Alternative land use regulations and environmental impacts: assessing future land use in an urbanizing watershed

Tenley M. Conway\textsuperscript{a,}\textsuperscript{*}, Richard G. Lathrop\textsuperscript{b}

\textsuperscript{a} Department of Geography, University of Toronto, 3359 Mississauga Road North, Mississauga ON Canada L5L 1C6
\textsuperscript{b} Grant F. Walton Center for Remote Sensing & Spatial Analysis, Natural Resources & Environmental Sciences Building, Cook College, Rutgers University, 14 College Farm Road, New Brunswick, NJ 08901-8531, USA

Received 3 September 2002; received in revised form 20 August 2003; accepted 24 August 2003

Abstract

Land use models provide a way to examine the impacts of future urbanization and alternative land use regulations on the environment before irreversible changes are made. A simple spatially-explicit model was used to explore potential build-out conditions under different sets of regulations for the Barnegat Bay watershed, New Jersey, USA. Four build-out scenarios were created based on: (1) current regulations, (2) down zoning, (3) protecting a buffer around wetlands, and (4) open space protection. Various indicators were used to measure the impacts of build-out land use on: (1) water demand, (2) urban non-point source pollution, and (3) terrestrial habitat fragmentation. Potential change from 1995 to build-out and differences between the four build-out scenarios were identified based on the indicators. The analysis suggests that substantial changes will occur in the watershed before build-out, but that there is little difference between the four regulatory scenarios examined. In all cases, water demand is projected to exceed water supply, water quality is projected to be severely impacted in several locations, and terrestrial habitat will be further fragmented. Based on these results, the ability of regulatory approaches commonly used in the United States’ coastal zones to protect water and terrestrial resources from future development should be questioned.

© 2003 Elsevier B.V. All rights reserved.

Keywords: Land use change; Build-out; Land use regulations; Environmental indicators

1. Introduction

The cumulative ecological impacts of land use change at broader watershed or landscape scales are regularly ignored in local level land use planning decisions. Part of this omission may be that there is little geographically specific ecological knowledge available to planners (Crist, 1994; Press et al., 1996) and a limited means of assessing future impacts. Several recent efforts have tried to address this problem, by making critical information more accessible to planners and the public (Denzer et al., 2000; Theobald et al., 2000), but much work remains to be done. Another factor contributing to the omission of natural resource and ecological concerns is that land use planning and natural resource management is often administered through different agencies and/or different levels of government (Wang and Yin, 1997). In response to this disconnect, the United States government is encouraging local adoption of a watershed management framework as a holistic approach to bridge the gap between land
use planning and natural resource management (EPA, 1996).

However, even within a holistic watershed management approach, it is unclear if the regulatory strategies identified during the planning process will be effective at protecting local resources over the long-term, especially in watersheds undergoing large scale conversion due to urbanization (Lee et al., 1998). Land use change scenarios and models are an increasingly valuable tool for examining future landscapes to investigate: (1) the process of change and (2) potential landscape configurations before permanent changes are made. Presently within the landscape ecology and regional planning literature, there is great interest in developing land use change models that focus on simulating the processes that drive the spatial and temporal dynamics of change. While it may be possible to model the temporal dynamics of future change, it is a difficult task as many factors influence the process (Heilig, 1994). If the overriding concern is landscape configuration at a future endpoint and the resulting environmental implications, then a build-out model provides an alternative approach to dynamic models (Botequilha Leitão and Ahern, 2002). A build-out model can be used to examine the form of the fully developed landscape, while avoiding the complexity of predicting when changes will occur. In many locations in the United States, build-out is a reasonable scenario to plan for as present trends indicate it will likely occur within a few decades.

No where are the cumulative impacts of human land use change more acutely felt in the United States than in the coastal zone where human population and associated development is growing twice as fast as inland areas (Bartlett et al., 2000). This paper presents a case study of the Barnegat Bay Estuary Program (BBEP), which was established in 1995 to address environmental degradation in this rapidly growing coastal region of New Jersey, USA. In recognition of the direct connection between human land use and the degradation of coastal water and habitat quality, the BBEP explicitly incorporates a watershed based management approach, as do other National Estuary Programs elsewhere in the country (Kennish, 2000). This paper examines the utility of build-out models in the Barnegat Bay watershed as a way to assess the impact of future development scenarios on a suite of resource indicators that include water demand, non-point source pollution, and terrestrial habitat. Several scenarios were developed to test the potential efficacy of adopting commonly used regulatory approaches. Results from this analysis are used to assess the long-term implications of land use change within the context of the BBEP’s comprehensive conservation and management plan (CCMP).

