A Green Infrastructure Plan
for the
Hampton Roads Region

HAMPTON ROADS
PLANNING DISTRICT COMMISSION

February 2010

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A Green Infrastructure Plan for the Hampton Roads Region

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Abstract
This report documents the effort undertaken to update *The Hampton Roads Conservation Corridor Study* that was published by the HRPDC in 2006. Through a series of stakeholder meetings and updates to the geographic information system (GIS) model, the updated network provides local and regional planners with an improved tool for conservation planning. There are four main components to the plan: an updated Hampton Roads green infrastructure network and analysis of the change in the network, a model identifying the vulnerability of green infrastructure to development pressure, a discussion of the impact sea level rise may have on the green infrastructure network, and an updated parks and recreation inventory.

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Virginia Coastal Zone
MANAGEMENT PROGRAM

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Executive Summary

The Hampton Roads green infrastructure plan represents an ongoing effort by the HRPDC to develop a useful planning tool for local and regional planners. The goal is to identify and prioritize a network of valuable conservation lands in order to achieve multiple benefits, such as habitat protection, drinking water supply protection, storm water management and recreational opportunities.

Numerous challenges face the Hampton Roads region in the next several years and decades and a green infrastructure approach could prove to make the planning process more efficient. Localities must tackle new water quality regulatory requirements such as storm water management regulations, Total Maximum Daily Loads (TMDL) implementation plans, and Urban Development Area (UDA) requirements.

In this project, the original green infrastructure network (published in 2006) was updated by incorporating more current data into the geographic information systems (GIS) model. There were also several discussions with a diverse group of stakeholders that led to improvements in the green infrastructure plan. Stakeholder meetings were held for planners from Hampton Road localities as well as experts from natural resource agencies.

The original green infrastructure network and the newly updated network were compared to ascertain where changes occurred on landscape that caused the green infrastructure to increase or decrease in ecological value. Factors such as changes in regional land use are discussed. Two small site studies were also conducted to gain a better understanding of the dynamics of the change analysis.

A new component to the Hampton Roads green infrastructure plan is the Vulnerability to Development model. This model looks at potential future growth data for the Hampton Roads region to try and identify where this growth will occur. The next step was to identify which areas of the green infrastructure network are most at risk for development. The goal of this analysis is the ability to include development pressure as an element in prioritizing lands for protection through conservation easements or purchase when funding is available through grant programs or other sources.

This report also discusses the potential impacts of climate change and associated sea level rise. The eastern portion of Hampton Roads is extremely vulnerable to sea level rise due to a combination of low elevation and gradual subsidence. Wetlands and adjacent uplands will be gradually inundated, setting up a difficult set of natural resource management challenges.

The last component of the regional green infrastructure plan is an updated parks and recreation inventory for Hampton Roads. Existing GIS data from state agencies was used as a starting point to update and correct the information as needed. The parks and recreation information will help planners identify existing or potential connections between valuable green infrastructure resources.

INTRODUCTION

The Hampton Roads green infrastructure network is the first and most fully realized regional conservation planning effort of its kind in Virginia. The green infrastructure project was developed to address the need for a comprehensive regional approach to conservation planning in an area of Virginia that is both blessed with a rich array of natural resources and challenged by development pressures and use conflicts (see Figure 1). The project was a result of a multi-year team effort among a broad range of stakeholders, including the staff and member localities of the Hampton Roads Planning District Commission (HRPDC), the Virginia Coastal Zone Management Program (Virginia CZM), and the Virginia Natural Heritage Program. The resulting regional network consists primarily of lands that have high intrinsic value for the protection of water quality and critical habitat. The original project is documented in detail in *The Hampton Roads Conservation Corridors Study* report (Hampton Roads Planning District Commission, 2006).

Implementation Successes

The regional green infrastructure network has already seen successful implementation in the years since the original plan was complete. A report by the HRPDC provides a synopsis of green infrastructure planning efforts in Hampton Roads (Hampton Roads Planning District Commission, 2007). Most significantly, the network has been used in several local comprehensive plans, parks and recreation plans, and purchase of development rights programs. The following are examples of how the green infrastructure network was incorporated into local and regional planning:

- The City of Chesapeake included the green infrastructure network in its most recent comprehensive plan and on the future land use map for the City.
- The City of Virginia Beach included the Southern Watershed Area conservation corridor system in its comprehensive plan by reference.
- The regional green infrastructure network was recently used in the development of a Parks and Recreation Plan for Southampton County.
- The Cities of Chesapeake and Virginia Beach, in conjunction with the U.S. Department of Defense, are using the green infrastructure network as an element in the selection of lands to buffer Naval Air Station Oceana, Naval Auxiliary Landing Field Fentress and the Northwest Annex in Chesapeake and Virginia Beach from encroachment.

It is worth noting that there is an ongoing effort to encourage a green infrastructure approach in the comprehensive plan update process. There are already several Hampton Roads localities that have expressed interest in proceeding with this approach on their next update cycle.

The most significant implementation action associated with the regional green infrastructure network program has been the fee simple purchase and acquisition of development rights on lands within the green infrastructure network. Several organizations have been involved in the purchase of land and development rights in Hampton Roads, including The Conservation Fund, The Nature Conservancy, the Department of Defense, the Virginia Department of Conservation and Recreation (DCR), the U.S. Fish and Wildlife Service, and the Cities of Chesapeake and Virginia Beach. These purchases, totaling tens of millions of dollars and thousands of acres, are intended to accomplish a variety of goals including protection of water quality and habitat, buffering of military facilities from encroachment by development and provision of open space and recreational opportunities for localities. The degree to which the green infrastructure network drove the decision to purchase these parcels varied from case to case.

Lee Hall Reservoir – Photo Courtesy of Newport News Tourism Development Office

The Need for an Updated Plan

A regional green infrastructure plan should be an ever-evolving plan in that it can adapt to meet local and regional planning needs as they change over time. The goal of the green infrastructure network is always to provide maximum utility to the localities of Hampton Roads while achieving multiple benefits. This report documents the first update to the Hampton Roads green infrastructure network since the original work was completed in 2006. There are a variety of issues facing Hampton Roads localities over the next several years and decades which can benefit from using a green infrastructure approach.

Regulatory Compliances

The Hampton Roads green infrastructure network provides a valuable framework for local governments that are faced with complying with several related water quality regulatory programs. Regulatory programs that are intended to enhance management of non-point source water pollution have a shared weakness in that they are typically silent on questions of landscape scale ecological planning. The regional green infrastructure plan provides a mechanism to remedy that situation. Watershed planning at the local level, when linked with the regional green infrastructure network, can address both local water quality regulatory requirements and regional ecological planning objectives. The revised Virginia storm water management regulations provide an opportunity for localities to develop watershed management plans as a means of gaining some additional flexibility in program compliance. The regional green infrastructure network provides a template to link adjacent watershed plans so that each plan contributes to a larger conservation vision.

In the same way, Total Maximum Daily Load (TMDL) implementation Plans are watershed based and will benefit from linkage to a regional template. The Chesapeake Bay-wide TMDL will require the majority of Hampton Roads localities to comply with multijurisdictional implementation plans in a coordinated fashion. The value of efforts to manage nonpoint source pollution associated with the Bay-wide TMDL will be enhanced if they are tied to the regional green infrastructure network.

The Urban Development Area (UDA) requirements for high growth localities are intended to focus new development in urban nodes. This type of nodal development pattern works in conjunction with a green infrastructure approach in that the green infrastructure network provides guidance on the best location of the urban nodes.

Sea Level Rise

The Hampton Roads region is one of the most vulnerable areas in the United States regarding sea level rise impacts. The amount of sea level rise that is likely to occur in Hampton Roads is uncertain, but the Governor's Commission on Climate Change supports the findings that by 2100, the water will rise approximately 0.7 – 1.6 meters (2.3 – 5.2 feet) (Governor's Commission on Climate Change, 2008). Particularly in Hampton Roads, this means a significant amount of the built infrastructure (roads, utilities, etc.) could potentially be lost or damaged and in need of replacement or relocation. Fortunately, given the long time frame, planners can anticipate and make preparations for altering the built environment as necessary.

The impacts on our valuable natural landscape, however, prove to be more difficult to identify and quantify, let alone plan for remediation. Sensitive habitats that exist close to the shore are in danger of disappearing as well. Risks to green infrastructure due to sea level rise include salt water intrusion, beach erosion, wetlands destruction, and deterioration of barrier islands. Particularly concerning is the intensification of flooding following storm events as the sea level rises in the region.

In this report, we take a first step at identifying areas of valuable green infrastructure that are at most risk of either being destroyed or severely impacted by sea level rise. A multi-year regional Climate Change study, which looks at this subject in more detail for the Hampton Roads region, is also underway by HRPDC staff.

GIS Data Updates

Not only are regional planning issues driving the need for an updated plan but also the availability of high quality regional geographic information systems (GIS) data. One of the challenges of creating regional GIS models is finding data that covers the entire area of interest with the same accuracy and resolution. There were two updated datasets incorporated into the model: land cover and the Virginia Natural Landscape Needs Assessment (VaNLA) ecological cores. There was also one new dataset produced through a collaboration of several state agencies that was considered for inclusion in the model update. This dataset is called the Priority Conservation Areas (PCA).

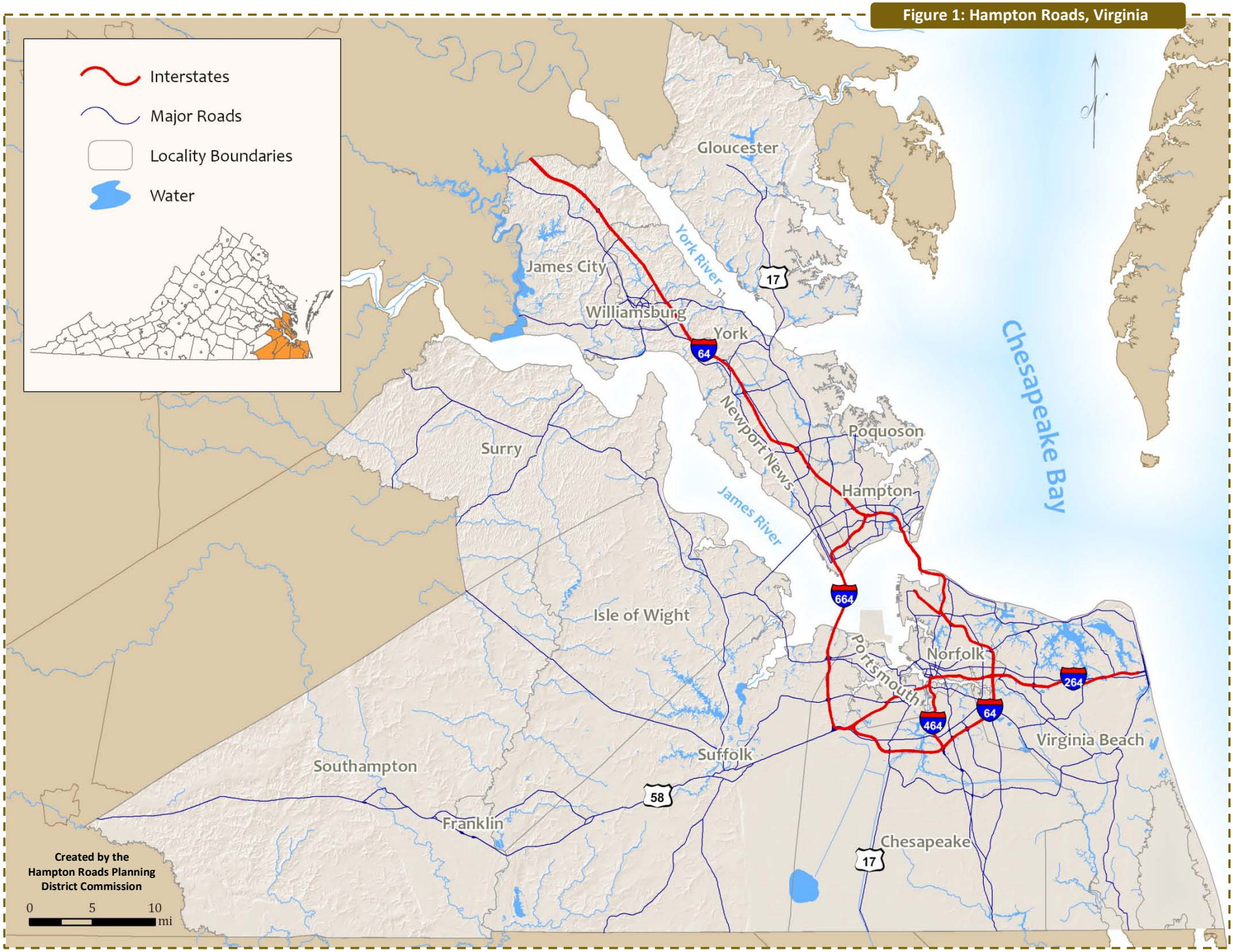


Figure 1: Hampton Roads, Virginia

Stakeholder Involvement

Several different processes were used to provide opportunities for stakeholder input in the update of the Hampton Roads green infrastructure network. A series of four meetings with local government staff of the HRPDC member localities was held to collect information on local planning initiatives. There were also several meetings, telephone conversations, and email correspondence with natural resource experts with the Virginia Department of Conservation and Recreation (DCR), the Virginia Institute of Marine Science (VIMS), and the Virginia Department of Game and Inland Fisheries (VDGIF).

Locality Meetings

Meetings were held with four groups of Hampton Roads localities based on geography: Western Tidewater (Franklin, Isle of Wight, Southampton, Suffolk, and Surry), Southside (Chesapeake, Norfolk, Portsmouth, and Virginia Beach), Southeast Peninsula (Hampton, Newport News, and Poquoson), and Northwest Peninsula (Gloucester, James City, Williamsburg, and York). Prior to the meetings, the HRPDC researched planning documents from each of the localities to investigate local green infrastructure planning efforts. Documents that were reviewed included comprehensive plans, growth management plans, and parks and recreation plans, among others. The packets were distributed to attendees prior to the meetings.

The meetings with the localities consisted of two parts. To begin, the HRPDC gave a presentation describing the background and goals of the project. Then each locality was asked about ongoing updates to their comprehensive plans as well as information on how they were integrating green infrastructure into their plans and policies.

