Waterfront Development and Potential Impacts to Aquatic Habitat
A Planning Tool for Evaluating Resource Sensitivity

final report

submitted to

Department of Environmental Quality
Virginia Coastal Resources Management Program

submitted by

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SECTION I. INTRODUCTION

Background

Sustainable development describes thresholds at which the development community and the environment achieve a status of equilibrium. Should this equilibrium be disrupted, environmental resources may be impacted or sacrificed. Strategies for managing development at jurisdictional levels seek to achieve balances that minimize impacts to nature while achieving high quality of living standards in their communities.

The coastal zone is a geographic province where these issues are paramount. Studies have demonstrated links between increased development and degradation of aquatic resources. Loss of essential habitat and reduced water quality have stressed coastal ecosystems such that declines in important aquatic flora and fauna have resulted. In some urban areas, aquatic health has been reduced to unrecoverable states as a result of coastal development.

It is true that residential development along the coast presents less threat than industrial development, however the persistent and increasing conversion of lands to residential use has not been without environmental consequence. Implementation of environmental regulatory programs with obtainable goals are effective mechanisms for minimizing future degradation to aquatic resources. These environmental programs are often implemented at the local government level. Here to are made the planning and zoning decisions which must be made in concert with environmental decisions in order to achieve sustainable development approach in community planning. Too often, however, the development planning processes act independently resulting in conflicts in resource management.

There is a great desire among coastal resource specialists to integrate environmental and development interests in the decision making of local and regional planners in waterfront communities. The Virginia Coastal Program (VCP) with grant funds through the Coastal Zone Management Act administered by the National Oceanic and Atmospheric Administration (NOAA) has sponsored the development of this management tool. The tool is designed to provide the ability to assess the relative risk to aquatic resources from residential development. With this knowledge, there is an expectation that community planners will direct development away from areas where sensitive habitats are at risk.

Objective and Approach

The capacity to assess the risk to aquatic resources expected to result from shoreline development is the objective of the GIS-based protocol. The protocol operates from a defined set of criteria characterizing environmental condition in aquatic habitats. Criteria include elements that characterize water quality, sensitive habitat, and land use. A set of defined rules related to each criterion reflect environmental sensitivity, potential impact, or importance in contributing to the overall aquatic health of a region. A ranking system assigns points to represent these conditions as assessed in the analysis.

The protocol is restricted to criterion that can be modeled using available GIS data, and relies on best professional judgement from a committee of scientific and planning experts. Since the project focus is toward regions under development or experiencing development pressure, existing urban areas within Virginia's coastal management zone were generally excluded. However, the model was developed to be flexible for application along any tidal shoreline.

This protocol was not designed with the intention of identifying reaches where development should be encouraged or restricted. The model does not account for comprehensive planning underway within a locality nor does it incorporate a mechanism to balance a localities need for economic growth and community enhancement. It also does not address terrestrial environmental risks, specifically. Rather, the model is a predictive assessment of the aquatic environmental risk of development activity. The model output is intended to be used by community planners to visualize how waterfront development along a particular stretch of coastline might impact existing natural aquatic resources and incorporate that understanding in land use decision making processes. With the knowledge of which aquatic resources may be impacted, where they are located and to what extent they are at risk, local governments may implement management approaches as deemed necessary and appropriate.

Two committees participated in the development of the protocol. A steering committee organized by the Virginia Coastal Program (VCP) includes members from that office, local community planning offices, and regional planning district commissions. The steering committee is also comprised of members from the Technical Advisory Committee charged with development and implementation of the GIS-based model, oversight of data collection, scientific rationale, and final deliverables. The committees agreed upon a small pilot area where the final protocol would be tested and reviewed.

Report Organization

This report is devoted to a detailed description of the protocol, its components, and its limitations. Each criterion applied in the protocol is described with the scientific rationale for inclusion and ranking. A comprehensive list of all criterion considered is included. Instructions for viewing the GIS output is provided. Recommendations are made for additional criterion to be integrated into the model when data are available. Results of the selected pilot model run for Greenvale Creek in Lancaster County is presented .

Acknowledgments

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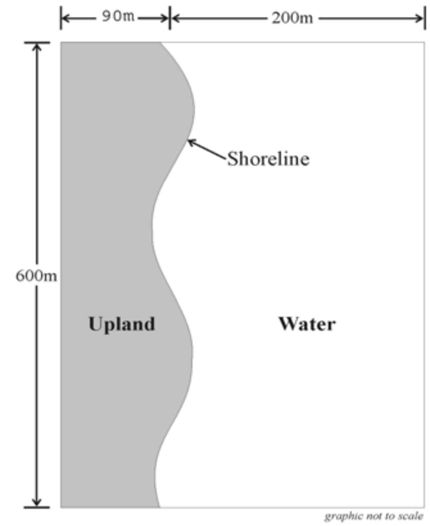

Figure 1. Analytical unit is 600m by 290m.