2. Study area

Barnegat Bay, a shallow lagoon-type estuary nearly 70 km long and 2-6 km wide, is the largest estuary located completely within the state of New Jersey. The bay’s 660 km² watershed is located on the outer coastal plain in southeastern New Jersey, USA (Fig. 1). This region has long served as a summer resort area for the New York City and Philadelphia metropolitan regions and more recently has seen a surge in year round population and development. The Barnegat Bay watershed is characterized by sandy, acidic soils, and a pine-oak upland forest, locally known as the “pine barrens”. Along the estuary’s edges are extensive Spartina dominated salt marshes, while freshwater forested wetlands occur throughout the watershed.

Fig. 1. The Barnegat Bay watershed.
A sand dune vegetation community is found on the barrier islands, although today the islands are almost completely covered by high density residential development.

3. Model

A spatially explicit build-out model was developed to project future land use within the Barnegat Bay watershed. The build-out modeling approach is only valid where there is some concrete form of spatial planning that constrains the location and type of future development. In the United States, spatial planning is usually codified through municipal zoning. Zoning regulations define the best and highest use for the land but rarely take into account environmental consequences, especially cumulative impacts over time at the watershed scale. The omission of environmental impacts from planning decisions is partially due to the general lack of zoning maps in a digital format. If build-out models include zoning and other land use regulations then the environmental consequences of these regulations can be analyzed using environmental indicators, contributing critical information to the planning process.

Estimates of future development are made by determining the amount of vacant land that is available for development within designated land use zones and subject to other regulatory constraints. Traditionally, land use planners have developed simple build-out estimates using an aspatial spreadsheet technique. More sophisticated analyses can be undertaken through an explicitly spatial approach within the context of a geographic information system (GIS).

Digital land use/land cover (LULC) data for 1995, created by the New Jersey Department of Environmental Protection (NJDEP, 2000), were used to determine the land available for development. The LULC dataset was derived from digital aerial photos and has a minimum mapping unit of 0.4 ha (1 acre). Land was considered available for development if it was not already developed (all urban land uses and roads), not permanently protected as open space, not excluded from development based on wetlands regulations, and was zoned for development. Alteration of wetlands and a buffer zone around water bodies is limited by several state regulations such as the New Jersey Freshwater Wetlands Act, Tidelands Act, Coastal Area Facilities Review Act, and the Pinelands Commission’s Management Plan. The regulated buffer zone around water bodies varies from 0 to 91 m depending on surrounding land use, wetlands size, presence of threatened or endangered species, and if the water body is located in the Pinelands Management Area (PLMA). To account for these regulations, wetlands and designated buffer zones around wetlands, tidal areas, and other water bodies were considered unavailable for future development.

Zoning regulations were primarily used to determine the intensity of development allowed on the available land in the model. In several cases presence of sewer services allows more intense development in a specific location, so the NJDEP’s digital sewer service data (NJDEP, 1997) was used to determine which areas are served by sewers. Relying on zoning data to model future land use has several limitations. Zoning maps and regulations are frequently reviewed and modified so the likelihood that current zoning regulations will remain in place until build-out is doubtful. Economic and social factors also play an important role in determining future development, as the probability of certain types of development occurring in specific places is affected by land value, tax rates, population growth, employment potential, and quality of life issues (Anderson, 1987). Market conditions, development practices, and/or land use demand often leads to development occurring at less than maximum capacity (Moudon and Hubner, 2000). On the other hand, a build-out model highlights what is allowed under specific sets of regulations; while development may not occur at maximum capacity based on today’s zoning regulations, understanding what is allowed helps identify ways to change regulations to better protect resources.

Based on discussions with state and local officials and public input received as part of the CCMP scoping process, we created several build-out scenarios that represent land use regulations currently being considered for adoption in the watershed. These scenarios represent regulations that either restrict the location or limit the intensity of future development. The scenarios are:

1. Current regulations scenario: Based on current municipal zoning, state environmental regulations, and existing protected open space.
2. Down zoning scenario: The current regulations scenario but with the minimum lot size of future residential development outside sewer service areas forced to be at least 1.3 ha. Down zoning is when there is an increase in the minimum lot size. For example, if the original zoning density was one dwelling unit per 0.4 ha in a non-sewer service area, this scenario would down zone the density to one dwelling unit per 1.3 ha. The Pinelands Commission determined 1.3 ha (3.2 acres) is the minimum lot size that can support a septic tank without negative environmental impacts as a result of local soils and hydrology (Pinelands Planning Commission, 1982). We believe the down zoning scenario is the most likely scenario to occur in the watershed based on the current planning environment.