These discussions revealed that Hampton Roads localities are working on many projects that relates to regional green infrastructure planning. The localities were at different stages in the comprehensive planning process at the time of the meetings. Some localities had recently finished a plan or plan update (Isle of Wight, Smithfield, Newport News, Hampton, Poquoson, Williamsburg, and York), while others were just beginning (Chesapeake and Gloucester) or were well into the process (Virginia Beach, James City, Franklin, and Norfolk). Several localities were putting together bicycle and pedestrian plans (Franklin, Isle of Wight, and Smithfield) or already have them (Williamsburg and Virginia Beach). A few of the localities have open space acquisition or preservation plans (Isle of Wight, Chesapeake, and Virginia Beach). Two localities, Chesapeake and

Hampton, were working on urban forestry plans. Several were updating their parks and recreation plans at the time of the meetings (Virginia Beach, Norfolk, James City, and Gloucester). Regionalism and connectivity between neighbors are also finding official sanction in some of the plans (Franklin, Isle of Wight, Chesapeake, Norfolk, James City, Williamsburg, and York).

Natural Resource Agency Meetings

Meetings were also held with staff from DCR and VIMS. These meetings were held to introduce the green infrastructure plan and ask for both information and comments on project scope and methodology.

The meetings with DCR and VIMS revealed several programs that both agencies were working on that could integrate with the green infrastructure update. DCR suggested several of its projects that might benefit the green infrastructure network update. These included the Virginia Biodiversity Assessment, the Vulnerability Model, and the Virginia Conservation Lands Needs Assessment, which includes several other models as components.

At the time of the meeting, DCR was also working with the VDGIF and Virginia Commonwealth University (VCU) on the creation of a new geographic information systems (GIS) model to produce a dataset called the Priority Conservation Areas (PCA). This model was identified as being potentially useful and could help identify areas of high ecological significance and/or areas that are at risk of being destroyed.

VIMS discussed several studies with potential for informing the green infrastructure network. Two of the studies, a maritime forest cover study and a shallow water habitat study, could help identify areas of high ecological significance. VIMS staff offered their advice in putting together a methodology for incorporating prioritization or risk of development into the green infrastructure model.

A small group meeting was held later in the process at the HRPDC to review draft work products of the green infrastructure plan update. Staff from DCR, VDGIF, and VIMS attended. This group provided useful feedback and made suggestions for improving the green infrastructure model and the vulnerability to development model as well. There was

also a detailed discussion of how to include the PCA dataset in the plan. Many of the suggestions were incorporated into the final results.

Other suggestions for the green infrastructure update from both the localities and natural resource agencies included incorporating recreational green and open space such as trails and parks and having a more fine-grained approach to what is included in the network and regional plan. This approach would also include green infrastructure that does not connect into the larger system. Another suggestion that came out of the meeting was for localities to develop their own open space corridor plans that would then fit into the regional plan; these locality plans could include more of the smaller scale sites. VIMS and DCR both suggested incorporating some sort of risk component to prioritize areas for acquisition based on how threatened they are or the likelihood of development.

Joint Environmental Committee Meetings

The HRPDC Joint Environmental Committee (JEC) was used to provide status reports to local government and state agency staff on the green infrastructure update process and as a forum to discuss related issues of watershed planning and regulatory compliance. These discussions provided valuable feedback to HRPDC staff as options and data for the update were considered. The broad range of expertise of the participants in the JEC, including urban and environmental planning, storm water management, engineering, and program management make it a valuable forum for the discussion of crosscutting issues.

Multiple Benefits Conservation Plan Memorandum of Agreement Meeting

The signatory agencies to the Multiple Benefits Conservation Plan Memorandum of Agreement (MBCP MOA) participated in a meeting hosted by the HRPDC to discuss the possibility of expanding the MOA beyond the southern watershed to the entire Planning District. The MBCP MOA was developed during the Southern Watershed Area Management Program (SWAMP) to improve wetlands mitigation by encouraging the selection of mitigation sites in and adjacent to the green infrastructure network. Several aspects of the possible expansion of the geographic area of application of the MOA were discussed. One potential problem with the expansion identified by Virginia Department of Environmental Quality staff is the heterogeneous nature of the wetlands and watersheds across the large area of the Hampton Roads Planning District. Given this issue a single regional MOA would be difficult to administer. While no one at the meeting was opposed to the possible expansion little support existed for actively pursuing it.

Green Infrastructure Network Update

The green infrastructure network update process was completed utilizing geographic information systems (GIS) modeling techniques. In addition to updating the network, several other tasks were completed to enhance the usability of the network for green infrastructure planning. The four primary components in the green infrastructure plan are:

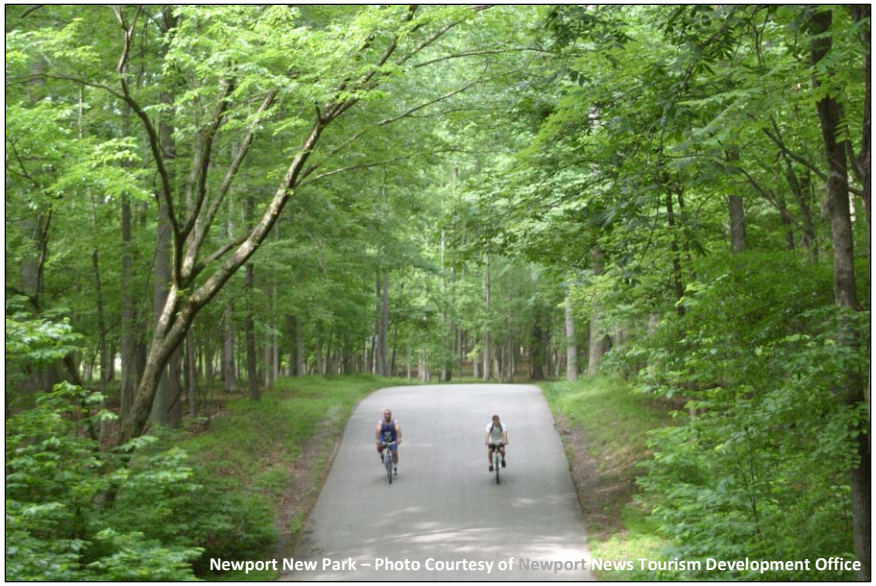
1. **An updated Green Infrastructure Network and change analysis;**
2. **The Vulnerability to Development Model;**
3. **Vulnerability to Sea Level Rise Assessment; and**
4. **A regional Parks and Recreation Inventory.**

The main focus of the plan is the updated green infrastructure network. The goal is not only to update the network with newer information but also to investigate where changes in the landscape have occurred and why these changes have occurred.

The updated plan goes a step further and attempts to identify those ecologically high valued lands that are most vulnerable to future development. A Vulnerability to Development model was developed for this purpose.

The updated plan also begins to look at how green infrastructure might be impacted by sea level rise through the end of this century. A map was created to show where the green infrastructure network may be vulnerable to increased sea levels.

Finally, the last component of this Plan is an updated regional Parks and Recreation map and database. Parks are recreation facilities are vital to creating linkages between conservation areas as well as to provide access to the public.


Newport New Park – Photo Courtesy of Newport News Tourism Development Office

GIS Data Updates

The updated green infrastructure network was created using the same GIS methodology that was developed in *The Hampton Roads Conservation Corridor Study* (Hampton Roads Planning District Commission, 2006). In the original model, four regional GIS data layers were utilized: wetlands, riparian corridors, Virginia Natural Landscape Needs Assessment (VaNLA) ecological cores, and land cover.

Two of the original datasets used were not updated for this project as no new information was available on a regional scale. The wetlands data is from the National Wetlands Inventory (NWI) program administered by the United States Fish and Wildlife Service (USFWS). The riparian corridors were derived from hydrology data that was included in the statewide Virginia Base Mapping Project (VBMP) in 2002.

In order to reflect changes in the landscape over a period of four years, updated versions of the remaining two layers – the VaNLA ecological cores and land cover – were incorporated into the model. Since the HRPDC's Conservation Corridor Study was published in 2006, the Virginia Department of Conservation and Recreation (DCR) updated its VaNLA ecological cores dataset, which is now available for the entire state of Virginia. Ecological cores are areas of un-fragmented natural habitats with at least 100 acres of interior conditions (Bulluck, Ciminelli, & Weber, 2007). Originally, only the Coastal Zone of Virginia was completed for the VaNLA pilot project. Consequently, Southampton County was not included in this dataset and so the 2006 green infrastructure network had a data gap. Since the latest version of VaNLA

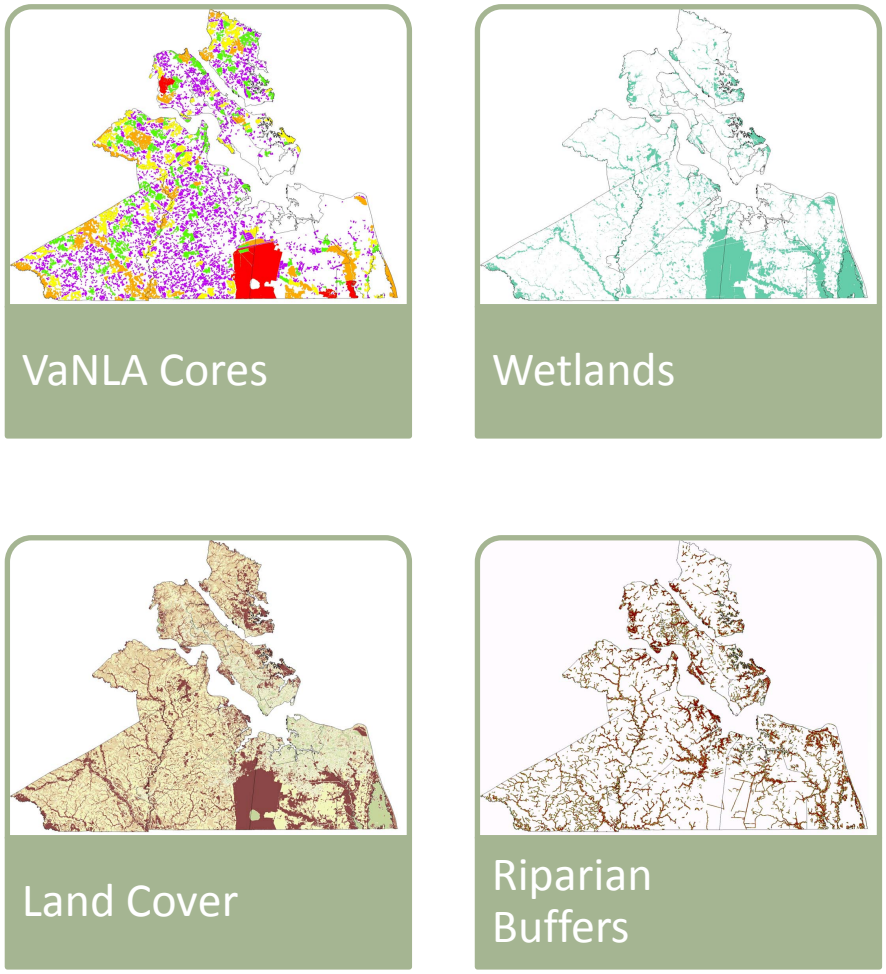


Figure 2: Green Infrastructure Model Inputs

includes Southampton County, the updated model is inclusive of all of the sixteen jurisdictions in the Hampton Roads Planning District.

The second data layer that was updated was the land cover. In the 2006 Network, the National Land Cover Dataset (NLCD) (2001) from the United States Geologic Survey (USGS) was used. Since the NLCD has not been updated since 2001, a substitute was made using the Virginia 2006 Land Cover Data available from the National Oceanic and Atmospheric Administration's (NOAA) Coastal Change Analysis Program (C-CAP). This dataset is derived in a similar fashion as the NLCD as both are derived from Landsat satellite data. However, the C-CAP land cover classifications were refined to better reflect land cover found in coastal areas of the United States.

Green Infrastructure Model

The GIS methodology used to update the Network was replicated from the original Plan in order to develop a proper comparison between the two networks. In summary, a weighted overlay analysis model was created to identify areas most suitable as green infrastructure. Each of the four datasets was converted into a raster GIS format. Then the attributes of the individual layers were ranked based on suitability for green infrastructure. For example, the "forest" category outranked the "developed" category in the land use dataset and the riparian buffers closest to the water were ranked higher than those that were further away. After each of the four datasets was ranked, the datasets were weighted with a certain percentage and multiplied with each other.

The percentage that each of the data layers was assigned during multiplication was derived from input through a series of stakeholder meetings held during the preparation of the 2006 Conservation Corridors report. The stakeholders included professionals from local governments and state natural resources agencies. They participated in two exercises. The first asked them to rank each of the four data layers against each other from the perspective of habitat preservation. The exercise was repeated using a water quality preservation perspective when ranking the layers. The stakeholders' inputs were assembled and used to complete the green infrastructure model.

In order to maintain consistency and study the change in green infrastructure over time, the same stakeholder-derived inputs were used for the updated network. Figure 3 shows the final green infrastructure network for the Hampton Roads region. Those areas in green show land that is valued highly from both the habitat and water quality perspective. Further details regarding the original GIS methodology can be found in the original Conservation Corridors report (Hampton Roads Planning District Commission, 2006).

Figure 3: 2010 Green Infrastructure Network

Incorporating the Priority Conservation Areas

Green infrastructure planning is also a high priority at the state level in Virginia, as evidenced by the collaboration of several state agencies to produce a new GIS product called the Priority Conservation Areas (PCA). The PCA was developed by staff from the Virginia Department of Game and Inland Fisheries (VDGIF) in partnership with Virginia Department of Conservation and Recreation (DCR) – Division of Natural Heritage, and Virginia Commonwealth University – Center for Environmental Studies (VCU). In general, the PCA represents conservation data that has been synthesized and prioritized into one dataset with the goal of assisting local and regional planners in their green infrastructure or comprehensive planning initiatives (Virginia Department of Game and Inland Fisheries, 2009).

The PCA incorporates several diverse conservation datasets from these different state agencies. VDGIF developed a new dataset called the Priority Wildlife Diversity Conservation Areas (PWDCA) for the purpose of informing the PCA. DCR contributed its Conservation Sites and Natural Land Network datasets to the effort. Finally, VCU provided aquatic conservation information with its Aquatic Resource Integrity Layer (see Figure 4).

