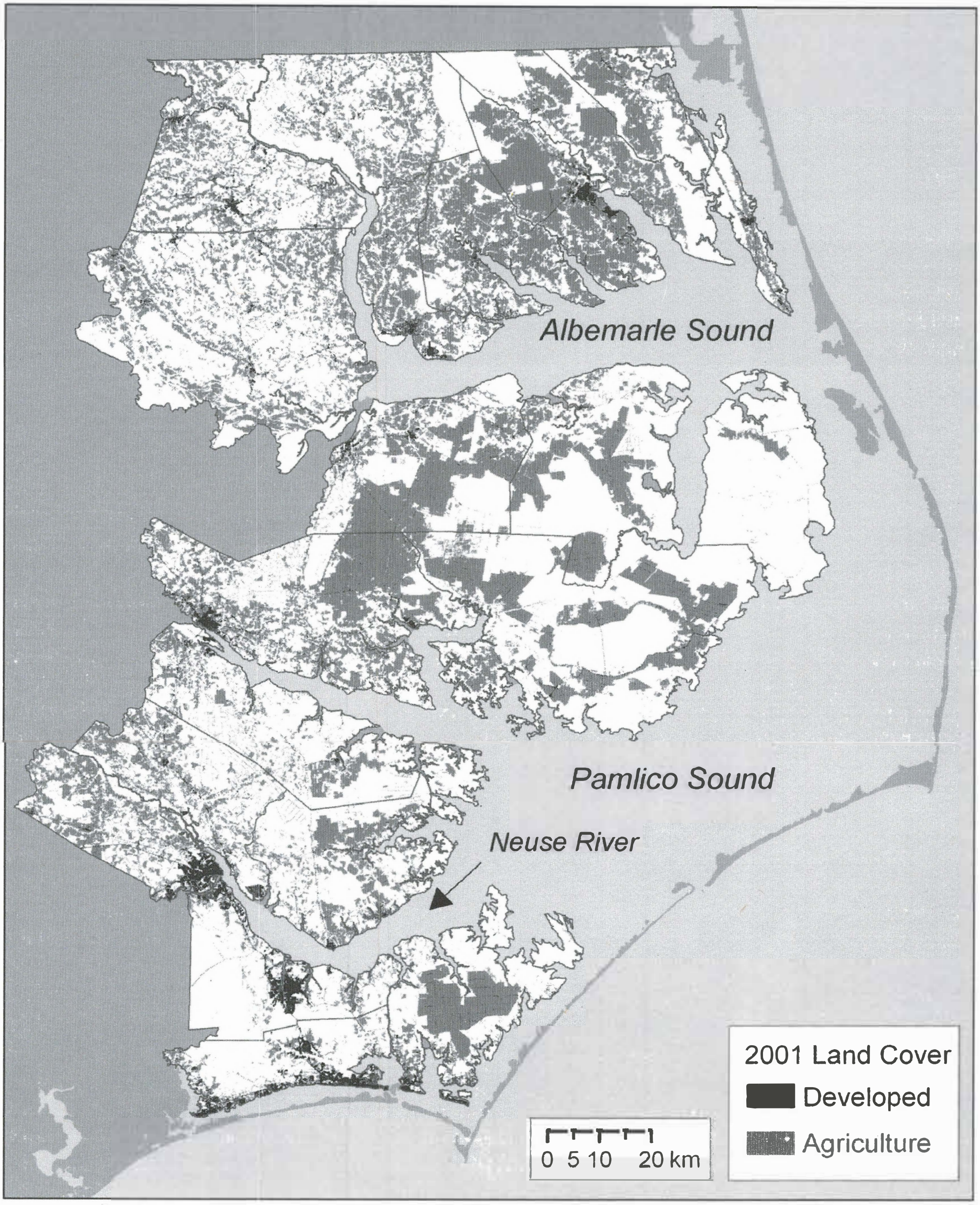


**Figure 4.** 2001 land cover: developed and agriculture. Source: derived from NOAA-CCAP.

cording to their relative proportions in 1996. This represents a random process of gain by ensuring that, for a gaining class, gains from other classes are proportional to how the other classes populated the study area in 1996. For diagonal entries, expected gain is set equal to observed gain in order to hold persistence constant and thereby examine off-diagonal transitions given the observed level of persistence.