3. Large buffer scenario: The down zoning scenario with the undevelopable buffer zone around all freshwater wetlands and streams increased to 91 m and the buffer zone around all tidal areas increased to 152 m. The 91 m buffer is the minimum width sufficient to maintain biological integrity within wetlands in the region (Pinelands Planning Commission, 1982). The 152 m tidal buffer represents the farthest inland that the New Jersey Waterfront Development Act can limit development (NJDEP, 1998).

4. Open space scenario: The down zoning scenario with an aggressive plan to protect open space. The land preserved in this scenario represents the 100 sites the Trust for Public Land identified as important to protect in the watershed, representing unique or critical habitats (Blanchard, 1996).

4. Indicator analysis

To determine the consequences of future land use on the environment, indicators were used to quantify potential changes. We focused on indicators measuring water demand, urban non-point source pollution, and terrestrial habitat fragmentation because these issues have been identified as high priority by the Barnegat Bay Estuary Program (Barnegat Bay Estuary Program, 2000). Comparisons were made between: (1) 1995 and the projected build-out conditions based on current regulations to understand the potential magnitude of change if no additional regulations are adopted, and (2) the current regulations scenario and alternative build-out scenarios to assess the impacts of adopting additional regulations.

4.1. Water demand indicators

Most water used in the Barnegat Bay watershed comes from shallow underground aquifers. Increasing water demand is of particular concern as withdrawals from the aquifers have already reduced water levels to such an extent that saltwater intrusion is contaminating groundwater in some locations. Withdrawals from one of the regions aquifers, the Kirkwood-Cohansey system, has caused reductions in stream flow, with further declines likely to continue to change the chemistry and ecology of the Barnegat Bay estuary (Barnegat Bay Estuary Program, 2000). We focus on residential water use because residential land uses are the primary type of development projected to occur in the future, while agriculture and industrial uses are on only 3% of the land in 1995 and are unlikely to expand by build-out.

Dwelling units and population were used as indicators of future change. A projected build-out water budget was created based on estimated population size, per capita water demand, and estimates of available water. The number of new dwelling units was estimated by calculating the number of units that could be built on each patch of available land based on the required minimum lot size. Only 80% of each patch was considered available for building lots as the other 20% was reserved for public infrastructure (roads, public buildings, etc.) required to support the new residential development. The 80:20 ratio is typical for new development in the watershed (McKeon personal communication).

To calculate potential build-out population, the number of dwelling units projected in each build-out scenario was multiplied by the average number of people residing in a dwelling unit in Ocean County, based on the 2000 census. The total water demand was then determined by multiplying the projected population at build-out by the average per capita water use. Estimated water demand for the different scenarios was compared to the supply of water identified as available to the watershed in the New Jersey Statewide Water Supply Plan (NJDEP, 1996) to determine if the projected future demand could be met by the available supply. The State’s estimates represent...
the amount of water in the watershed that can be used before negatively impacting stream flow, and includes water currently imported into the watershed.

4.2. Non-point source pollution indicator

Beginning with the 1970 Clean Water Act there has been a concerted effort to improve the biological, chemical, and physical characteristics of the nation’s waterways. Following initial success in improving water quality through regulation of point source pollution, increasingly efforts have focused on non-point source pollution, the next leading threat to water quality. Non-point source water pollution includes pollution from stormwater run-off, percolation to groundwater, and atmospheric deposition or precipitation. Allan and Flecker (1993) identified land use as one of the most important factors determining the level of non-point source pollution. The percent of impervious surface cover has been proposed as a more refined measure of urban non-point source pollution in urban and suburban areas (Schueler, 1994). Arnold and Gibbons (1996) compared data from several studies and found that only 10% impervious surface cover was needed to begin to negatively impact water quality.

The NJDEP’s LULC dataset includes measures of impervious surface in 1995. To estimate impervious surface at build-out based on the projected land use, zoning class averages derived from already developed areas in 1995 were used. If the area was deemed unavailable for future development, then the 1995 impervious surface value was retained in the build-out scenario estimates. The impervious surface values derived for different land uses in the Barnegat Bay watershed fall within the range of estimates from previous studies (Soil Conservation Service, 1975; Sleavin et al., 2000; Reilly et al., 2001; Table 1). Public rights-of-ways were included in the estimates as certain widths and density of roads are associated with specific types of land uses. The percent impervious surface was calculated for the entire watershed as well for the 76 smaller catchment areas in the watershed that correspond to the smallest hydrological unit (HUC 14) the USGS has defined in New Jersey (USGS, 1982).