SECTION II. MODEL DEVELOPMENT

Computer Resources

This model is developed to run in ArcInfo®. The GIS programming language AML (Arc Macro Language) is used to model the protocol established by the committee. Model output can be viewed in ArcGIS® or ArcView®. Components of the model development and testing were performed using a Gateway Professional running Windows 2000 with a 1.4 Ghz processor and 512 MB of memory, and a Sun Ultra 10 Unix machine running Solaris 7.

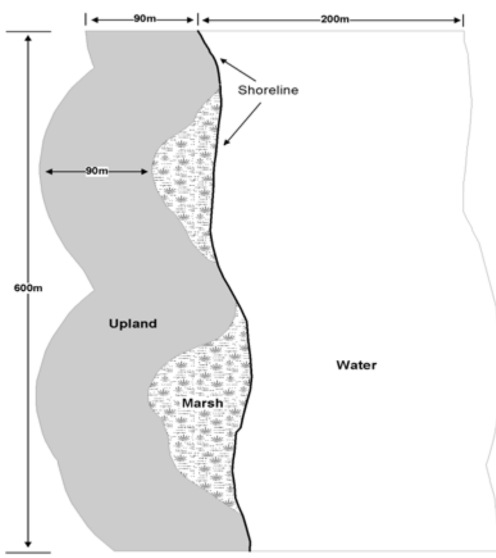

Figure 2. Boundaries of analytical unit are adjusted when marshes are present.

Analytical Unit

The analytical unit in this model refers to the "segments" to be analyzed along the waterfront. These segments define a surface area delineated from a basemap feature. In this case, the basemap feature is the shoreline position. The GIS model performs the analytical protocol on each analytical unit or segment. Since each unit is evaluated independent of all others, it has a unique ranking indicative of landscape and environmental characteristics within the unit.

The analytical unit in this project is 600 meters alongshore, 200 meters channelward of the shoreline, and 90 meters landward of the shoreline (Figure 1). The project uses a digitized shoreline coverage generated from USGS 1:24,000 topographic maps. This scale is comparable with most data layers integrated in the model. These maps vary in age, and accuracy is reported to be approximately +/- 9 meters (see Appendix 5. Metadata).

One exception to these boundary conditions exist. Where tidal marshes are present, the interface between upland and marsh becomes the baseline boundary of the analytical unit rather than upland and shoreline (Figure 2.). This shift is ecessary to insure land use characteristics are captured where marsh complexes extend more than 90 meters landward of the shoreline. Therefore in these cases the analytical unit remains 600 meters longshore, 200 meters channelward of the shoreline, but 90 meters inland of the upland boundary of the marsh.

Protocols

Segments alongshore are evaluated in three ways: a) for baseline land use condition referred to as the "Base Modifier", b) impacts to sensitive habitat present, c) impacts to water quality. Each evaluation element (land use, aquatic habitat, and water quality) contributes to, and reflects, the overall health of the aquatic ecosystem differently. Criteria specific to each group are used to evaluate the segment for impacts. Associated with each criterion is a range of possible scores. The scores reflect the relative contribution the criterion makes towards effecting aquatic conditions in that river segment. The ranks may be based on the presence/ absence of a resource or a quantifiable value. The higher the score, the more likely the impact.

a.) Base Modifier: The first group is called the "Base Modifier". The base modifier is actually a weighting factor. It is applied to the analytical unit and qualifies the probable existing aquatic health based strictly on existing adjacent land use/land cover. Three land use/land cover classes are considered: forested, agricultural, and developed. The National Land Cover Dataset of 2000 (NLCD) provides the source for these data. The ranking system is listed in Table 1. Since forest cover is considered the most pristine condition, the base modifier assigns a unit where forest cover dominates and development is less than 25% a score of 15. The model assumes that forest landscapes are associated with healthier aquatic ecosystems. This generally is the case, and this state could be seriously compromised if the forest cover were converted to some other land use. The weighted score of 15 insures the baseline landscape condition and presumed aquatic condition is accounted for in the final ranking. In other words, addition or subtraction of points in other areas can not adjust for this conditional value.