In a similar fashion, expected loss under a random process for class pair *ij* is defined as:

$$l_{ij} = (c_{i+} - c_{ii})\left(\frac{c_{+j}}{100 - c_{+i}}\right), \forall i \neq j$$

This assumes that the loss of each class is given. The observed loss is then distributed among the other categories according to their relative proportions in 2001.

Given the focus on change for the "developed" land class, subsequent analysis focuses largely on this single category. Additionally, since there was no loss of land identified as developed in 1996 (i.e. the developed class only experienced gains from other classes) analysis was further limited mainly to inspection of gains in development from 1996 to 2001.

For each from-to transition, the difference between the empirically observed gain and the expected gain under a random process are calculated via simple subtraction and is defined as observed gain minus expected gain. An interpretation is that a large positive deviation between observed gain and expected gain indicates a systematic propensity for class *i* (e.g. developed) to gain from class *j* (i.e. one of the previously non-developed classes). A large negative deviation indicates a systematic propensity for class *i* to avoid gaining from class *j*. Caution should be taken when comparing the raw magnitudes of deviations due to the fact that larger areal classes in 1996 would be expected under a random process of change to have larger deviations due simply to the fact of their larger areal size. For example, if forest area is five times larger than scrub area in 1996, then under a random process the expected gain in developed from forest should be five times larger than the expected gain in developed from scrub. This can result in a larger raw deviation for the forest-to-developed class pair due solely to forest's originally large areal size in 1996. To enable valid comparison, a final step normalizes the deviations of the empirically observed gain from the expected gain by dividing by the expected gain to create a normalized deviation ratio which is defined as $(c_{ij} - g_{ij})/g_{ij}$. As a hypothetical example, if the observed gain in developed from forest ($c_{ij}$) is 0.10% and the expected gain ($g_{ij}$) is 0.05%, then the deviation ratio is: (0.10 – 0.05) / 0.05 = 1.00. An interpretation is that developed gained 100% more from forest than would be expected randomly – or the developed class gained two times more from the forest class than expected. If the observed gain in developed from forest ($c_{ij}$) is 0.05% and the expected gain ($g_{ij}$) is 0.10%, then the deviation ratio is: (0.05 – 0.10) / 0.10 = -0.50. In this case the developed class gained 50% less from the forest class than would be expected randomly, or half as much as expected.

## Results

Land cover percentages and net change were extracted from the computed transition matrix (Table 3). Wetlands, agriculture, and forest were the largest classes for both years. Developed land increased from 2.42% to 2.55% of the study area for a net change of 0.13 percentage points – a net change that was the second smallest in raw magnitude. Note however, that a simple focus on raw net change may mask important systematic patterns of change that more detailed analysis of the transition matrix is designed to capture as described above in the methods. Mindful of this caveat, the two largest net changes were for forest (-1.65) and scrub (1.24). It is likely that this represents a transition between these two classes with selected forest sites being cleared since 1996 and appearing as scrub in the 2001 classification. Additionally, given the originally large areas of agriculture and forest in 1996, their raw net changes, while large compared to net change for developed area, most likely indicates fairly stable land cover proportions for agriculture and forest. Focusing on the developed class, a summary of net

**Table 2.** Derivation of a land cover transition matrix (percents).

| | 2001 | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 1996 | Developed | Agriculture | Forest | Scrub | Wetland | Other | Total 1996 | Loss |
| Developed | $c_{11}$ | $c_{12}$ | $c_{13}$ | $c_{14}$ | $c_{15}$ | $c_{16}$ | $c_{1+}$ | $c_{1+} - c_{11}$ |
| Agriculture | $c_{21}$ | $c_{22}$ | $c_{23}$ | $c_{24}$ | $c_{25}$ | $c_{26}$ | $c_{2+}$ | $c_{2+} - c_{22}$ |
| Forest | $c_{31}$ | $c_{32}$ | $c_{33}$ | $c_{34}$ | $c_{35}$ | $c_{36}$ | $c_{3+}$ | $c_{3+} - c_{33}$ |
| Scrub | $c_{41}$ | $c_{42}$ | $c_{43}$ | $c_{44}$ | $c_{45}$ | $c_{46}$ | $c_{4+}$ | $c_{4+} - c_{44}$ |
| Wetland | $c_{51}$ | $c_{52}$ | $c_{53}$ | $c_{54}$ | $c_{55}$ | $c_{56}$ | $c_{5+}$ | $c_{5+} - c_{55}$ |
| Other | $c_{61}$ | $c_{62}$ | $c_{63}$ | $c_{64}$ | $c_{65}$ | $c_{66}$ | $c_{6+}$ | $c_{6+} - c_{66}$ |
| Total 2001 | $c_{+1}$ | $c_{+2}$ | $c_{+3}$ | $c_{+4}$ | $c_{+5}$ | $c_{+6}$ | 100 | |
| Gain | $c_{+1} - c_{11}$ | $c_{+2} - c_{22}$ | $c_{+3} - c_{33}$ | $c_{+4} - c_{44}$ | $c_{+5} - c_{55}$ | $c_{+6} - c_{66}$ | | |