4.3. Terrestrial habitat fragmentation indicators

Maintaining the integrity of the New Jersey Pine Barrens landscape was one of the major spurs to establish the Pinelands National Reserve and International Biosphere Reserve (Good and Good, 1984). Habitat fragmentation creates small isolated patches, reducing total habitat area and connectivity between patches while increasing habitat edge (Forman, 1995). Development and the resulting conversion and fragmentation of the Pine Barrens habitat are expected to have negative consequences for a number of sensitive plant and animal species, as well as heighten issues related to the long-term maintenance of this fire dependent ecosystem. To assess if there is an increase in fragmentation between 1995 and the projected built-out landscape, three pattern metrics were calculated examining changes in natural cover (forest and wetlands). Due to the design of the model, wetlands are protected from future development and cannot convert to another LULC class, so the metrics are primarily reflecting changes in upland forest cover. However, wetlands and forest were considered together because many of the wetlands in the watershed are linear forested

<table>
<thead>
<tr>
<th>Land Use</th>
<th>This study</th>
<th>NJDEP</th>
<th>Soil Conservation Service</th>
<th>Olympia, Washington</th>
<th>NEMO</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5–1 DU/AC</td>
<td>12–21</td>
<td>14</td>
<td>12–20</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>1–2 DU/AC</td>
<td>21–24</td>
<td>22</td>
<td>20–25</td>
<td>14–16</td>
<td></td>
</tr>
<tr>
<td>2.4–3 DU/AC</td>
<td>24–36</td>
<td>33–35</td>
<td>25–38</td>
<td>67</td>
<td>21</td>
</tr>
<tr>
<td>At least eight DU/AC</td>
<td>43</td>
<td>59</td>
<td>65</td>
<td>65</td>
<td>39</td>
</tr>
<tr>
<td>Industrial</td>
<td>62</td>
<td>76</td>
<td>75</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>


1. These values do not include rights-of-ways, which had between 38 and 64% impervious surface.
2. Values for 3–7 units.
wetlands surrounded by upland forest cover, representing a continuous natural cover matrix.

The first metric, percent of total area for natural cover, is a simple aspatial measure of landscape composition. The other two metrics, the contagion index and correlation length, evaluate the distribution of cover types across the landscape. The contagion index measures interspersion and dispersion based on the proportion of cells that are adjacent to cells of the same class type (O’Neill et al., 1988). If a landscape contains large patches of each class type then the contagion metric will be close to 100, while a landscape with smaller patches has a contagion close to zero. The contagion index is scale dependent, with a smaller grain size increasing the proportion of like adjacencies because there will be more interior patch cells. Correlation length is a measure of patch extent, defined as the average distance an individual could move within a patch before reaching the edge if randomly placed in the landscape (Keitt et al., 1997). A relatively high correlation length indicates greater patch extent. To determine if there is a shift in the structural scale of the pattern between 1995 and build-out, metrics were calculated at four grain sizes (80, 120, 160, and 200m cell length). Fragstats Version 3.2 (McGarigal et al., 2002) was used for all metric calculations.

5. Results

Based on the 1995 NJDEP LULC dataset, 25% of the study area was already urbanized and 27% is mapped as available for future development. In the open space plan, the land available for development is reduced by 32%, while increasing buffer size reduces available land by 19%.

In the current regulations scenario, an additional 18% of the land in the watershed is projected to be urbanized, for a total of 43% urban land use by build-out (Table 2). Only 18% of the land is projected to become urban, although 27% is available for development, because some land is limited to very low density development (i.e. 1 dwelling unit per 6 ha) and was not considered urbanized. The increase in urban land mostly impacts forest, as the other dominant land cover, wetlands, cannot be converted to urban uses based on the model design. The western section of the watershed is least altered, with urbanization primarily projected in the northern section and central corridor in all build-out scenarios (Fig. 2). In residential areas, urban land was defined as zoning lots smaller than 1.6 ha so the down zoning scenario is projected to have the same amount of urban land as the baseline scenario. The projected amount of urban land differs by less than 5% in the large buffer and open space scenarios from the current regulations scenario, indicating these management strategies will have little impact on build-out land use composition (Table 2).

In 1995, 246,817 dwelling units and 619,511 people were in the Barnegat Bay watershed (Table 3). To assess the validity of the model estimates, the build-out model was run for 1995 conditions and compared with independent estimates of the number of dwelling units obtained from the Ocean County Planning Department. This comparison showed that the model over-estimated 1995 units by 17%, suggesting that existing development was not built to the maximum allowable density as determined by existing zoning. To account for the possible data limitations and “under” development (i.e. less than maximum allowable density), a range of potential new dwelling units was estimated with the high endpoint representing a fully built model and the low endpoint

<table>
<thead>
<tr>
<th>Class</th>
<th>1995</th>
<th>Current regulations scenario</th>
<th>Down zoning scenario</th>
<th>Large buffer scenario</th>
<th>Open space scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban</td>
<td>25</td>
<td>45</td>
<td>43</td>
<td>39</td>
<td>40</td>
</tr>
<tr>
<td>Agriculture</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Barren land</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Forest</td>
<td>45</td>
<td>30</td>
<td>30</td>
<td>33</td>
<td>36</td>
</tr>
<tr>
<td>Wetlands</td>
<td>26</td>
<td>26</td>
<td>26</td>
<td>26</td>
<td>26</td>
</tr>
</tbody>
</table>

Values do not equal 100 because of rounding.
Fig. 2. Urban and non-urban land uses in 1995 (A), the current regulations build-out scenario (B), the down zoning build-out scenario (C), the large buffer build-out scenario (D), and the open space build-out scenario (E).