In contrast the base modifiers for agriculture or developed lands are set low to indicate that aquatic condition may already be degraded due to land use. In the model, where development or agricultural use dominate, or development exceeds 25% of the land use/land cover in the segment, the base modifier is set equal to 5. The scores are the same because a scientific rationale for concluding if either of these conditions is more detrimental to aquatic resources is lacking and so no distinction is made between "developed" or "agriculture". Both land uses include practices that can result in significant impacts to habitat and water quality. Agricultural practices introduce significant amounts of nitrogen to receiving waters. Nutrients along with sediment discharge is a common water quality issue surrounding development. In addition, waterfront development is also a leading cause of wetland and shallow water habitat impacts.

Points are assigned to each segment based on these baseline conditions. Additional points are added based on the degree of impact to water quality and sensitive habitat that may result from development. The ranking for these are discussed separately below.

Table 1. Base modifier scores based on land use conditions in the analytical unit

EXISTING LAND USE	**SCORE**
dominant land use/cover = forest and <25% developed	15
dominant land use/cover = forest and >25% developed	5
> 25% land use/cover = developed	5
dominant land use = agriculture	5
MAXIMUM POINTS POSSIBLE	15

b) Sensitive Habitat: The protocol assesses the presence of several sensitive habitat types within each analytical unit. Four habitats are considered: tidal marshes, submerged aquatic vegetation (SAV), oyster reefs restoration sites, and riparian forests. Data for tidal marshes are derived from the VIMS Tidal Marsh Inventory Series. SAV data come from the 2001 Chesapeake Bay SAV Coverage (Orth et.al., 2001). Oyster reef restoration sites were surveyed by the Virginia Marine Resources Commission and digitized by CCI (Berman et.al., 2000). Riparian forests are defined as forest stands within the 30 meter wide zone extending landward from the shoreline. Using the NLCD land cover dataset, riparian forests are that portion of forest cover within the analytical unit that extends 30 meters landward from the shoreline. Table 2 summarizes that ranking system applied in the protocol.

Table 2. Ranking of Sensitive Habitat

HABITAT TYPE	SCORE	
	Present	Absent
Tidal Marshes	3	0
Submerged Aquatic Vegetation	3	0
Oyster Reef Restoration Sites	3	0
Riparian Forest = < 33%	0	
Riparian Forest = 33.1-66%	3	
Riparian Forest = >66%	6	
MAXIMUM POINTS POSSIBLE	15	

Rankings within the segment is based on presence or absence for tidal marshes, SAV, and oyster reefs. For each habitat type present the unit is given 3 points. No points are assigned if the habitat is not present.

The riparian buffer score depends on percent cover within the segment. If more than 66% of the riparian zone is forested the unit is scored 6 points. If forest covers 33.1-66% of the riparian zone the unit receives 3 points. No points are assigned if the riparian buffer is less than or equal to 33% forest cover.

The significance of the ranking within the Sensitive Habitat group speaks to the important role these habitat play in maintaining aquatic ecosystem health. The rankings suggest that development of the upland can adversely impact sensitive habitats. In its ranking, however, the protocol acknowledges that impacts to tidal marshes, SAV, and oyster reefs may not necessarily be direct impacts (i.e. removal of the habitat). For this reason presence is ranked with a three as a measure of the potential vulnerability of these habitats to adverse impacts from development. In contrast, there is the assumption that the forest buffers are likely to be would be directly impacted if the waterfront were developed and therefore the ranking is significantly higher depending upon the amount of forest buffer present.

c) Water Quality: Water quality is assumed to be a major indicator in aquatic ecosystem health. In and of itself, water quality is assumed to be degraded by development in the following manner(s): 1) introduction of sediment and nutrients through runoff; and 2) introduction of sediment and nutrients through coastal erosion. Water quality is presumed to be enhanced or improved by the following : 1) nutrient uptake by riparian forests; and 2) nutrient uptake and sediment sinks by coastal marshes. Riparian forested buffers mitigate adverse impacts on water quality through the slowing of upland runoff, thereby trapping sediment and nutrients, and through the interception and uptake of nutrient laden groundwater. In much the same way that detention ponds store and filter upland runoff, tidal marshes filter runoff and accumulate sediments draining off the fastland. Marshes also act as buffers to wave action and therefore protect the upland from erosion. These premises are the basis for the criteria and their subsequent ranking within the Water Quality group. For discussion purposes, the group is divided into Criteria that Degrade Water Quality and Criteria that Mediate Water Quality. The ranking system reflects this division.