change by county (Figure. 5) reveals geographic variation with northern and southern tier counties experiencing the largest net gains of developed area in terms of percentage point gains.

The empirical transition matrix reports percents of from-to change for every class pair (Table 4). To focus analysis on growth of developed land area, the full matrix was subsetted to include only transitions involving conversion of non-developed classes to the developed class and was expanded to also report: expected gain, deviations between observed and expected gain, and the normalized deviation ratio (Table 5). Recall that there were no instances of the developed class converting to the agriculture, forest, scrub, wetland, or other classes. For empirically observed gain, the developed class gained the most from forest followed by gains from agriculture, scrub, and wetland. However, inspection of the normalized deviation ratios reveals that the strongest positive signal of change was for scub-to-developed followed by forest-to-developed. Thus, there was a systematic propensity for scrub and forested land to convert to developed. Agriculture-to-developed had a negative ratio indicating a systematic propensity for developed to avoid gaining from agriculture even though this transition had the second highest empirically observed magnitude. There was an even stronger propensity for developed to avoid gaining from wetland as is evident from the fact that the wetland-to-developed transition had the largest negative ratio.

Results for the entire IBX region presented above were disaggregated and mapped at the county level in order to describe geographic patterns of changes. A threshold deviation ratio of 0.20 was employed to identify counties depicted with thick boundaries that exhibited a systematic propensity for developed area to gain from agriculture, forest, and scrub. Systematic transitions from agriculture-to-developed were clearly concentrated in the northern tier counties (Figure 6a). Transitions from forest-to-developed occurred widely throughout the IBX region in all three tiers (Figure 6b). Transitions from scrub-to-developed were present in only the central and southern tiers (Figure 6c). Every county had a negative ratio for the wetlands-to-developed transition indicating the aforementioned avoidance of gain in developed from wetlands. To highlight the strength of this avoidance, a threshold deviation of -0.90 was employed (i.e. counties with a ratio less than or equal to -0.90). Results show that northern tier counties had the strongest tendency to avoid conversion of wetlands to developed (Figure 6d).

## Discussion

Transition matrix analysis techniques provided answers to two main research questions. Focusing on change for developed land area, developed area grew from 2.42% to 2.55% of the Inner Banks study area over the period 1996-2001 for a net change of 0.13 points. While this net change was lower than net change for most other classes, transition matrix analysis involving calculations of expected change under a random process revealed more nuanced information pointing to systematic signals of conversion. Deviations ratios showed that the major processes of conversion involved shifts from forest and scrub to developed. While conversion from agriculture to developed had the second highest magnitude, its negative deviation ratio suggests that this type of transition was not as important as conversion from forest or scrub. However, a caveat is that land classified as scrub in 1996 may in fact have been old agricultural land that was not being cultivated and consequently appeared as scrub in the NOAA C-CAP land cover product. For example, tobacco farms that have been taken out of production may undergo vegetative succession and eventually be sold to developers for conversion to residential development by 2001. Thus, agricultural conversion may play a more prominent role in land cover change for the Inner Banks than suggested by a simple focus on transition matrix results. Geographically, conversion from agriculture was more pronounced in the northern tier, conversion from forest was distributed among all three tiers, and conversion from scrub was more pronounced in the central and southern tiers.