Table 3
Projected number of dwelling units, population, and water demand

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Dwelling units</th>
<th>Population</th>
<th>Water demand (MGD)</th>
<th>Percent increase from 1995</th>
</tr>
</thead>
<tbody>
<tr>
<td>1995</td>
<td>246817</td>
<td>619511</td>
<td>96.0</td>
<td></td>
</tr>
<tr>
<td>Current regulations scenario</td>
<td>338236–353118</td>
<td>859119–896920</td>
<td>131.6–137.4</td>
<td>37–43</td>
</tr>
<tr>
<td>Down zoning scenario</td>
<td>319904–331802</td>
<td>802959–832823</td>
<td>124.5–129.1</td>
<td>30–34</td>
</tr>
<tr>
<td>Large buffer scenario</td>
<td>301961–310838</td>
<td>757922–780454</td>
<td>117.5–121.0</td>
<td>22–26</td>
</tr>
<tr>
<td>Open space scenario</td>
<td>308359–318377</td>
<td>773986–799126</td>
<td>125.9–130.8</td>
<td>25–29</td>
</tr>
</tbody>
</table>
scaled downward by 17%. Likewise, the population estimates were projected for a high and low range.

Under current regulations, 338,236–353,118 dwelling units and 802,959–832,823 people are projected in the watershed at build-out, an increase of 37–43% from 1995. If down zoning outside sewer service areas occurs, the projected increase would be limited to 30–34% above 1995 values. A substantially lower population is projected in the large buffer zone and the open space scenarios (Table 3). Even though the open space scenario allows less land to be developed in the future, the large buffer scenario has the smallest future population growth. This counterintuitive result is explained by the low density zoning in the proposed open space sites (i.e. removing these areas does not remove a lot of the future population growth). Conversely, the large buffer zone scenario removes a disproportionate amount of land from the western edge of the Bay and northern section of the watershed where there is higher density zoning, and thus a larger potential future population.

5.1. Water demand indicator

The projected increase in dwelling units and associated population suggest that water demand will also increase by about 30% from 1995 to build-out (Table 3). If the total available water is compared to estimated demand, there is a small surplus of water in 1995 (Table 4). However, in all build-out scenarios there is a projected water deficit of 13–36%, indicating that the current supply of water will not be enough to meet the increase in residential demand at build-out. While estimates of the water supply are not yet available at the sub-watershed level, future water deficits could potentially be much higher in specific sections of the watershed based on the distribution of the available water and location of future growth.

5.2. Water quality indicators

Overall, the Barnegat Bay watershed is estimated to have had 8% impervious surface cover in 1995, slightly below Arnold and Gibbons’s (1996) 10% threshold, suggesting urban non-point source pollution is not greatly impacting water quality. However, at a finer scale (i.e. USGS HUC14 catchments) problematic areas of higher impervious surface are evident. Twenty-four of the 76 catchments were above the 10% threshold, with most impervious surface located in the northeastern section of the watershed (Fig. 3).

In the current regulations scenario, impervious surface cover is projected to increase to 13% of the watershed. This increase is projected in not only the northeastern catchments, but also along the central north-south corridor in the southern part of the watershed, where most new commercial, industrial, and high density residential development is likely to occur.

If down zoning occurs, impervious surface cover could increase to 12% by build-out (Fig. 3), with 35 of the 76 catchments above the 10% impacted threshold. The differences between the current regulations and down zoning scenarios are primarily in the southern catchments because sewers are mostly located in the northern part of the watershed. Down zoning did not have a large effect in decreasing impervious surface because low density development still has a high per dwelling unit level of impervious cover. In the large buffer zone and open space scenarios, the percent of impervious surface cover in the watershed is very similar to the down zoning scenario, with 12% of the watershed covered by impervious surface.