The PCA offers several advantages for green infrastructure planning in that it incorporates a diverse set of conservation data that is not found in the VaNLA alone. This dataset is ideal for use in this type of analysis and is an excellent resource for local and regional planners who are beginning green infrastructure planning. Thus, the HRPDC considered using the PCA in lieu of the VaNLA cores during the update of the green infrastructure network. To compare and contrast the results using different data sources, the HRPDC created a second version of the green infrastructure network using the PCA data.

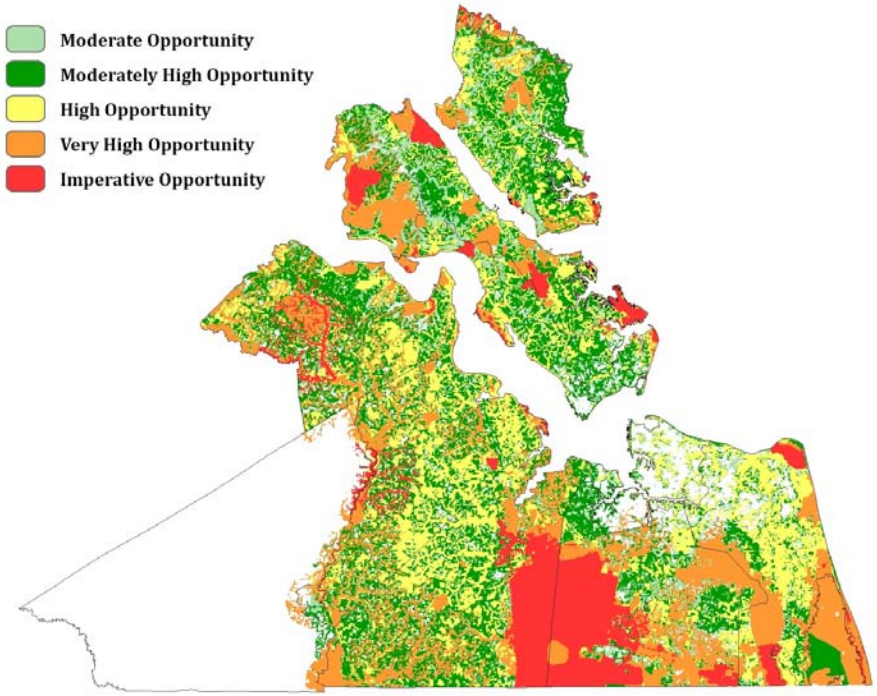


Figure 4: Priority Conservation Areas

In order to make this comparison, the 2010 Green Infrastructure Network was altered so that the VaNLA component to the model was substituted with the PCA. The PCA was ranked in the same way as the VaNLA cores. All other variables remained the same in the model. The result of substituting the PCA into the HRPDC green infrastructure model is shown in Figure 5.

Overall, the results show a remarkably similar pattern of green infrastructure. The PCA version of the HRPDC model does identify several large areas of green infrastructure not shown in the VaNLA version of the network, particularly in York County and James City County. Riparian areas stand out more in the PCA version of the green infrastructure network as well. This may be due to the fact that the PCA was processed at 100 meter cells while the HRPDC model was run with 30 meter cells. The difference in cell size means that while more areas were identified using PCA, some of the details are lost due to the larger resolution.

Although the PCA is a tremendous resource, ultimately the HRPDC decided to use the VaNLA cores in the "official" green infrastructure network for this project. The primary reason is to create continuity between the previous effort and this current project as well as retain the ability to conduct a change analysis. Also, with the PCA only covering the Coastal Zone, Southampton County is left out of the analysis.

The HRPDC recommends that the PCA should be completed for all of Virginia to allow users from all across the state to utilize the valuable information. It would also be likely that the PCA would be included in any future updates to the green infrastructure network in Hampton Roads if the entire planning district was available.

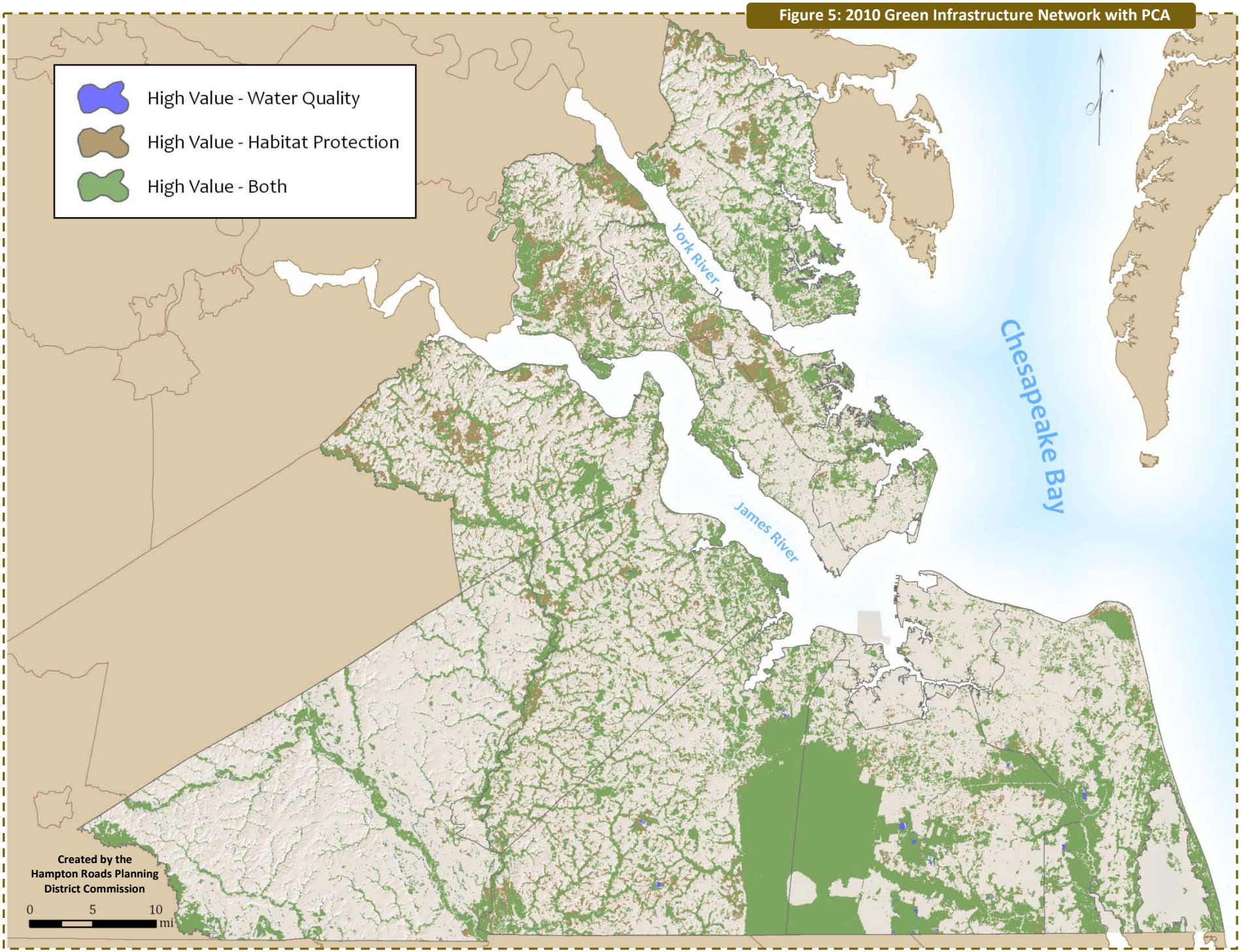


Figure 5: 2010 Green Infrastructure Network with PCA

Green Infrastructure Change Analysis

A change analysis study was conducted using GIS to determine where the green infrastructure network had changed over a four year time period. For the purposes of this plan, the 2006 and 2010 green infrastructure networks were compared to identify areas where the ecological value of the green infrastructure increased or decreased over a four year time frame.

It was necessary to calibrate the green infrastructure model from the 2006 Plan to make a proper comparison between the 2006 and 2010 green infrastructure networks. Since the updated model is utilizing the C-CAP land cover data, the 2006 model was recreated by replacing the NLCD land cover (2001) with the C-CAP land cover data (2001). By making this substitution, both models are utilizing data created by the same source. This makes the change analysis more accurate and eliminates one possible source of discrepancy in the change analysis (see Figure 6).

The change analysis was done by simply calculating the difference in values between the 2006 and 2010 green infrastructure networks to determine if there was an increase or decrease in ecological value. The results are shown in Figure 7. Any area that experienced an increase in value is depicted in green; likewise, an area that saw a decrease in value is shown in red. Those lands that did not change in value are reflected by the gray area on the map. There were ten different scenarios for how the Network changed. These different categories were collapsed to simplify the map. The land cover change matrix is shown in Table 1.

From (2006)	To (2010)	Map Category
Low	Both	Increase
Low	Water Quality	Increase
Low	Habitat	Increase
Water Quality	Both	Increase
Habitat	Both	Increase
Habitat	Low	Decrease
Both	Water Quality	Decrease
Water Quality	Low	Decrease
Both	Habitat	Decrease
Both	Low	Decrease

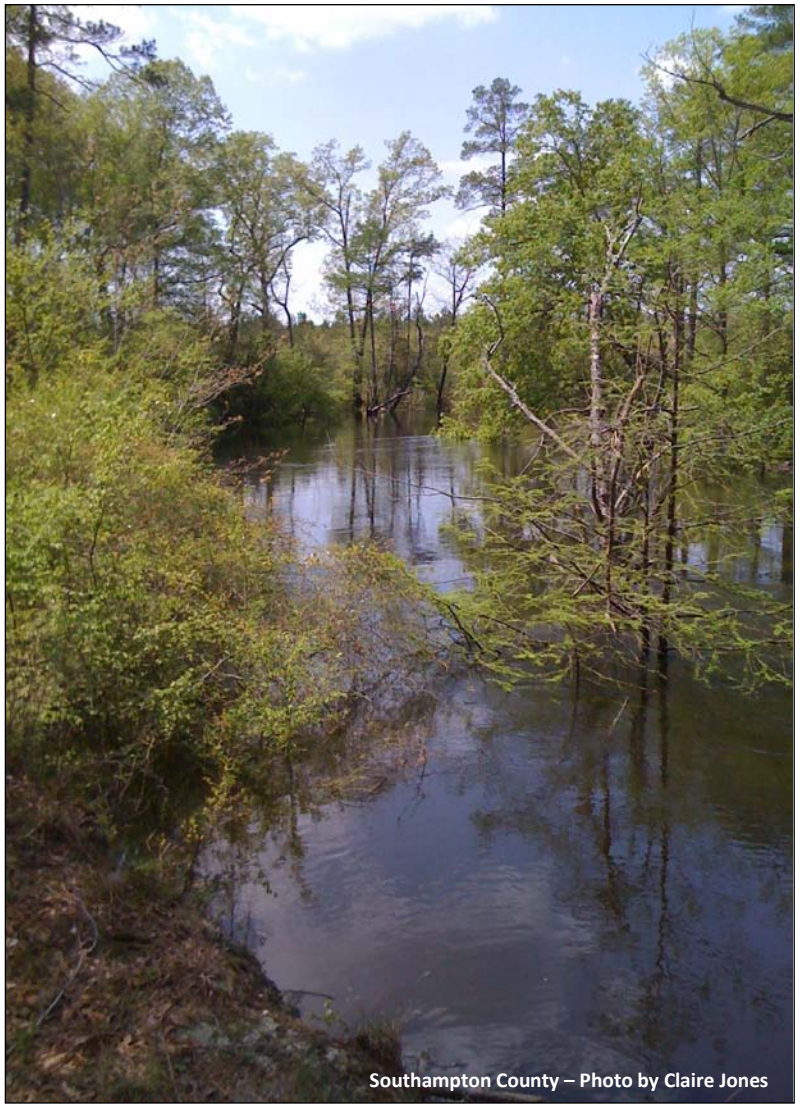
Table 1: Summary of Green Infrastructure Network Changes

Low = Low value for green infrastructure (GI)
Water Quality = High value for GI from water quality perspective
Habitat = High value for GI from habitat protection perspective
Both = High value for GI from both water quality and habitat protection

The lands that decreased in value fell into two main groups. Three of the categories describe once highly valued areas that dropped to Low. Two of the categories describe land that was highly valued in both water quality and habitat protection but now are only valued highly for one or the other.

It is important to note that the areas in red on Figure 7 merely show a change in value from 2006 to 2010 – it does not necessarily mean that those areas have been lost to development.

Additionally, Southampton County shows a large amount of land that increased in ecological value. This is because the VaNLA data did not exist for Southampton County in the 2006 Network. Therefore, the change shown in this area depicts only an increased value, which may or may not be an accurate representation of the actual change.