The vast majority of land cover (95%) experienced no change during the 1996-2001 period. This study period may slightly precede or represent the early beginnings of the inland "coastal boom" re-

**Table 3.** Land cover percents and net change.

| Class | % 1996 | % 2001 | Net Change |
|---|---|---|---|
| Developed | 2.42 | 2.55 | 0.13 |
| Agriculture | 29.47 | 29.97 | 0.51 |
| Forest | 23.03 | 21.38 | -1.65 |
| Scrub | 5.72 | 6.96 | 1.24 |
| Wetland | 36.77 | 36.51 | -0.26 |
| Other | 2.59 | 2.62 | 0.04 |

ported in the Raleigh News & Observer (Price 2006). In fact, it would be surprising to find high levels of change over such a short period for a largely undeveloped, geographically remote, and lightly populated region like the Inner Banks. It is indeed common in land change research to find high levels of persistence. Persistence levels in Wear and Bolstad (1998) and Pontius et al. (2004) for five different study regions ranged from 69% to 90%, although these studies ranged over 20 year periods. Despite the low quantities of change, the methods employed here enabled nuanced identification of systematic signals of change focusing specifically on conversion to developed land.

The idea of "inland boom" warrants further comparative research with other coastal or inland regions to place these rates in context. Certainly rates for high growth metropolitan regions experiencing suburbanization will outpace rates for the Inner Banks, a relatively undeveloped region. However, this does not diminish the fact that systematic land cover change occurred during 1996-2001 as revealed in this baseline analysis. Results warrant continued monitoring of the Inner Banks during the present decade for which media coverage and anecdotal evidence is suggesting more dramatic transitions. If the Inner Banks is indeed North Carolina's final coastal frontier, then population growth and land development during the next decades have the potential to dramatically alter the region's land cover, ecosystems, economy, and cultural sense of place.

Another interior coastal region of North Carolina that is experiencing change is Brunswick County which is located in the southern part of the Wilmington metropolitan area and is adjacent to the Myrtle Beach metropolitan area in South Carolina. Similar to the Outer Banks, the barrier island portion of Brunswick County is highly developed. Retirees have been particularly attracted to this region due to various environmental amenities as well as cultural and economic amenities associated with the neighboring metropolitan centers. In fact, some observers have referred to the region using the moniker "Retirement Alley." Interior land area within the county acts as a spatial outlet to absorb in-migration and development pressure. Land transition in Brunswick County is further along than transitions in most of the Inner Banks; however, there are likely similarities among many of the driving processes. Thus, sustained monitoring and comparative research of both the Inner Banks and other interior coastal regions such as Brunswick County that may be at different historical stages of development is likely to yield rich insights regarding patterns, processes, and consequences of coastal land cover change.