Five catchments are projected to cover at least an additional 10% of the land with impervious surface by build-out in almost every scenario. The largest in-

Table 4
Projected water budget in the watershed based on current estimates of water availability (in millions of gallons per day)

<table>
<thead>
<tr>
<th></th>
<th>1995</th>
<th>Current regulations scenario</th>
<th>Down zoning scenario</th>
<th>Large buffer scenario</th>
<th>Open space scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available water</td>
<td>101.6</td>
<td>101.6</td>
<td>101.6</td>
<td>101.6</td>
<td>101.6</td>
</tr>
<tr>
<td>Water demand</td>
<td>96.0</td>
<td>131.6–137.4</td>
<td>128.5–129.1</td>
<td>117.5–121.0</td>
<td>125.9–130.8</td>
</tr>
<tr>
<td>Water surplus</td>
<td>5.6</td>
<td>30.0–35.4</td>
<td>22.0–27.5</td>
<td>15.9–19.4</td>
<td>24.3–29.2</td>
</tr>
</tbody>
</table>
crease is from 6% impervious surface in 1995 to potentially 30% impervious surface cover at build-out. Four of the five catchments projected to have a greater increase in impervious surface are contiguous to each other (northern hotspot; Fig. 4). The other catchment of high impervious surface increase (southern hotspot) is located along the Barnegat Bay (Fig. 4). In the southern hotspot, only 8% of the land was covered by impervious surface in 1995, while 20% is projected to be impervious at build-out. In the open space scenario, a large portion of the projected future development is removed through additional open space protection, and the impervious surface is projected to increase to only 10%. In this situation, open space protection is an effective policy in reducing impervious surface cover and limiting non-point source pollution at a catchment scale.

5.3. Terrestrial habitat indicators

In 1995, natural cover represented 71% of the landscape, and the low contagion index in 1995 highlights
the intermixing of urban and natural cover, found in the northern section of the watershed (Table 5). The high correlation length indicates many of these small natural cover patches are connected (Table 5), forming a complex mosaic. The proportion of the landscape under natural cover is projected to decrease by 26% between 1995 and build-out under current regulations. There is also a reduction in the contagion index and correlation length projected between 1995 and build-out, reflecting the elimination of patches and connections between remaining patches.

There is little difference between the projected build-out scenarios for either the percent of the landscape in the natural cover class or the contagion index (Table 5). The correlation length is greater for the large buffer and open space scenarios, highlighting the benefits of protecting natural cover adjacent to or connecting undevelopable patches to increase natural cover connectivity. The constant value of the proportion of the landscape in the natural cover class and the reduction in the contagion index as the images are coarsened is expected (Fig. 5). The slight non-linear change in the correlation length across scales for the open space scenario indicates there may be a shift in patch connectivity between scales. These results represent a preliminary analysis of the general trends expected between 1995 and build-out under different sets of regulations, with a decrease in natural cover and the connections between remaining patches expected. Further work needs to be completed in the region to better understand the effects of the projected change on terrestrial habitat in the watershed.

### 6. Discussion

The results of the analysis indicate there will be significant changes by build-out in the Barnegat Bay watershed. Although the exact amount of additional development may vary based on the amount of land protected as open space, zoning and other regulations, and socioeconomic factors, all present signs indicate that additional development will occur in the water-

---

**Table 5**

<table>
<thead>
<tr>
<th>Grid cell size (m)</th>
<th>80</th>
<th>120</th>
<th>160</th>
<th>200</th>
</tr>
</thead>
<tbody>
<tr>
<td>PLAN</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1995</td>
<td>71</td>
<td>71</td>
<td>71</td>
<td>71</td>
</tr>
<tr>
<td>Current regulations scenario</td>
<td>56</td>
<td>56</td>
<td>56</td>
<td>56</td>
</tr>
<tr>
<td>Down zoning scenario</td>
<td>59</td>
<td>59</td>
<td>59</td>
<td>59</td>
</tr>
<tr>
<td>Large buffer scenario</td>
<td>62</td>
<td>62</td>
<td>62</td>
<td>62</td>
</tr>
<tr>
<td>Open space scenario</td>
<td>62</td>
<td>62</td>
<td>62</td>
<td>62</td>
</tr>
<tr>
<td>Contagion index</td>
<td>1995</td>
<td>29.84</td>
<td>26.43</td>
<td>24.23</td>
</tr>
<tr>
<td>Current regulations scenario</td>
<td>25.99</td>
<td>22.07</td>
<td>19.70</td>
<td>17.61</td>
</tr>
<tr>
<td>Down zoning scenario</td>
<td>23.84</td>
<td>21.87</td>
<td>19.54</td>
<td>17.46</td>
</tr>
<tr>
<td>Large buffer scenario</td>
<td>26.30</td>
<td>22.26</td>
<td>19.86</td>
<td>17.72</td>
</tr>
<tr>
<td>Open space scenario</td>
<td>26.92</td>
<td>23.12</td>
<td>20.83</td>
<td>18.79</td>
</tr>
<tr>
<td>Correlation length</td>
<td>1995</td>
<td>14865</td>
<td>14287</td>
<td>14477</td>
</tr>
<tr>
<td>Current regulations scenario</td>
<td>10465</td>
<td>10596</td>
<td>10167</td>
<td>10210</td>
</tr>
<tr>
<td>Down zoning scenario</td>
<td>10443</td>
<td>10572</td>
<td>10141</td>
<td>10191</td>
</tr>
<tr>
<td>Large buffer scenario</td>
<td>12348</td>
<td>12289</td>
<td>12333</td>
<td>12129</td>
</tr>
<tr>
<td>Open space scenario</td>
<td>11607</td>
<td>11708</td>
<td>10440</td>
<td>11299</td>
</tr>
</tbody>
</table>