Southampton County – Photo by Claire Jones

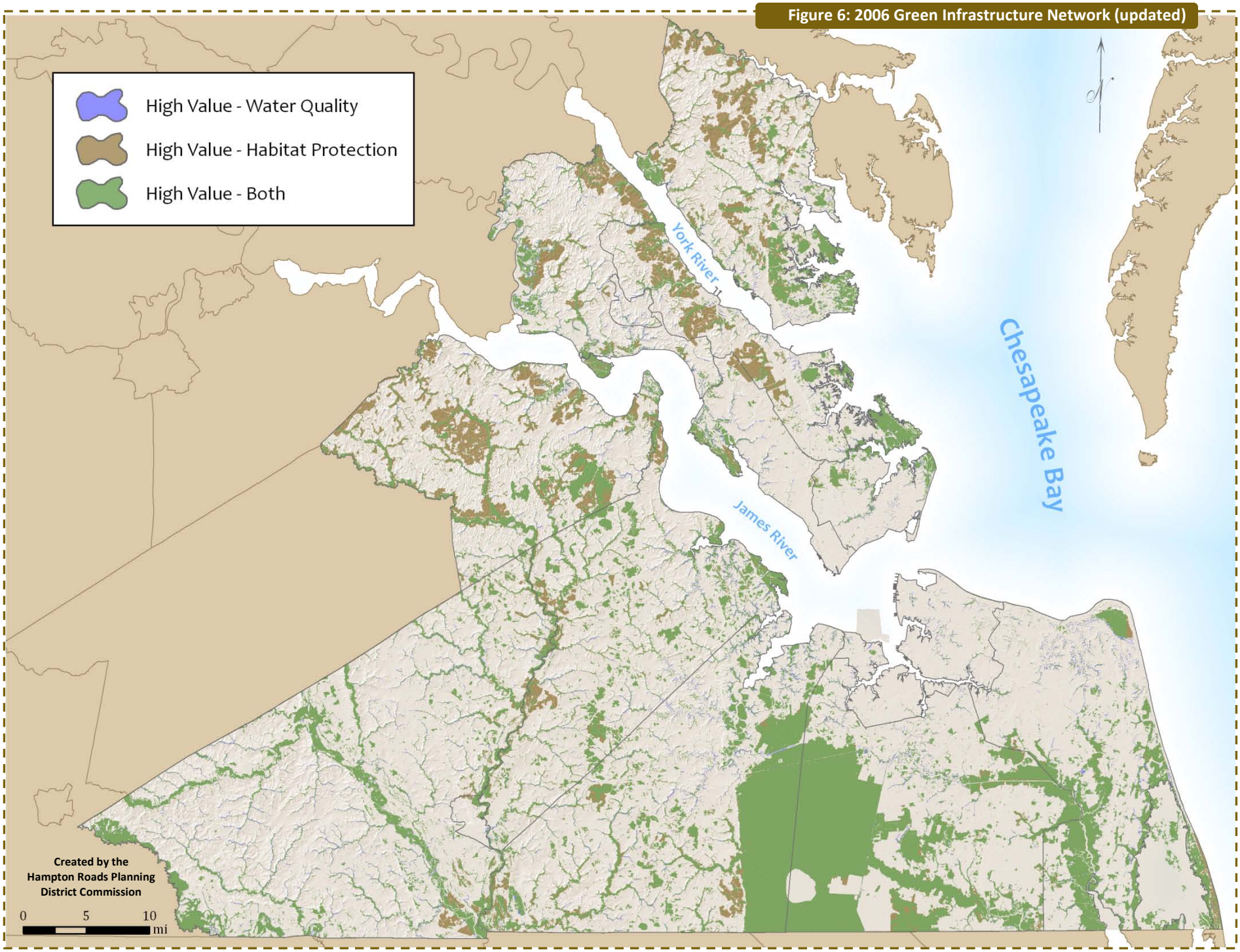


Figure 6: 2006 Green Infrastructure Network (updated)

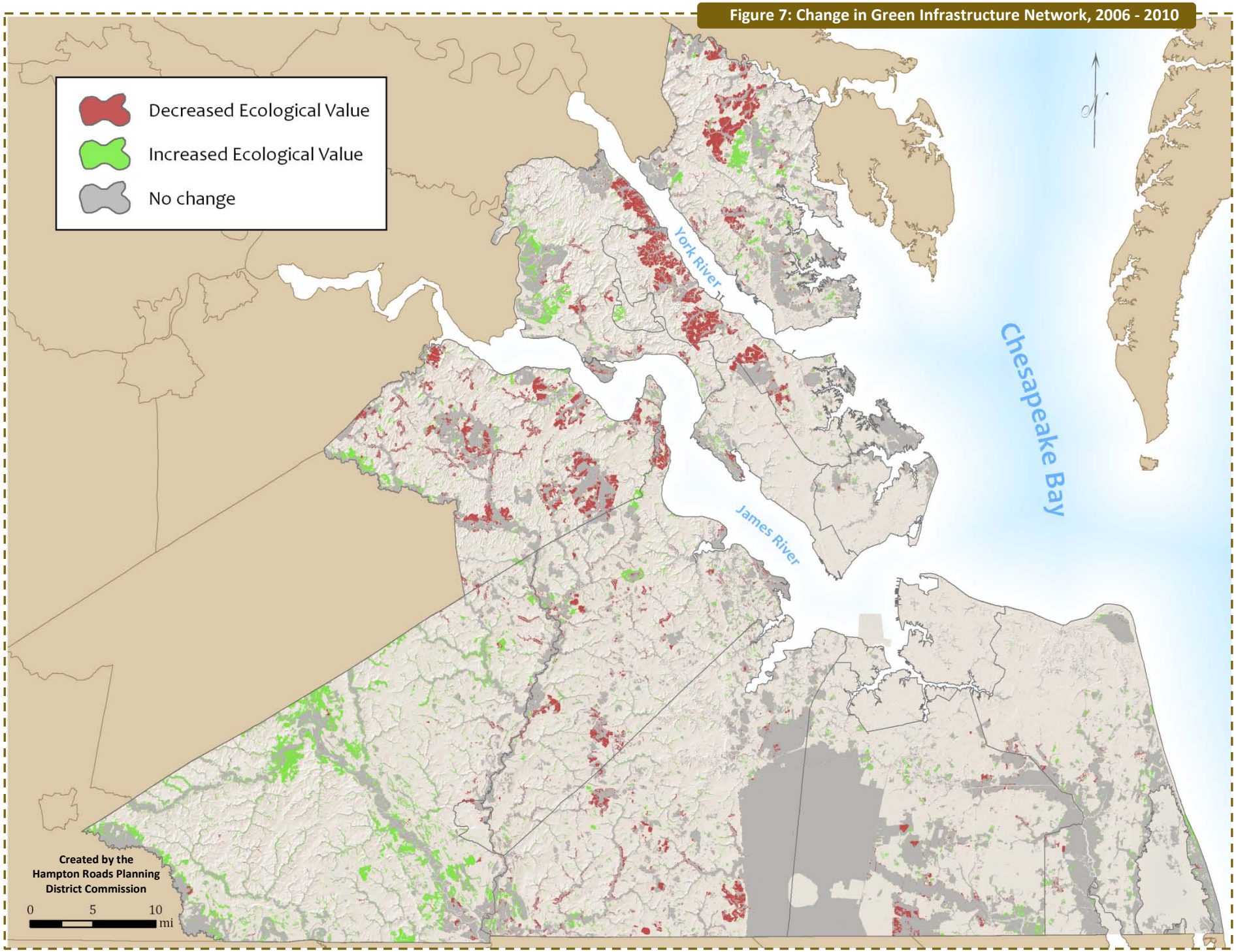


Figure 7: Change in Green Infrastructure Network, 2006 - 2010

Green Infrastructure Change Analysis Discussion

The results of the green infrastructure change analysis showed that a significant portion of the 2006 green infrastructure network decreased in ecological value in a period of just about four years. In order to understand why this is the case, the HRPDC took a closer look at changes that occurred on the regional landscape in that time frame.

Regional Land Use Changes

The first tool used was land cover change analysis. As a component of the C-CAP Regional Land Cover Program, NOAA also developed datasets that show the change in land cover over time. For the purpose of this project, the *Virginia 2001-2006 Land Cover Change Data* was reviewed. The major categories of land use change can be seen in Figure 9.

As shown in Figure 8 on the right, the largest category of land cover change is Forest to Grassland/Scrub at 37%. This combined with the Grassland/Scrub to Forest (14%) category supports the notion that timber harvesting activity is being picked up in this change analysis. Timber harvesting is prevalent in the western Hampton Roads region. Southampton County alone accounted for 4% of the value of timber harvested in 2007 in Virginia (Virginia Department of Forestry, 2009). This ranks Southampton County third in the Commonwealth for total value of harvest timber. This land-altering activity is attributed to causing the most change seen between the 2006 and 2010 green infrastructure networks.

The large percentage of change of Pasture/Hay to Cultivated suggests that the agricultural cycle is being highlighted in the data. This category accounts for 21% of the change.

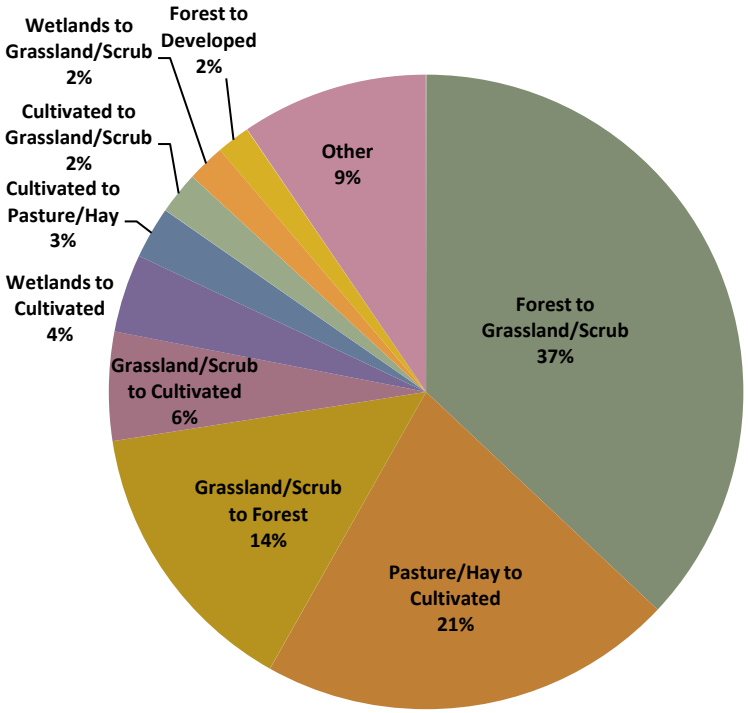
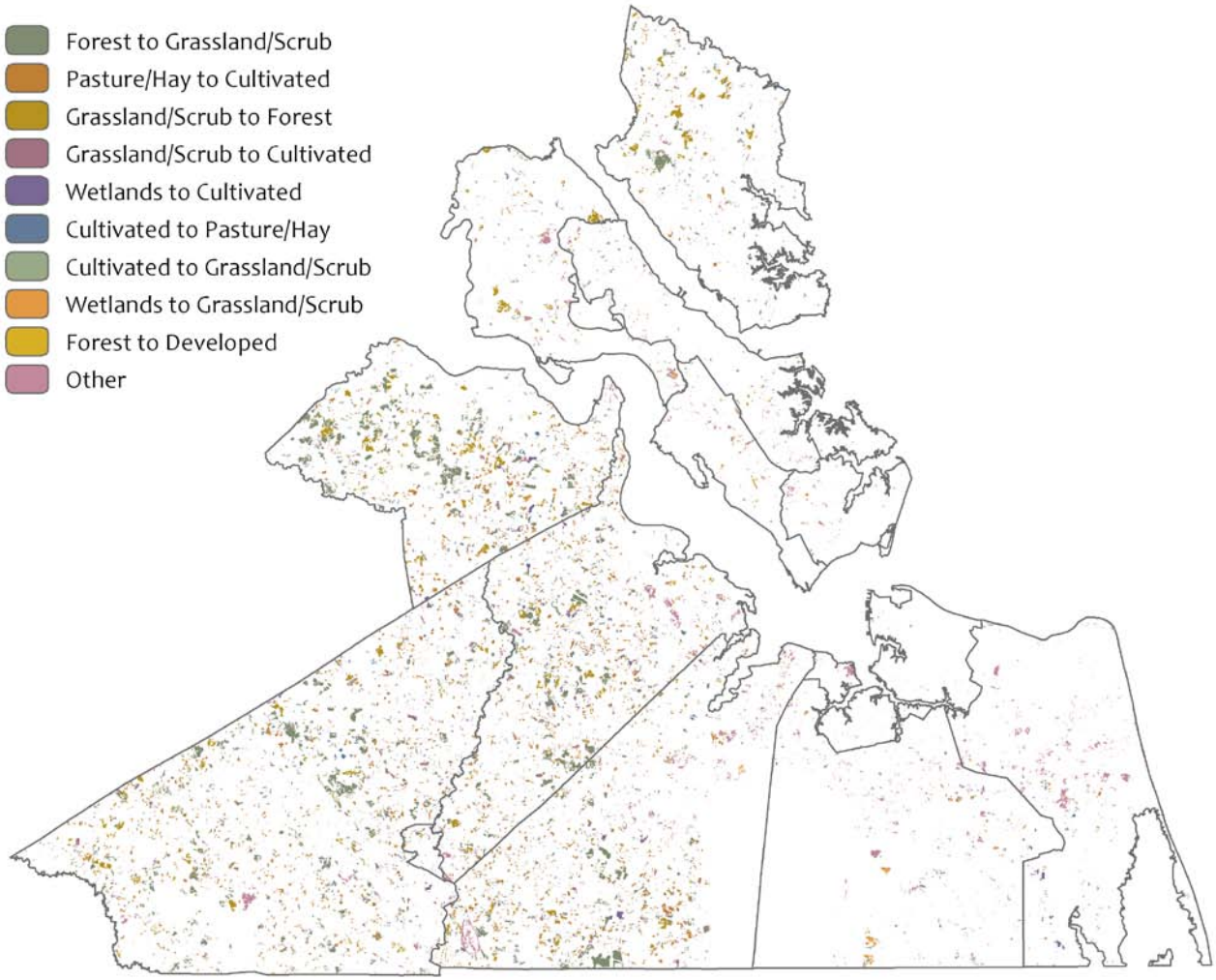


Figure 8: Percent of Land Cover Change by Category

Figure 9: Land Cover Change 2001 - 2005



The amount of land that was converted to development was approximately 6% of the total land that changed. The largest category was Forest to Developed at 2% of the total change. Other categories that each represented 1% of the total were Developed Open Space to Developed, Cultivated to Developed, Wetlands to Developed, and Grassland/Scrub to Developed. It is also interesting to note that a majority of the land that was developed in some capacity between 2001 and 2005 was not identified as valuable in the green infrastructure network.

VaNLA Ecological Cores Update

DCR produced a major update to its VaNLA ecological cores data, which was completed in 2007. The modeling was expanding to cover the entire state of Virginia. The VaNLA data was refined by updating the land cover data which better depicted certain problematic categories such as Barren, Beaches and Maritime Grasses. DCR also updated the method in which the Ecological Integrity (EI) score was calculated, which includes some 53 characteristics relating to rare species and habitats, species diversity, and water quality, among others (Bulluck, Ciminelli, & Weber, 2007). The updates made to the VaNLA cores were a definite factor in how the Hampton Roads green infrastructure network changed. Figure 10 compares the VaNLA cores between the 2004 and 2007 versions.