Criteria that Degrade Water Quality

Since values associated with water quality parameters are not measured locally, regional values reported in various monitoring programs throughout the Chesapeake Bay are not considered useful at the scale this project is addressing. Therefore, surrogate data that can be measured locally are used in their place.

Soil characteristics are an important consideration in any proposed development. Should development be proposed in an area where soils are prone to erosion and permeability, the potential for sediment discharge is very high. This in turn could adversely effect the quality of receiving waters. Soil data applied in the pilot project was extracted from the Soil Survey

Geographic Database (SSURGO). SSURGO is a vectorized digital database that uses 1:24,000 topographic maps as its base. Other databases could be substituted in the protocol provided the attributes and coding for "erodibility" and "permeability" were essentially the same.

Soil ***erodibility*** as defined by the "k-factor" is assessed in this study for surface soil horizons. The k-factor is an index representing the potential erodibility of a soil by water, based on soil texture (Florida Dept. of Forestry, 1991). As the k-factor increases the risk of erosion from development increases. Thus, the potential for water quality impacts as a result of that development is elevated.

Permeability refers to the rate at which water or air move through the subsoil (West Virginia University Extension Service, 2003). The more permeable the soil the quicker it may drain and transport upland derived constituents like nutrients and chemicals into the receiving waters. Permeable soils may also be less stable when cleared and under construction. Since this project is concerned with water quality impacts, the characteristics of permeability that might give rise to water quality problems is the focus. Therefore in this model, the impacts to water quality increase as the permeability (measured in inches/hour) increases (see Table 3 for scores). Other characteristics of soil permeability, not necessarily consistent with this premise, might be considered if sites were evaluated for other matters related to development.

In addition to problems associated with soils on the fastland, erosion along the shore caused by wind and wave activity should also be considered as sediment input from this source can also degrade water quality. Since recent erosion rates are not available for Virginia, the protocol substitutes other data sources as proxies. From these data sources erosion potential at the shore can be inferred.

Bank stability and ***bank height*** are qualitative measurements collected by the CCI as part of the field surveys to generate the Virginia series of Shoreline Situation Reports (Berman and Hershner, 1999). Bank stability assesses the relative condition of the bank face at the time of survey. Stability is assessed as either "stable", "eroding", or "undercut". Stable banks generally are well vegetated or armoured and exhibit no signs of sloughing or sliding of material. In contrast, a bank that is eroding will frequently have large exposed areas of soil. Exposed roots will be obvious if vegetation is present, and the base of the bank may have sediment accumulated from slides. Banks classified as undercut do not show the typical signs of bank face erosion. Instead, the erosion is restricted to the very base of the bank. Undercutting is typically caused by tidal currents, boat wake activity, and intense waves generated by storms. Sea level rise may also contribute to this type of erosion but on very different time scales.

The shoreline surveys that collect and report this information do so on a linear basis. In other words the data is reported alongshore and for all points along the surveyed shoreline. For this protocol, these datasets are assessed based on the percent of shoreline within the analytical unit that meets the defined conditions for these criteria. For bank erosion, if more than 50 percent of the shoreline within the analytical unit is classified as stable the risk of water quality impacts is considered low. The unit receives a score of "0" to reflect this risk. If less than 50%

of the shoreline is stable (i.e. > 50% = unstable), the risk or erosion is considered higher and the analytical unit receives a score of “2".

Bank height is also surveyed as part of the data collection for the Virginia Shoreline Situation Reports. It is surveyed as a range of heights which can be observed from the survey vessels. The scoring for bank height reflects not only the vulnerability of the bank to erosion from waves, but also the susceptibility for flooding due to low elevations. A dichotomy of role of bank height in effecting water quality is reflected in the possible scoring scenario for this factor. First, banks which are low offer little protection from high energy wave action or long term sea level rise. Both physical processes will introduce sediment into the receiving waters. Additionally, low upland elevations present potential problems related to septic system failures, and the discharge of pollutants via groundwater. For these reasons, development along banks less than 5 feet in height increase the risk of adverse impacts on water quality. An analytical unit will receive a score of 2 if these conditions are observed. If bank heights exceed 10 feet, the unit is also scored a two. Generally speaking very high banks are susceptible to erosion resulting from slope failure. Additionally, vegetation on the bank can not perform the same water quality functions as the active root zone does not extend deep enough to uptake nutrient laden groundwater being discharged. For these reasons, development along banks greater than 10 feet in height also create a risk to water quality.