PLAN: percent of landscape in natural cover class. The correlation length is in meters.
Fig. 5. The percent of landscape in natural cover (PLAN; A), contagion index (B), and correlation length (C) for 1995 and the build-out scenarios at four grain cell sizes.

The potential for the population to exceed levels that can be supported by the current water supply is the most pressing problem identified in the analysis. There may be additional complexity as the model indicates new development will not be evenly distributed across the watershed nor will municipalities’ experience the same proportion of development as in the past. New development is projected to primarily occur in the northwest corner of the watershed and the central corridor in the southern section of the watershed. While most land in the northern half of the watershed has access to a public water supply, many areas in the southern half of the watershed rely on shallow, private wells. The difference in supply and location of growth may disproportionately impact one part of the watershed over another. These results signal the importance of addressing the spatial disparities of new growth, associated water demand, and available water

shed and will substantially impact water and terrestrial resources.
supply through watershed-wide planning and coordination between local water authorities.

Limiting the amount of impervious surface cover in the watershed should be another management goal as projected build-out levels indicate water quality in streams and the downstream estuary will continue to be impacted by future growth. The Coastal Zone Management Rules in New Jersey allow high levels of impervious surface in a few designated areas, while the majority of the coastal zone is limited to less than 5% impervious surface (NJDEP, 2001). These rules currently apply to the eastern portion of the watershed, but the approach should be considered throughout.

The two hotspots of impervious surface increase identified in the analysis need to be addressed through watershed planning. Purchasing the three sites in the southern hotspot catchments already proposed for open space can mitigate that hotspot. The preservation of these sites in the watershed should be prioritized since they have such a large impact on the local impervious surface in an area that currently has very little impervious cover. The northern hotspot includes parts of three sub-watersheds and four municipalities. The cross-boundary problem of the northern hotspot illustrates the need for the BBEP with its explicit watershed-based focus to take the lead in organizing a plan to protect local water quality through impervious surface limits, changes to zoning, or other mitigation efforts. The GIS-based build-out model shows great utility in geographically highlighting trouble spots that may not have been identified if an aspatial approach was used due to the multi-jurisdictional extent of the problem.

The results of the analysis indicate the terrestrial habitat will be increasingly fragmented, with connections between areas of natural cover reduced throughout the watershed. Significant wetlands exist along the eastern edge of the watershed and the build-out model indicates that a large patch of forest will be preserved in the western section of the watershed (Fig. 2). However, most of the new development is projected to occur between these two protected areas, limiting east–west connectivity across the watershed. Protecting and restoring vegetated riparian corridors would help to maintain or increase cross-watershed connectivity, linking the bay and its fringing wetlands and upstream habitat areas. The vegetated corridors may also serve to reduce the amount of run-off that directly enter streams and help to filter groundwater discharge, partially mitigating the effects of increased impervious surface and urban non-point source pollution elsewhere in the watershed.

There was comparatively little difference between the results of the current regulations and the three alternative regulatory scenarios examined, suggesting that alone none of the approaches are sufficient to limit the impacts of future growth on water or terrestrial resources. These results are most likely due to the relatively low percentage of land affected by the buffer zone and open space scenarios, with the potential development in most of the watershed no different than that allowed under current regulations. The results of the down zoning scenario can, in part, be attributed to the unproportional relationship between lowering the density of residential development and impacts on water and terrestrial resources. For example, changing the minimum lot size from 0.4 to 1.2 ha means that the number of dwelling units would be reduced by two-thirds, but the percent impervious surface would only be reduced by one-half.

While the build-out model provided a useful tool to project future land use patterns, it does have limitations. First, secondary effects of the regulations were not included. For example, in the open space scenario any effects the new open space may have on surrounding areas were not considered. There is a strong possibility that limiting urban development in one area will increase the growth pressures in other areas, resulting in changes to zoning allowing even higher intensity development. A second potential limitation of the model is that the timing of urban development is not considered. This may be most limiting in the open space scenario, as it is likely that due to limited funding the open space protection plan will be phased in over many years, increasing the likelihood that some of the targeted pieces of land will be developed before they can be purchased for protection.