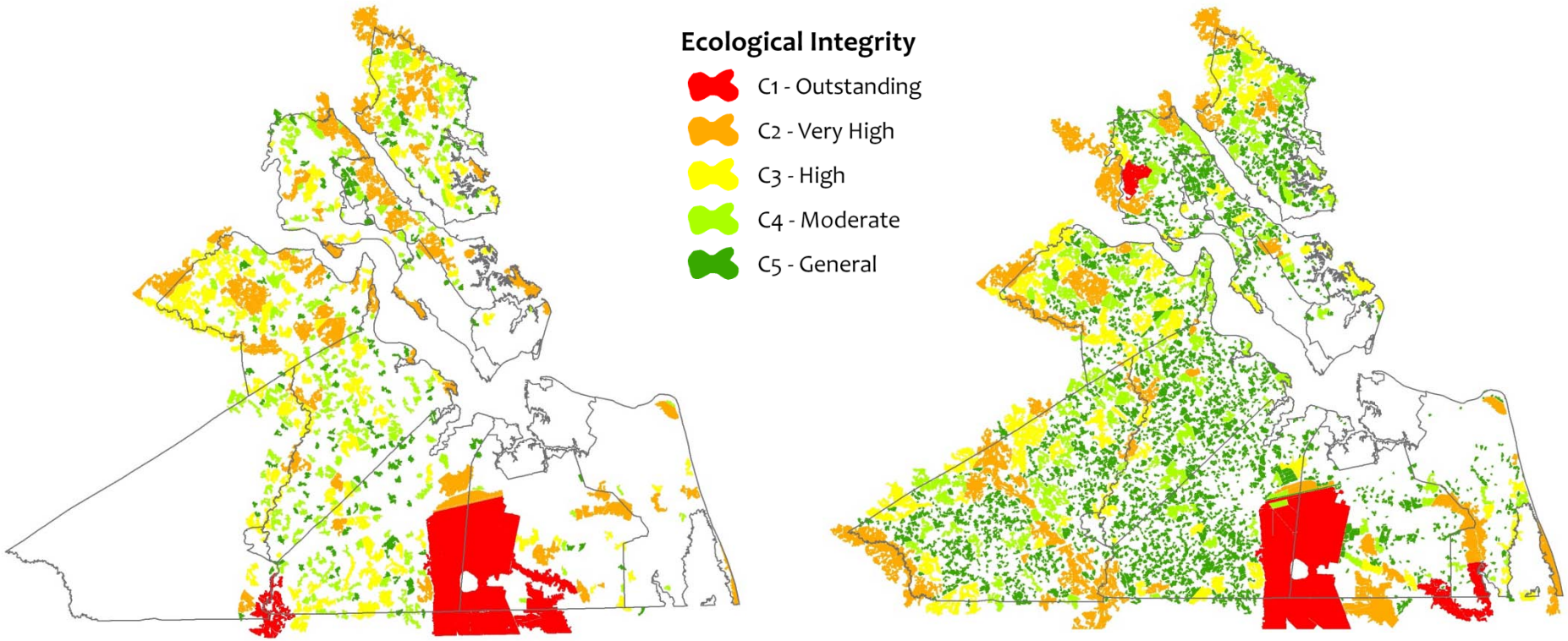


Figure 10: VaNLA Ecological Cores

Green Infrastructure Change at the Local Level

In order to give more insight into how changes on the landscape affect the green infrastructure network's integrity, two sample areas were identified for a more detailed analysis. Areas were chosen that belonged to the green infrastructure network in the 2006 report and were shown to have decreased in ecological value.

Study Area #1: Surry County

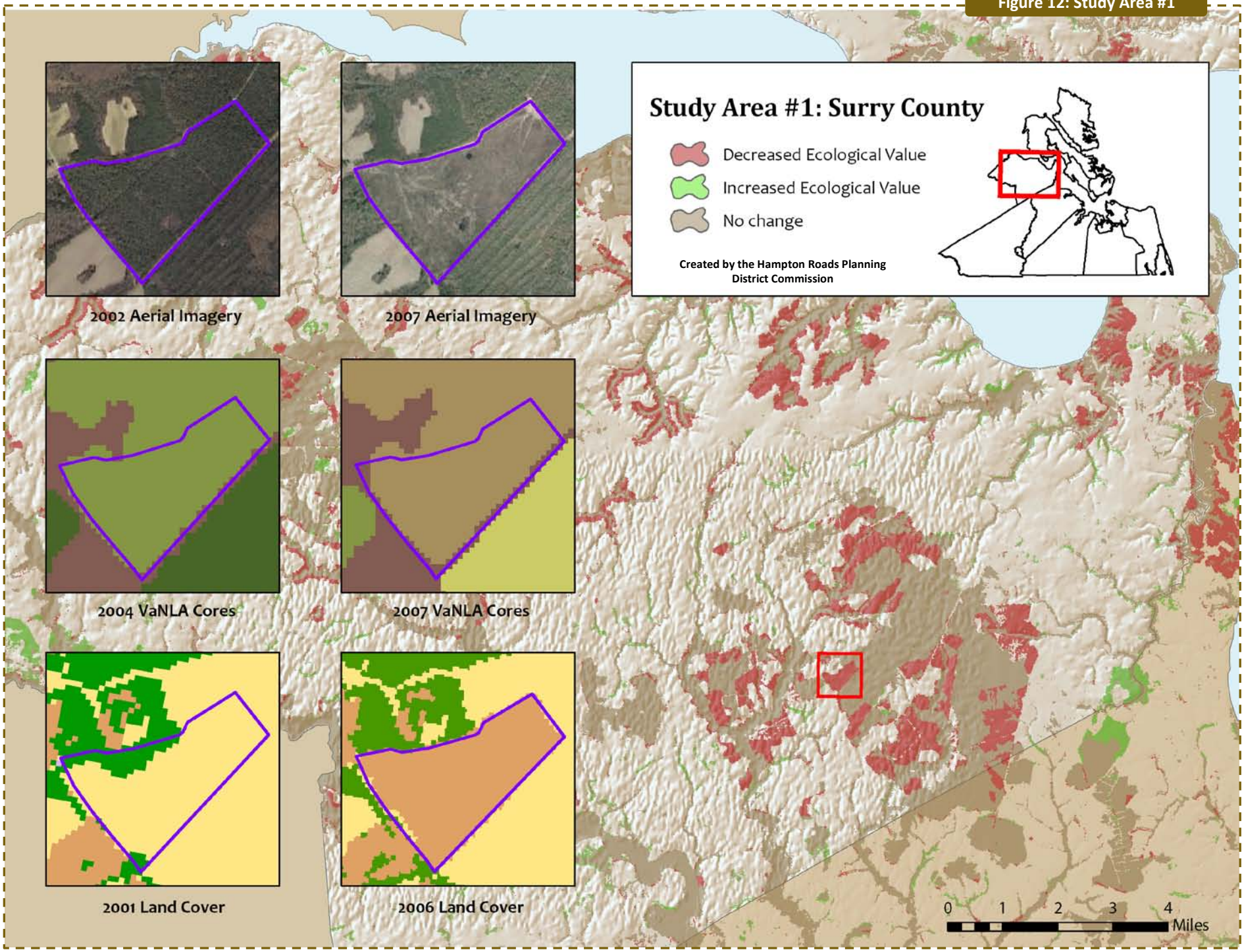
A significant portion of the green infrastructure in Surry County changed between the 2006 and 2010 plans (see Figure 7) and so the first study area was selected from here. This particular plot stood out because of the obvious change in land cover that occurred.

Figure 12 compares and contrasts several GIS datasets from the two time periods studied. From the aerial imagery, it is clear that trees have been removed from the property. The photo to the right (Figure 11) shows the land as it looked in 2009. According to the C-CAP data, the land cover in 2001 was Forested Wetland and a small area of Forested. In the 2005 land cover, it was classified as Grassland. This particular area also experienced a drop in value with the updated VaNLA ecological core dataset. What was once ranked as a C3 (High) core is now ranked as C4 (Moderate).

This tract of land was ranked high for both habitat and water quality protection in the 2006 green infrastructure network. In the current version of the network, it is not considered valuable for either category. The removal of trees that occurred in this area demonstrates that when large continuous areas of land cover are fragmented, their value for contributing to green infrastructure diminishes.

Figure 11: View of disturbed land in Surry County

Figure 12: Study Area #1



Study Area #2: York County

When the results of the change analysis were reviewed, it was surprising to find that much of the green infrastructure in York County had been completely left out of the updated Network (compare Figures 3 and 6). To understand why this happened, HRPDC staff looked at a small area in York County to review the individual GIS data layers.

The area selected is within the boundary of Camp Peary and is a riparian area with wetlands on a stream that branches off of Queen's Creek. There were no major changes to the land cover in the area when examining the orthophotography and the C-CAP land cover data from different years (see Figure 14).

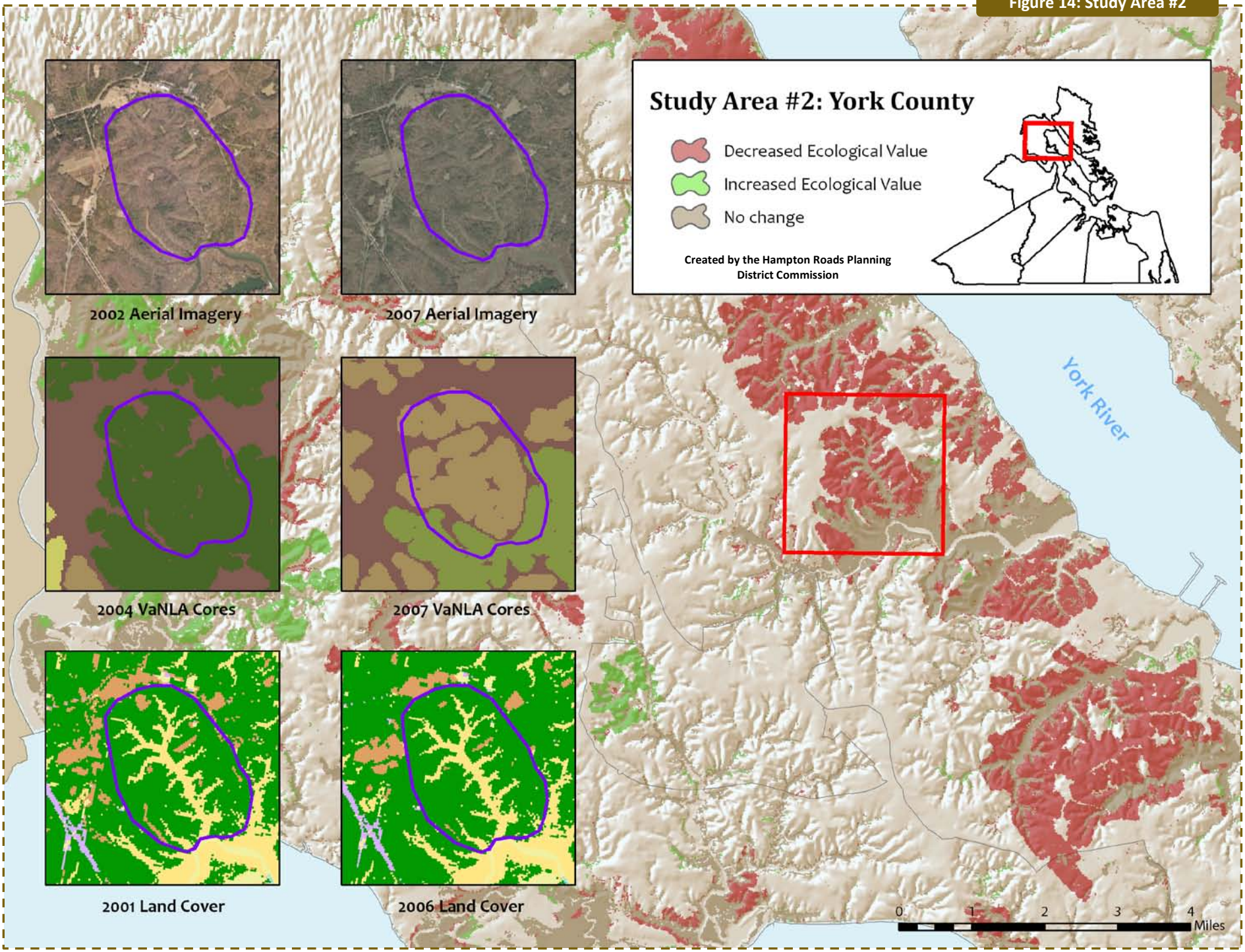
In the 2004 version of the VaNLA cores, this area was a continuous core ranked as C2 (Very High). In the updated version, the core had been fragmented by roads and was divided into a C3 (High) core and a C5 (General) core. The lower EI values caused this area to not reach the ranking threshold in the green infrastructure model. Consequently, it was not identified as highly valuable in the green infrastructure network.

The roads in this area existed during the first VaNLA project. However, after being updated, the model did a better job of identifying some of the smaller, more obscured roads like those found on military installations with an abundance of forested property.

This area near Queen's Creek still has value as a conservation area. The cores are still identified in the VaNLA project as landscape nodes. A landscape corridor also passes through the area, connecting the two cores together.

Figure 13: View of Queen's Creek from I-64

Figure 14: Study Area #2



Vulnerability of Green Infrastructure to Development

As the region experiences growth, there is always a concern that valuable conservation areas could succumb to the pressures of development. In order to mitigate this risk, it is prudent to understand where new development is likely to occur on a regional scale and what impact it might have on the green infrastructure network. Since funds for land acquisition are limited, identifying those areas with the highest conservation value that are most vulnerable to development gives localities and other organizations a tool to allocate their resources and prioritize acquisitions.

A vulnerability to development model was created as a component to this project to allocate potential future growth throughout the region and to identify those ecologically significant areas that might be under pressure for development.