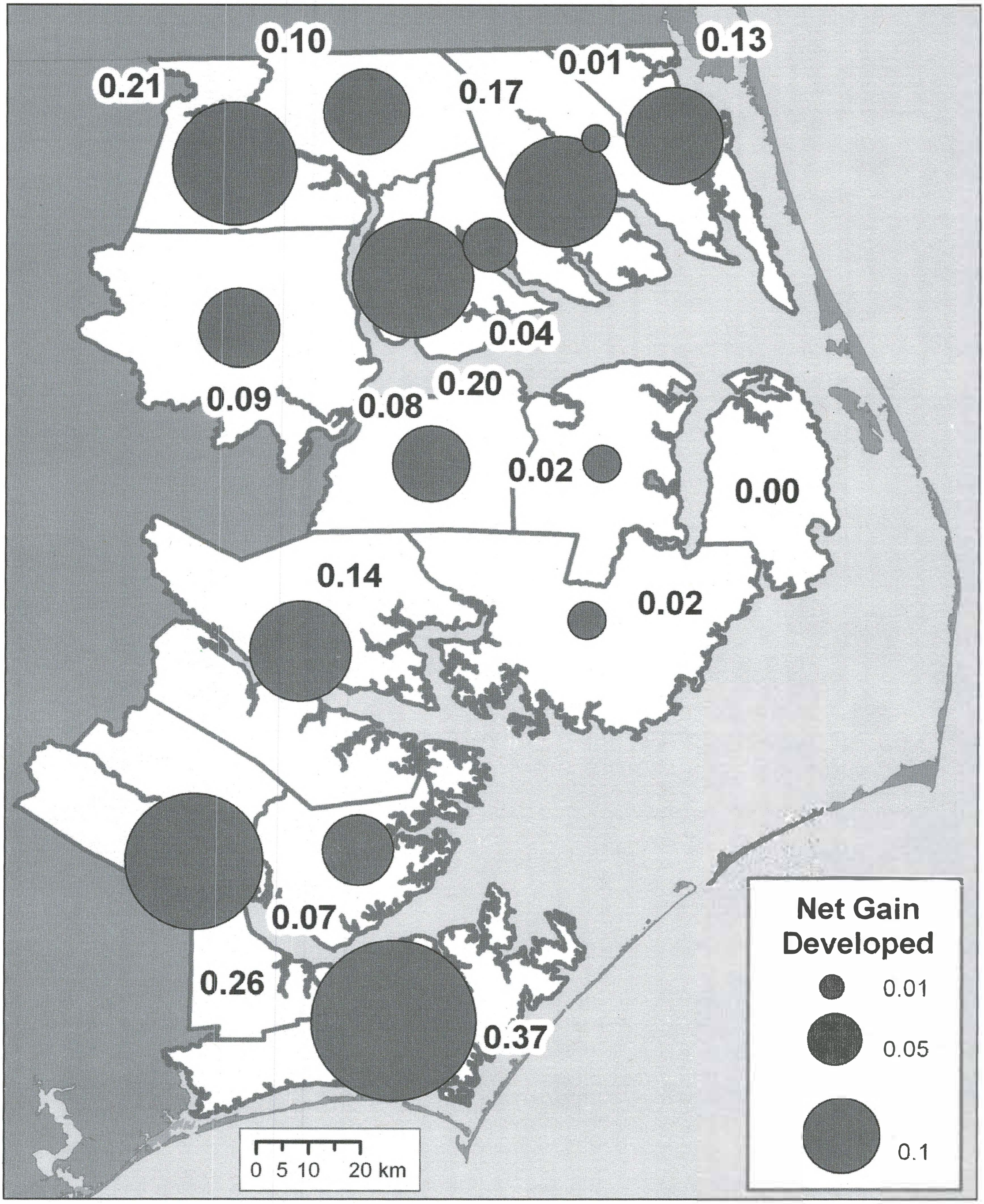


**Figure 5.** Net gain in developed land area by county, 1996-2001.

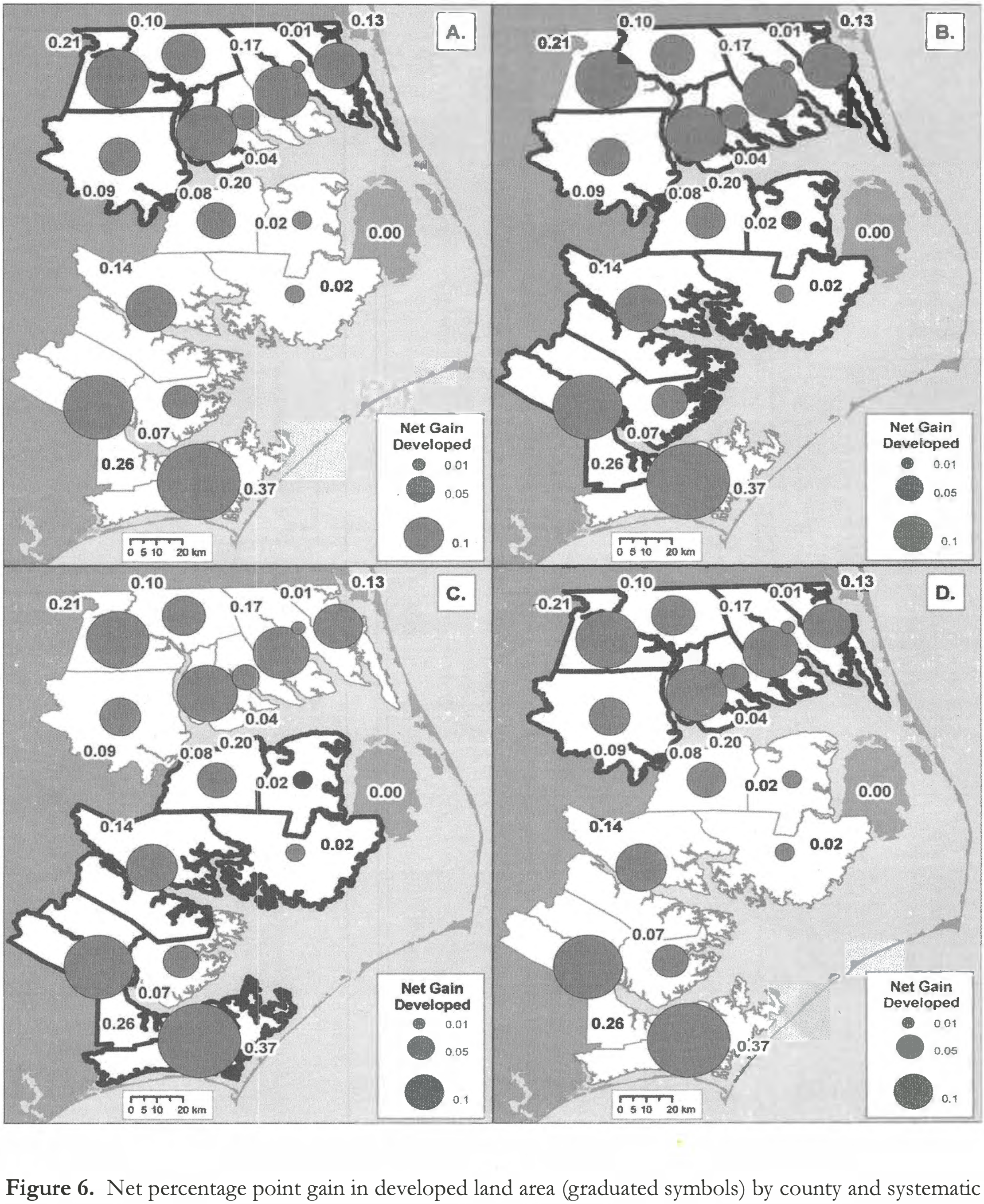


**Figure 6.** Net percentage point gain in developed land area (graduated symbols) by county and systematic and cover transitions (thick black boundaries): (a) agriculture-to-developed, (b) forest-to-developed, (c) scrub-to-developed, (d) wetland-to-developed (systematic avoidance of change).

**Table 4.** Empirical land cover transition matrix (percents).

| 2001 | Developed | Agriculture | Forest | Scrub | Wetland | Other | Total 1996 | Loss |
|---|---|---|---|---|---|---|---|---|
| 1996 | | | | | | | | |
| Developed | 2.42 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 2.42 | 0.00 |
| Agriculture | 0.03 | 28.52 | 0.08 | 0.51 | 0.31 | 0.02 | 29.47 | 0.95 |
| Forest | 0.06 | 0.96 | 20.64 | 1.23 | 0.13 | 0.02 | 23.03 | 2.39 |
| Scrub | 0.02 | 0.12 | 0.56 | 4.94 | 0.07 | 0.01 | 5.72 | 0.79 |
| Wetland | 0.02 | 0.36 | 0.10 | 0.28 | 35.98 | 0.03 | 36.77 | 0.79 |
| Other | 0.00 | 0.01 | 0.00 | 0.01 | 0.02 | 2.54 | 2.59 | 0.05 |