There may also been some limitations with the indicators used to compare the different scenarios. The large buffer scenario is projected to have levels of impervious surface similar to the current regulation scenario suggesting little positive effect on water quality, yet many of the positive benefits of vegetated corridors along water bodies (e.g. slowing and filtering of run off) are not captured by the impervious surface measurement.
Interpreting changes in the terrestrial fragmentation indicator is also difficult. There are numerous measures of fragmentation and no consensus exists over how much change is too much or where significant thresholds exist for a given metric (Tuner et al., 2001). While we project increased fragmentation between 1995 and build-out in the watershed, it is unclear if these changes are significant. Further works need to be completed to identify general thresholds and to better understand the relationships between changes to metrics and the impacts of fragmentation on organisms, wildfire, and other nutrient transport in the watershed. However, given these limitations, we believe that a build-out model approach is a valid way to consider future conditions as it highlights the level of development possible under a given set of regulations.

7. Conclusions

The application of spatially explicit build-out models provide a useful approach to examine the consequences of municipal zoning and other local level land use planning policies. The spatially-explicit nature of the model permits the estimation of watershed-wide trends as well as the identification of specific geographic locations vulnerable to change. Coupling the build-out model to an indicator analysis provided a way to quantify the potential impacts of the projected build-out land use on the environment and to compare alternative regulatory approaches. The results of this study highlight the disparities between the level of development allowed under municipal zoning and the amount of additional development this coastal region can support without negatively impacting resources. Identifying these disparities is critical to a successful estuary/watershed planning effort. Without acknowledging the full scope of future growth, there is little incentive or political will to adopt the necessary measures to control or mitigate the negative cumulative impacts.

In the case of Barnegat Bay, if we continue on present trajectories (as represented in the build-out model) then we expect the bay to be increasingly stressed by future development, making the goal of restoring the ecological health of the estuary that much more difficult, if not highly impossible to achieve. The results of the alternative scenarios demonstrate that the incremental change from growth control measures such as down zoning, wetland buffers, and open space protection did not substantially limit the negative impacts of future urban growth on the water or terrestrial resources in this study. These results are not entirely surprising given the mixed findings of previous studies examining how growth control regulations affect urban development over time (Logan and Zhou, 1989; Levine, 1999). We suggest that these incremental regulatory responses, while within presently politically acceptable limits, are inadequate in the long-term and more radical zoning and/or mitigation approaches are necessary. Further research must focus on identifying and testing alternative regulatory and non-regulatory actions that are more effective at protecting local resources from the negative consequences of future urban development.

In considering other estuary protection efforts, future urban growth conditions should be explicitly considered when developing conservation and management plans. While acknowledging that political, social, and economic conditions will likely alter in the future, a build-out model still provides a straightforward approach to project a vision of the future landscape under existing policies. Additionally, the build-out model allows one to examine the magnitude of potential future impacts so that management actions under consideration can be critically evaluated to ensure that they will be effective in creating the desired future conditions. While holistic watershed-based management represents a promising approach to incorporate ecological information and goals into land use planning for estuary protection, if ineffective management actions are adopted then the whole exercise is doomed to failure.

Acknowledgements

Dave McKeon and staff at Ocean Country Planning offered insight and aided in the data gathering process. Scott Haag and Steve Lennartz provided valuable assistance during the digitizing and analysis phases. Funding was provided by the US EPA through the Barnegat Bay National Estuary Program. T.C. was supported by a National Estuary Research Reserve Fellowship during this project.
References


Barnegat Bay Estuary Program. 2000. Physical characteristics.


Tenley M. Conway is a PhD student in Geography at Rutgers University. MS in Geography from Rutgers University (2001); BS in Natural Resources from Cornell University (1997). Her research addresses the relationship between human activity and the physical environment, with particular emphasis on the interaction between urban development and terrestrial habitat, the driving forces behind land use change, and representation and measurement of human dominated landscapes.

Richard (Rick) G. Lathrop Jr. is director of the Walton Center for Remote Sensing & Spatial Analysis and Associate professor in the Department of Ecology, Evolution & Natural Resources, Cook College, Rutgers University. PhD Environmental Monitoring (1988) and MS Forestry (1986) from University of Wisconsin-Madison; BA Biology (1981) from Dartmouth College. His research program attempts to integrate insights of landscape ecology and geography with the application of geo-spatial technology to improve our understanding of the structure and function of coupled human-environmental systems at broader landscape to regional scales and then translate that understanding into effective and appropriate techniques to improve on-the-ground natural resource management and land use planning.