Model Development

A literature review was conducted to identify characteristics that would indicate a high probability of future growth in the model. The focus was on identifying the types of indicators rather than specific data sources. The review showed that distance to existing roads and distance to existing development were two significant indicators of future growth. A third important indicator is population. Most growth pressure or vulnerability studies rely on population growth trends to predict the quantity of future growth and where the growth with be distributed. Case studies that were reviewed using this methodology included those

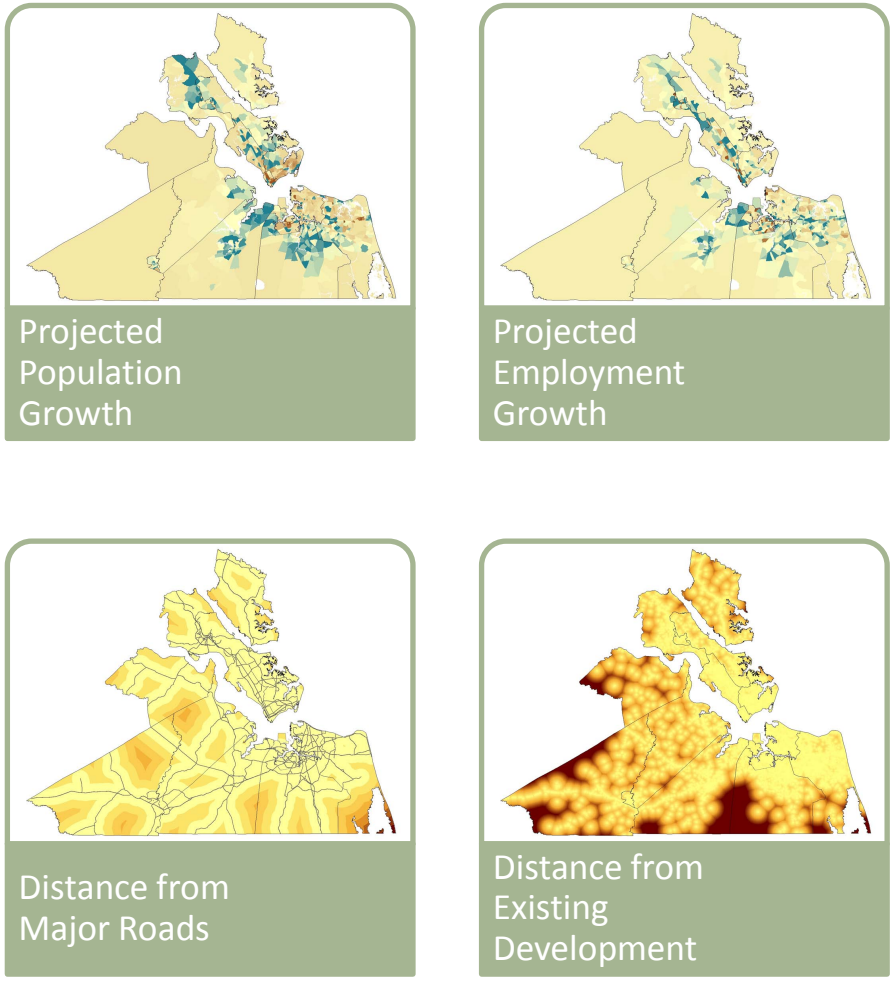


Figure 15: Vulnerability Model Inputs

done at Virginia DCR (Virginia Department of Conservation and Recreation, 2006), Maryland Department of Natural Resources (Weber, 2004), and University of Virginia (Lambert, 2009). These studies made use of United States Census data for current population or to create future population estimates based on past trends. The main concern with using 2000 Census data for the HRPDC vulnerability model was that the Census data is ten years old and a new Census count is currently underway.

A suitable population estimate was substituted to better refine the model for the Hampton Roads area. Both estimated population and employment numbers were used in order to model both residential and commercial development. Population and employment growth numbers were based on projections developed by the Hampton Roads Transportation Planning Organization (HRTPO) (Hampton Roads Transportation Planning Organization, 2008). Some areas of the Hampton Roads Planning District (Southampton County, Surry County, and northern Gloucester County) are not in the HRTPO; so population estimates in these locations were obtained from HRPDC socio-economic forecasts (Hampton Roads Planning District Commission, 2007). HRTPO population and employment estimates were made using Transportation Analysis Zones (TAZ), which are at a sub-locality level. Estimates for non-HRTPO areas were at the locality level. Most estimates were for the year 2034; estimates for the City of Franklin were for the year 2035.

Existing roads were obtained from the Road Centerline Program dataset provided by the Virginia Geographic Information Network (VGIN). For the purposes of this model, only primary roads were selected since most development tends to occur near existing major roads. Existing development was based on the 2005 C-CAP land cover data. To represent existing development, the high and medium intensity developed categories were extracted from the land cover dataset.

Once the data sources were identified, the data was refined for input into the model. First, new datasets were created for both population estimates and employment estimates by TAZ. Then, the growth per acre was calculated for each area TAZ by dividing the difference between the 2000 and 2034 population estimates with the number of acres in the TAZ. The population and employment growth layers were then converted into a raster format and reclassified into two categories: below average growth and above average growth. The above and below average technique was used as a simplified way to represent growth. This method smoothes out the data in order to highlight major trends.

To find the distance from major roadways and existing development, distance functions were run in the GIS. The resulting data layers were also reclassified into above average distance and below average distance categories. In all cases, the term “average” refers to the arithmetic mean.

A weighted overlay was created by combining each of the four reclassified layers (population growth, employment growth, distance to roads, and distance to existing development). The data was not validated using a regression model to determine precise weights for each input, so each of the four input layers was assigned equal importance. The final result was then compared to the HRTPO 2034 forecast maps showing expected changes in population and employment for validation.

Several areas of Hampton Roads were shown to be vulnerable to development pressure over the next 25 years. These areas include the City of Franklin, the areas along the Nansemond River in Suffolk, central Chesapeake, Isle of Wight County along the James River, the area around downtown Suffolk, Gloucester County along Route 17, York County along Route 17, and James City County between Williamsburg and the border with New Kent County (see Figure 16).

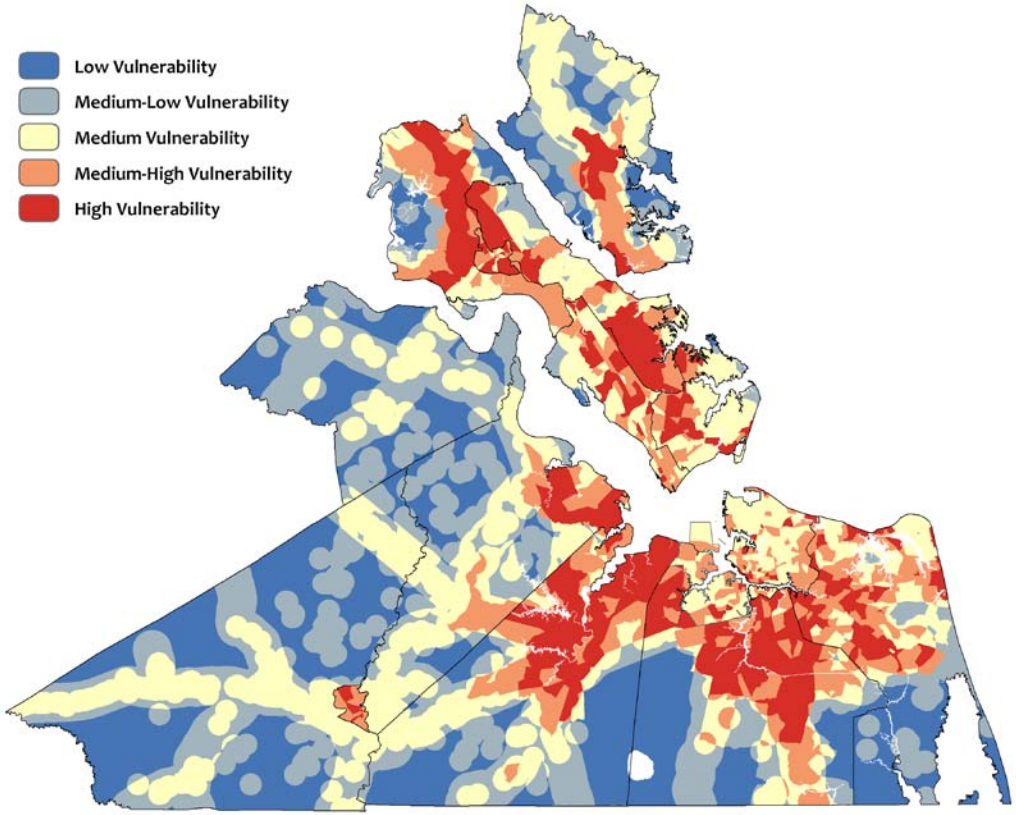


Figure 16: Vulnerability to Development Model

Assessing Green Infrastructure Vulnerability

Once the vulnerability model was complete, the next step was to combine this layer with the 2010 green infrastructure network to help identify which highly valued conservation lands might be facing development pressures in the future.

For this exercise, the green infrastructure model results were simplified so that all areas deemed highly valuable for habitat protection, water quality, or both were combined into one value. The top two categories from the vulnerability model were used to isolate High or Medium High vulnerability of green infrastructure. Finally, the areas that are already protected from development were removed from the results. The parks layer from the parks and recreation inventory was used for this purpose. The result is shown in Figure 17. The same exercise was repeated using the version of the green infrastructure network containing the PCA data. The result of this analysis is shown in Figure 18.

Again, the results between the two versions are quite similar. Both show that a significant amount of green infrastructure in vulnerable to development. Especially noteworthy is northern Suffolk, northern Isle of Wight, central Chesapeake and central Gloucester County. The version with the PCA data also picked up significant amounts of vulnerable green infrastructure in James City County and York County.

The results of this exercise could prove to be a very useful tool for local planners. It is anticipated that the map in Figure 17 will be used as a jumping off point for discussions at the local or regional level about protecting land that is under development pressure. It will also be helpful in prioritizing lands for acquisition as funds become available.

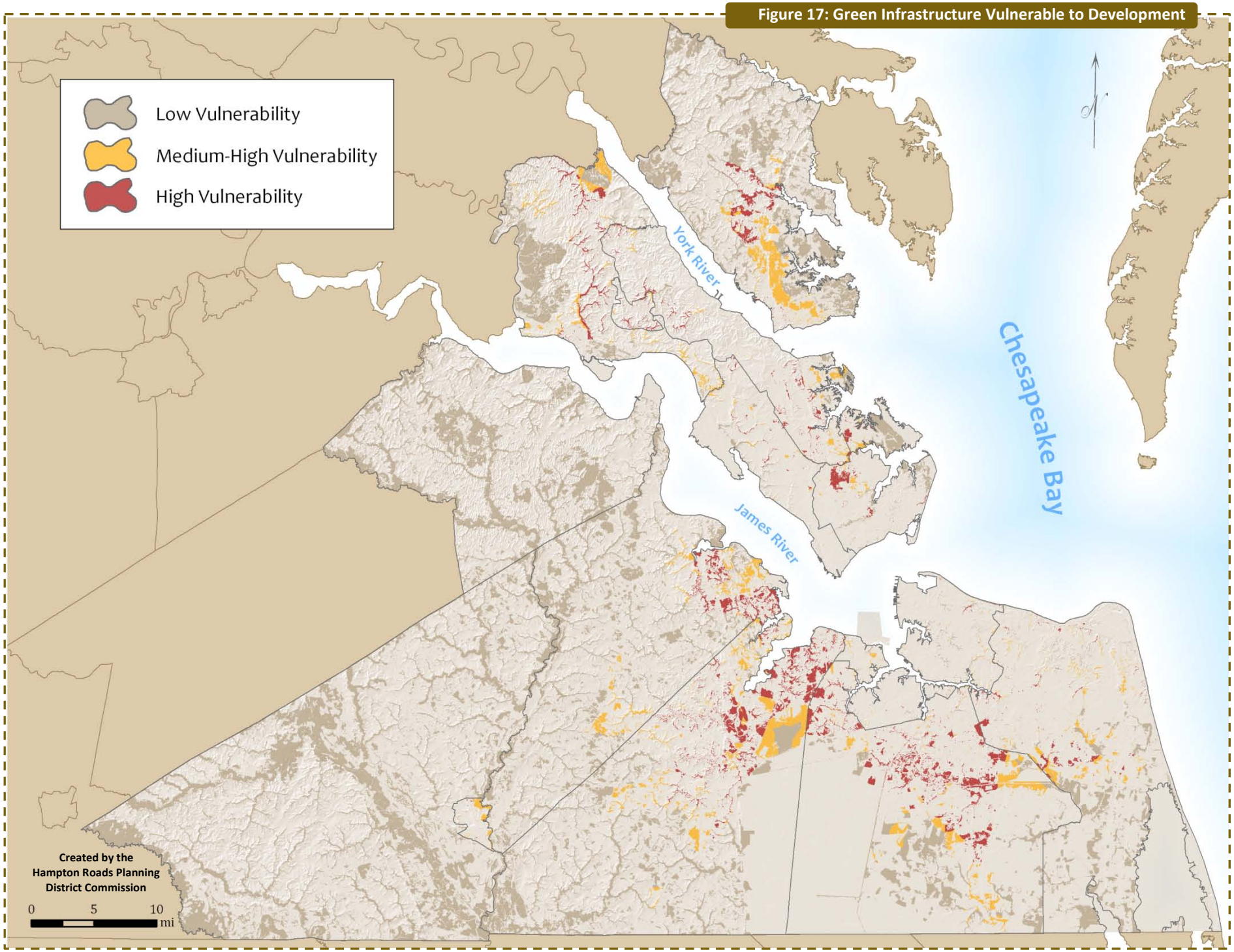
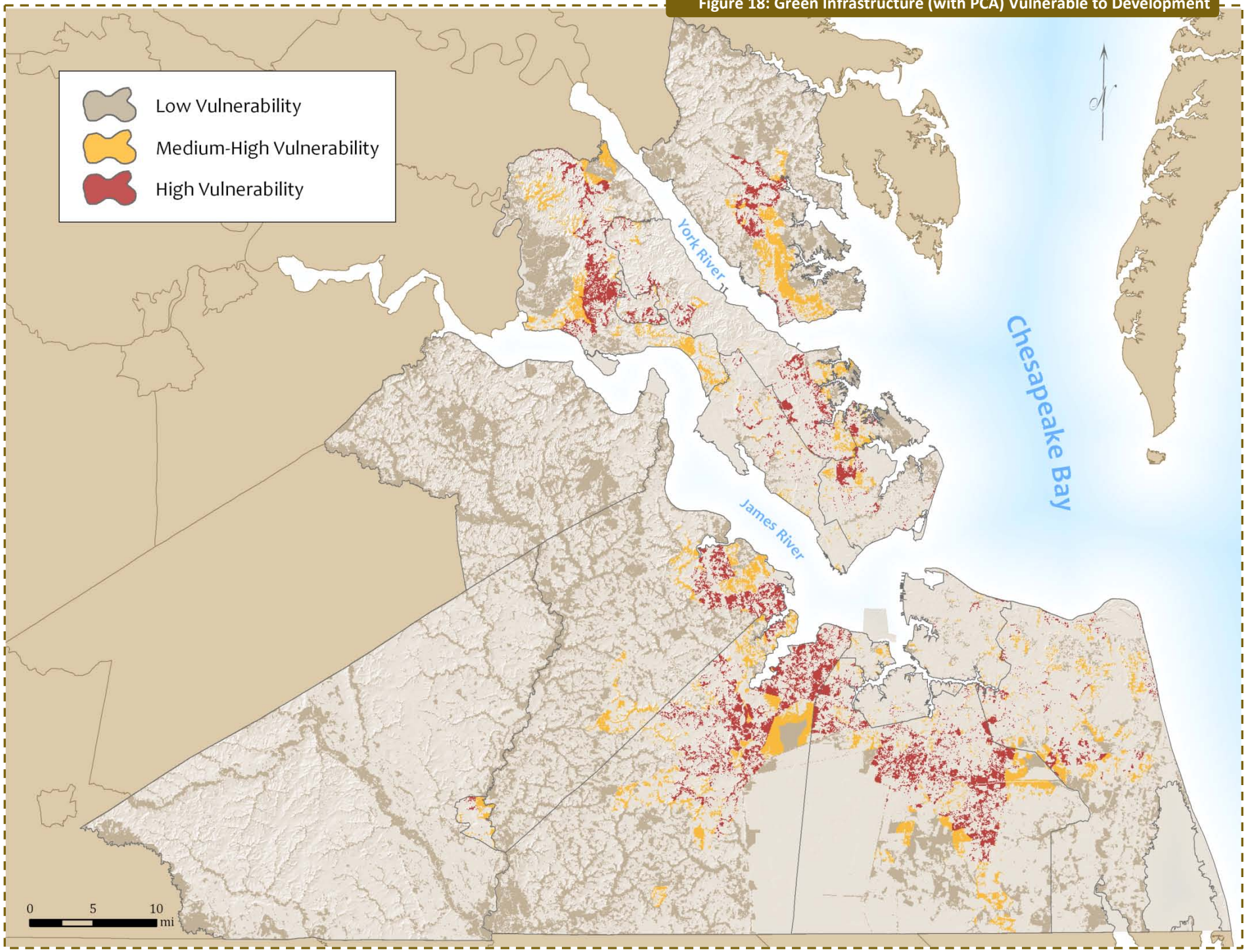