| Total 2001 | 2.55 | 29.97 | 21.38 | 6.96 | 36.51 | 2.62 | 100.00 | |
| Gain | 0.13 | 1.45 | 0.75 | 2.03 | 0.53 | 0.08 | | |

**Table 5.** Expanded land cover transition matrix for conversion from non-developed to developed (conversion from Other to Developed omitted).

| 1996 | 2001 Developed | |
|---|---|---|
| Agriculture | 0.03 | Observed Gain |
| | 0.04 | Expected Gain |
| | -0.01 | Deviation |
| | **-0.17** | **Deviation Ratio** |
| Forest | 0.06 | Observed Gain |
| | 0.03 | Expected Gain |
| | 0.03 | Deviation |
| | **0.89** | **Deviation Ratio** |
| Scrub | 0.02 | Observed Gain |
| | 0.01 | Expected Gain |
| | 0.01 | Deviation |
| | **1.21** | **Deviation** Ratio |
| Wetland | 0.02 | Observed Gain |
| | 0.05 | Expected Gain |
| | -0.03 | Deviation |
| | **-0.58** | **Deviation Ratio** |

## Acknowledgements

This research was supported by a grant from North Carolina SeaGrant and benefited from resources provided by East Carolina University's Center for Geographic Information Science.

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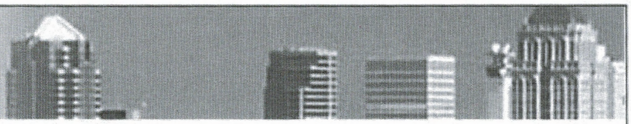

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