Figure 17: Green Infrastructure Vulnerable to Development

Figure 18: Green Infrastructure (with PCA) Vulnerable to Development



Green Infrastructure and Sea Level Rise

Sea level rise and associated increases in storm surge flooding are both significant factors in the long term viability of tidal wetlands and adjacent uplands in Hampton Roads. Unfortunately, several limitations complicate the identification and mapping of the areas that will be impacted by these changes. The difficulties include a lack of consistent, high resolution elevation data for the region, significant uncertainty about the rate of acceleration of sea level rise, and the inability to predict changes in coastal storm frequency and intensity. Given these limitations the best that can currently be done at a regional scale is to highlight those areas that are most at risk from the combined effects of sea level rise and storm surge.

In Figures 19 and 20, Category 1 storm surge is shown as a red overlay and is used to identify those areas that are most at risk. Figure 20 shows in detail the Category 1 storm surge juxtaposed with the green infrastructure network. The map is a close up view of the Grandview/Fox Hill area in the City of Hampton. The storm surge inundation data was obtained from the Virginia Department of Emergency Management (VDEM).

Category 1 storm surge is typically associated with sea level heights that are four to five feet above normal levels. Within the highlighted areas are wetlands and uplands that will be subjected to a combination of stresses including sea level rise rates that will exceed sediment accretion rates for some wetlands, areas where upslope migration of wetlands will not be possible due to shoreline hardening, and sections of the coast that will be reconfigured by storm events. These stresses will lead to failure and loss of some wetlands areas and transition from one ecosystem type to another in some areas.

A key component to making predictions about the impact of sea level rise on the built environment as well as green infrastructure is highly accurate elevation data. The most accurate elevation data is derived from data captured with LiDAR (Light Detection and Ranging) technology. LiDAR is similar to radar technology but it utilizes laser pulses to detect reflected signals rather than radio waves. When consistent and highly accurate elevation data is available for the entire region, it will be possible to use that information in modeling storm surge associated with different sea level rise scenarios. Thus, the ability to identify those areas of the green infrastructure network that are most at risk will be enhanced.

Figure 19: Green Infrastructure and Storm Surge Inundation

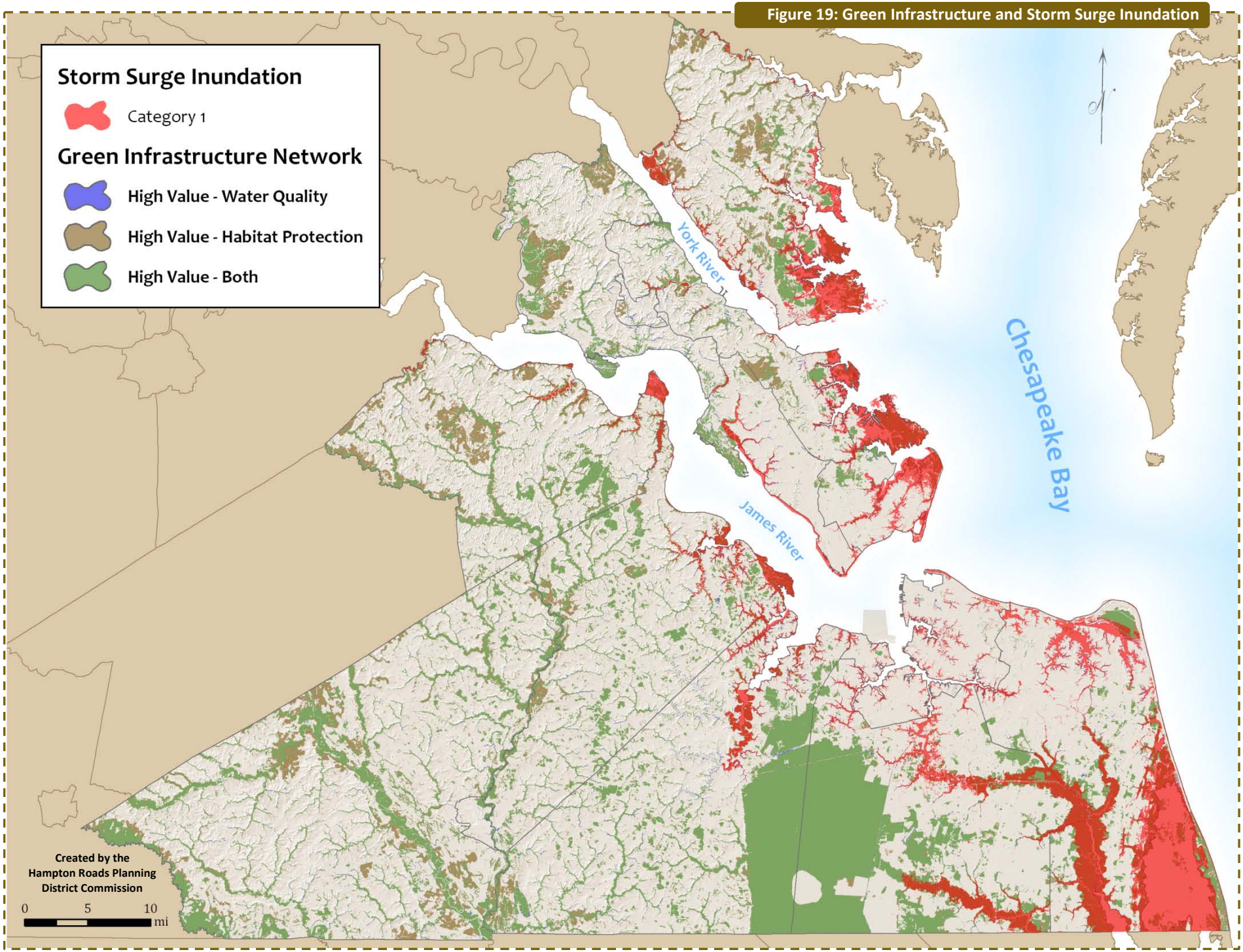


Figure 20: Category 1 Storm Surge Inundation and the Green Infrastructure Network in Hampton, Virginia

Parks and Recreation Inventory

From national parks to neighborhood parks and everything in between, Hampton Roads is rich with a variety of opportunities for recreation. Hampton Roads boasts an impressive amount of conservation land, which is protected by both government agencies and private parties. Much of this land is open to the public for recreational activities such as hiking, camping, bicycling, kayaking and canoeing, fishing, and swimming.

There are approximately 285,600 acres of protected land in Hampton Roads (including military installations). Creating an inventory of parks and other protected lands allows local and regional planners to identify where these resources are located and where there are gaps in connectivity. This provides the opportunity to identify potential linkages between jurisdictional boundaries.

These parks and recreation facilities are critical to the integrity of the green infrastructure network in Hampton Roads. Formally preserved parks and natural areas are the building blocks of the network. By creating conservation lands adjacent to each other, a linked network of green infrastructure emerges that provides multiple benefits to the region, such as protecting wildlife habitat, drinking water quality, and storm water management.

These linkages also provide a way to connect some of the smaller urban conservation areas with those in the rural areas, primarily via multi-use trails and small urban parks. Hampton Roads is a perfect example of a region that contains a heavily developed core area which is adjacent to thousands of acres of unspoiled natural lands. However, much of this land has already been fragmented and so the green infrastructure network will help inform planners as to where the best possible connections could be made. Figure 22 shows the protected lands and recreation layers on top of the green infrastructure network.

15% of Hampton Roads is protected from development

For those localities interested in pursuing the development of new trails or greenways, DCR and the Virginia Trails Association developed a trails "toolbox." This document assists planners throughout the process of developing the concept through acquisition and building of the trail (Virginia Department of Conservation and Recreation, 2000).
The Virginia Greenways and Trails Task Force has recommended that several state-wide trails be developed with the goal to connect local and regional systems (Virginia Greenways and Trails Task Force, 2009).

Three of the six recommended state-wide trails pass through the Hampton Roads region (see Figure 21). These include the East Coast Greenway, the James River Heritage Trail, and the Beaches to Bluegrass Trail.

The inventory focused on conservation areas, parks, and outdoor recreation sites, including major multi-use and scenic trails and boat ramps. The HRPDC did not survey facilities such as sports fields and basketball courts.

The inventory was based on existing datasets that have been compiled by DCR. DCR maintains a database of conservation lands and conservation easements which are continuously updated. HRPDC also obtained the data used by DCR in compiling the *2007 Virginia Outdoors Plan* (Virginia Department of Conservation and Recreation, 2007).These data sources were the building blocks of the inventory. Other agencies that supplied some data included VDGIF and VIMS.

Data was also obtained from the local jurisdictions to supplement the data received from state agencies. Additions, deletions, and changes were made as necessary. Research was also conducted on the Internet as needed to complete the inventory.

The Table 2 summarizes the types of conservation lands found in Hampton Roads by ownership:

Protected Lands	Acres
Conservation Easements	18,393
Conservation/Open Space	22,882
Estuarine Reserves	3,001
Federal Land	115,176
Local Parks	19,372
Military Bases	61,924
Mitigation Banks	5,336
Neighborhood Parks	3,065
Other (Private)	3,286
State Land	33,191
Total	**285,626**

Table 2: Protected Lands by Type

Figure 21: Protected Lands and Recreational Opportunities

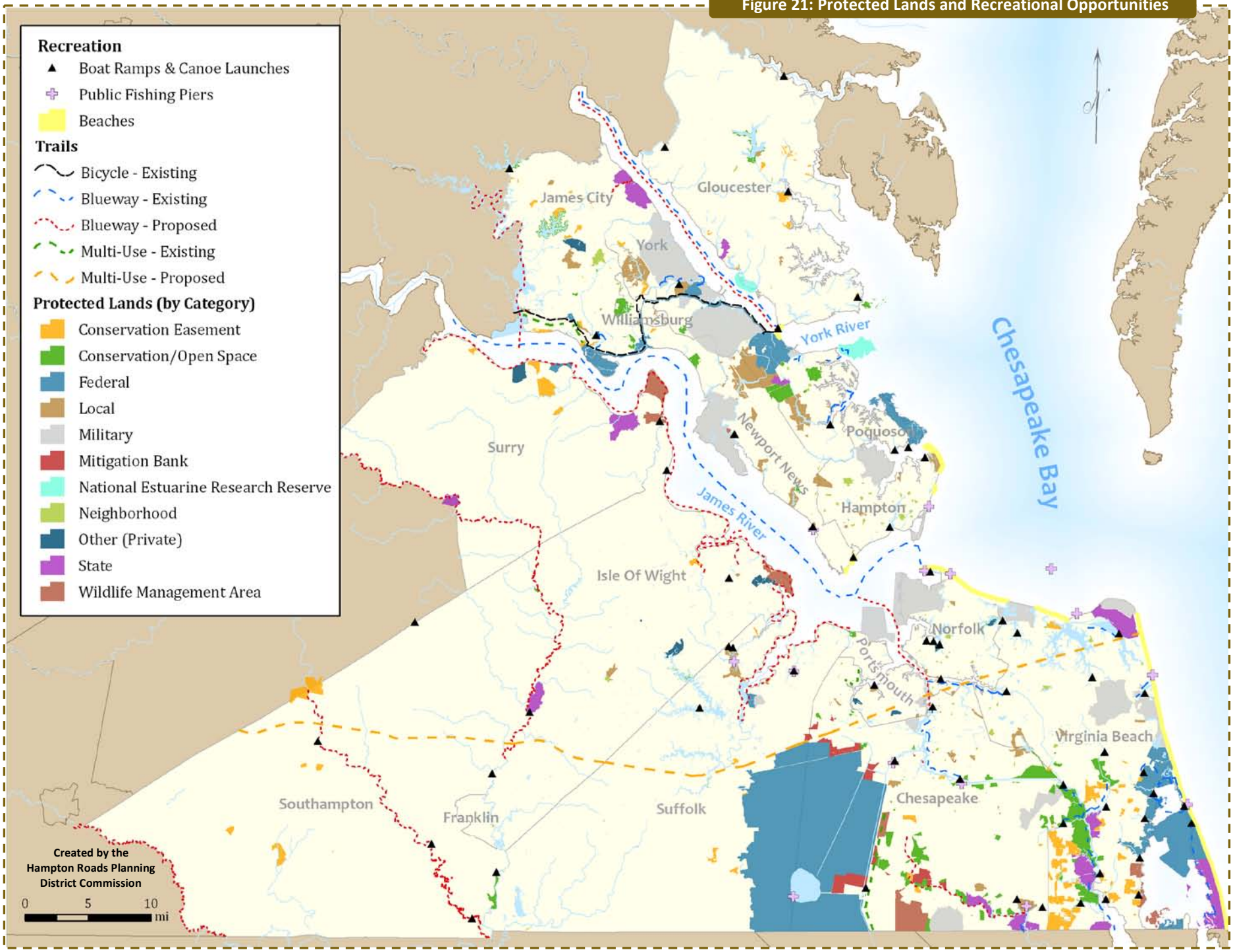
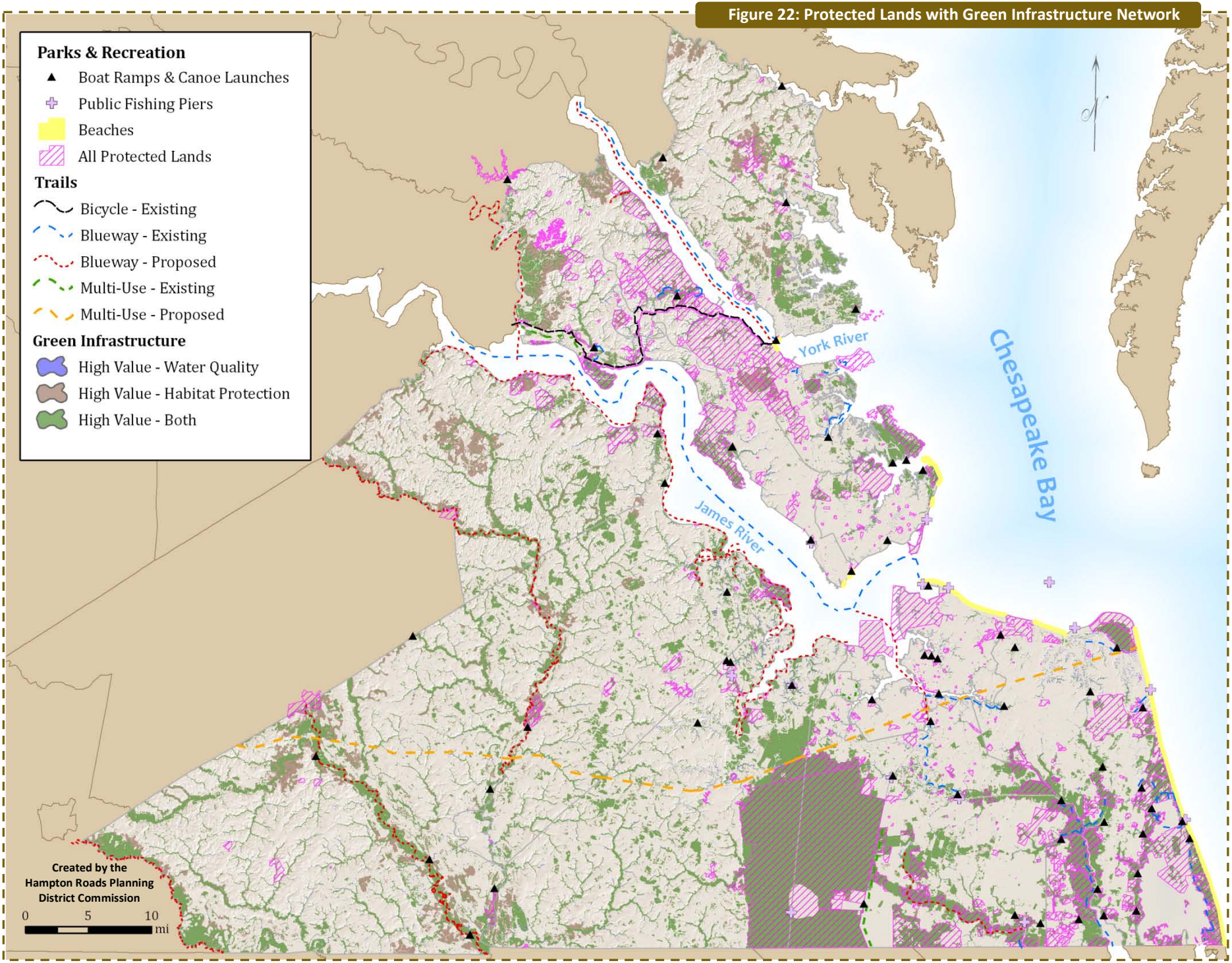


Figure 22: Protected Lands with Green Infrastructure Network



Conclusions & Recommendations

The update to the Hampton Roads Green Infrastructure Plan provides planners and other interested parties with an improved tool to assist with prioritizing conservation efforts in the region. This plan has expanded on previous work by upgrading the model with new information to better identify those areas which are a priority for conservation. Conducting a change analysis provided important insight into which effects have the potential to cause changes on the landscape. This will help inform the continuous process of updating the green infrastructure network. New analysis in this plan provides information on how the green infrastructure network may be impacted by such issues as development pressure and sea level rise. The parks and recreation inventory can help planners to identify where conservation areas are located regionally and where potential linkages can be made across jurisdictional boundaries.

It is highly recommended that site-specific studies are done first to assess the value of the land before any official actions are taken. The data used in this plan are at a regional scale and caution should be used before applying the information to a specific property. This plan should be not be substituted for proper legal or scientific guidance.

To assist planners using this document, a listing of GIS resources that were utilized in this plan or that could be used in green infrastructure planning were compiled into a table in Appendix A.

It is hoped that the guidance and maps provided in this plan will be influential in how Hampton Roads communities address the need for a regional network of protected lands and assist with prioritizing lands for acquisition. As such, the green infrastructure network will continue to evolve in the future as new issues of regional importance come to the forefront. The following paragraphs discuss some of the topics that have already been identified and recommendations on how to address them.

Refine Model with Updated Data

The green infrastructure network will continue to be updated as new regional land cover data is released. The PCA data should also be included in the next version of the network if it is updated to include the whole planning district. If other useful data becomes available at a regional scale, then it will be considered for inclusion in future versions of the model as well.

Linkage to Other Regional Green Infrastructure Networks

Other regions in Virginia have begun creating green infrastructure networks in the last few years. Of particular interest to the Hampton Roads area is the green infrastructure network developed by the

Richmond Regional Planning District Commission (RRPDC). Future work with the Hampton Roads green infrastructure plan should include discussions with the RRPDC staff about potentially linking the two networks together.

Vulnerability of Land Adjacent to Conservation Areas

An emerging trend that was identified during the stakeholder process is that development is beginning to occur near areas that are already in conservation protection. Many potential home owners view proximity to conservation areas as a benefit and may seek out developments that are adjacent to existing protected lands. Future versions of the green infrastructure plan could try to identify if there are any such areas in Hampton Roads.

Utilizing a Green Infrastructure Approach to Achieve Multiple Benefits in Regulatory Compliance

The regulatory environment affecting Hampton Roads localities continues to change. In particular, the outcomes of the proposed storm water management regulations and the Chesapeake Bay TMDL are still in flux. The HRPDC will continue to monitor these issues and if necessary, work with localities on how to incorporate the green infrastructure network into watershed management plans and TMDLs.

Adapting the Green Infrastructure Network for Climate Change and Associated Sea Level Rise

Climate change is placing a set of additional stresses on the natural resources in the green infrastructure network. Developing a management plan for the critically important natural resources in the network will be a complex process. Natural resource managers currently see this as a two step process. The first step is a vulnerability analysis to determine if climate induced stress will have an adverse impact on a given species or ecosystem. In those cases where adverse impacts are identified the nature of the risk will be characterized. The second step is the development of an adaptation plan for those species and ecosystems identified as being at risk in the vulnerability analysis. This is a relatively new area of science and it is not yet possible to determine the extent to which adaptation plans for natural systems will be successful.

Sea level rise and associated increases in storm surge are likely to have a profound impact the tidal wetlands and the adjacent uplands in Hampton Roads. As previously mentioned, a detailed vulnerability analysis will be needed to develop an adaptation plan for the at-risk wetlands areas. In some cases sediment accretion rates may be sufficient to keep pace with sea level rise. In other cases it is likely that accretion rates will not be sufficient and some areas of tidal wetlands will drown. Until detailed vulnerability analyses are complete a few

common sense management measures can be employed such as limiting shoreline hardening, providing opportunities for upslope migration of wetlands and protecting water quality so that wetlands remain as healthy as possible.

In the long term, the green infrastructure network in the eastern portion of Hampton Roads will need to be revisited in light of sea level rise to reflect the changing nature of the wetlands and the increasingly flooded adjacent uplands.

Works Cited

Bulluck, J. F., Ciminelli, J. M., & Weber, J. T. (2007). *Natural Landscape Assessment and Green Infrastructure - Completion and Distribution: Final Report.* Division of Natural Heritage. Richmond, Virginia: Virginia Department of Conservation and Recreation.

Governor's Commission on Climate Change. (2008). *Final Report: A Climate Change Action Plan.* Richmond, Virginia: Commonwealth of Virginia.

Hampton Roads Planning District Commission. (2007). *2034 Socio-Economic Forecast.* Retrieved August 2009, from Hampton Roads Planning District Commission: http://www.hrpdcva.gov/Documents/Economics/2034Forecast.pdf

Hampton Roads Planning District Commission. (2007). *Green Infrastructure in Hampton Roads.* Chesapeake, Virginia: Hampton Roads Planning District Commission.

Hampton Roads Planning District Commission. (2006). *The Hampton Roads Conservation Corridor Study.* Chesapeake, Virginia: Hampton Roads Planning District Commission.

Hampton Roads Transportation Planning Organization. (2008, May). *Hampton Roads 2000 and 2034 Socioeconomic Data by TAZ.* Retrieved August 2009, from Hampton Roads Transportation Planning Organization: http://www.hrtpo.org/Documents/Reports/2008/TAZ2000to2034.pdf

Lambert, J. H. et. al. (2009). *Risk-Based Framework Using Geographic Information Systems to Identify Transportation Corridors Vulnerable to Development.* Retrieved August 2009, from University of Virginia Center for Risk Management of Engineering Systems: http://www.virginiadot.org/vtrc/main/online_reports/pdf/08-cr8.pdf

Virginia Department of Conservation and Recreation. (2007). *2007 Virginia Outdoors Plan.* Richmond, Virginia: Commonwealth of Virginia.

Virginia Department of Conservation and Recreation. (2000, October). *The Virginia Greenways and Trails Toolbox.* Retrieved April 2009, from Virginia Department of Conservation and Recreation: http://www.dcr.virginia.gov/recreational_planning/documents/toolbox.pdf

Virginia Department of Conservation and Recreation. (2006). *VCLNA Vulnerability Model.* Retrieved August 2009, from Virginia Department of Conservation and Recreation Division of Natural Heritage: http://www.dcr.virginia.gov/natural_heritage/documents/VulnerabilityModelReportVer2.pdf

Virginia Department of Forestry. (2009, October 19). *2007 County Value and Volume*. Retrieved January 20, 2010, from Virginia Department of Forestry: http://www.dof.virginia.gov/econ/2007-county-value-volume.shtml

Virginia Department of Game and Inland Fisheries. (2009). *Sustainable Communities: Assessment of Priority Conservation Areas and their Vulnerability to Development.* Richmond, Virginia: Virginia Department of Game and Inland Fisheries.

Virginia Greenways and Trails Task Force. (2009, October 21). *Virginia's Long-Distance Trail Network: Connecting Our Commonwealth.* Retrieved January 2010, from Virginia Department of Conservation and Recreation: http://www.dcr.virginia.gov/recreational_planning/documents/grtrtfrep.pdf

Weber, T. (2004). *Risk of forest loss in Maryland's Green Infrastructure, based on 1997-2000 patterns of development.* Retrieved August 2009, from Maryland Department of Natural Resources: http://dnrweb.dnr.state.md.us/download/bays/development_risk_logit.pdf

Appendix A: GIS Data Resources for Green Infrastructure Planning

GIS Resource	Owner	How to Access
Blue Infrastructure Data	VIMS	http://ccrm.vims.edu/gis_data_maps/interactive_maps/blueinfrastructure/bi_intro.html
C-CAP Regional Land Cover	NOAA	http://www.csc.noaa.gov/digitalcoast/data/ccapregional/
Chesapeake Bay Watershed Land Cover Data Series	Chesapeake Bay Program	ftp://ftp.chesapeakebay.net/Gis/CBLCD_Series/
National Land Cover Database	USGS	http://www.mrlc.gov/
National Wetlands Inventory	US Fish and Wildlife	http://www.fws.gov/wetlands/
Priority Conservation Areas	VDGIF	http://www.dgif.virginia.gov/gis/gis-data.asp
Storm Surge Inundation Maps	VDEM	Request data from VDEM. http://www.vdem.state.va.us/threats/hurricane/stormsurge.cfm
Transportation Analysis Zones	US Census Bureau	TAZs available at: http://www.census.gov/geo/www/cob/tz_metadata.html Check with your regional Metropolitan Planning Organization to determine if population estimates have been done by TAZ. For Hampton Roads, see http://www.hrtpo.org/TPO_Data.asp
US Census Population Data	US Census Bureau	For 2000 and 2010 information, see http://www.census.gov ; for historic Census GIS files, visit the National Historical Geographic Information System http://www.nhgis.org/
VCLNA Models	DCR	Request data from DCR. http://www.dcr.virginia.gov/natural_heritage/vclna.shtml
Virginia Conservation Lands Database	DCR	http://www.dcr.virginia.gov/natural_heritage/cldownload.shtml
Virginia Wildlife Data	VDGIF	http://www.dgif.virginia.gov/gis/gis-data.asp