Lastly, erosion is a higher risk along lands exposed to long fetches. In these areas, there is the potential for high wave action generated by winds blowing across great distances. This wave action will cause erosion along natural shorelines, and can undermine existing shoreline defense structures in extreme events. ***Exposure*** is incorporated in the protocol to account for the introduction of sediment under these circumstances. Shorelines exposed to fetches that exceed 2 km receive a score of 2 to reflect this vulnerability. Shorelines exposed to fetches less then 2 km receive no points.

Criteria that Mediate Water Quality

This protocol has already accounted for the important habitat riparian forests and wetlands provide. Beyond their value as habitat, riparian forests and wetlands also have important functions related to water quality. This is well known and well documented. For this reason, they are ranked a second time in the water quality group. Their ranking, in this case reflect their role in improving water quality. Therefore if present, their scores reduce the overall potential for development impacts in the analytical unit (Table 3).

d.) Additional Modifiers - Additional criteria are added to scores to account for presence or absence of other landscape or aquatic features. They include: rare, threatened or endangered, species, aquaculture sites, sewer systems or lake pond drainage, and shoreline modifications. They are summarized in Table 4. These criteria do not necessarily represent habitat or effect water quality of aquatic ecosystems. Nevertheless, they are important considerations for any development plan along a waterfront. A brief discussion of each follows.

The presence of rare, threatened, or endangered species (RTE) delineated by the Virginia Department of Conservation and Recreation, Division of Natural Heritage is a high priority consideration for waterfront development. This protocol, since directed to preserving and enhancing ecosystem health discourages all development surrounding terrestrial or aquatic areas that support species of this status. Therefore, to elevate the importance of these sensitive resources, the ranking system assigns an analytical unit a score of 100 if RTEs are present. This score will weight the unit such that the final classification will be equal to “high impact”. No points are assigned if they are not present. The RTE databases are updated regularly. The most recent update available was used for the pilot.

Commercial aquaculture in shallow water habitat poses several considerations for waterfront development. The practice itself, requires relatively clean water and therefore terrestrial development may introduce sediments and nutrients to the shallow water zone that would not be desirable. Impacts to the commercial enterprise resulting from development are not well documented. Some impacts are to be expected. A modifying point of 1 is added to the score if aquaculture is located within the shallow waters of the analytical unit.

In rural areas septic systems remain a common mechanism for dealing with residential waste and waste water. Septic system failure can introduce fecal coliform bacteria in the adjacent watershed. The Department of Health surveys for these failures on a routine basis and monitors water quality. Particular attention is given to shellfish growing areas where elevated fecal coliform concentrations would close the fishery. Waterfront development in rural and suburban landscapes potentially threaten water quality should septic systems become sub-standard. Sewer systems on the other hand reduce the risk of water quality impacts. Therefore, the presence of sewer systems in communities is beneficial to water quality and aquatic health. The risk of development in areas not served by sewer systems is accounted for by an additional 4 points for that segment. While not as effective as sewer systems, lake pond drainage, which functions like a detention pond, is still a moderate best management practice. If lake pond drainage is present in the absence of a sewer system, the protocol subtracts one point (4-1) and the analytical unit receives a score of 3 rather than 4.

The last additional modifier included in the protocol considers shoreline structures constructed for erosion control; including bulkheads, riprap, and seawalls. Erosion control structures can stabilize banks and reduce the introduction of sediment to waters. At the same time, however, construction often impacts intertidal and shallow water habitat such as fringe marshes and SAV grasses. In some cases, these impacts are permanent, and in others they are temporary, with regrowth expected.

Table 3. Ranking of Water Quality Criteria

WATER QUALITY CRITERIA	SCORE	
	present	absent
erodibility		
k-factor >4	**3**	
k-factor 0.26-0.40	**2**	
k-factor 0.06-0.25	1	
k-factor 0.05-0.01	0	
permeability (inches/hour)		
low <0.06"-0.60"	1	
moderate 0.60"-6.0"	2	
high 6.0"->20"	3	
bank stability		
>50 % unit = stable banks; <50% unstable	0	
<50% unit = stable banks; >50% unstable	2	
bank height		
>50% unit = banks>10 ft.	2	
>50% unit = banks < 5 ft.	2	
other	0	
exposure		
fetch > 2 km	2	
fetch < 2 km	0	
riparian forest		
0-33% of unit	2	
33.1-66% of unit	1	
66.1-100% of unit	0	
wetlands	0	2
MAXIMUM POINTS POSSIBLE	16	

To account for the water quality improvement appreciated through shoreline stabilization, 2 points are assigned to a segment if less than 50% of the shoreline is stabilized. To account for the potential permanent or temporary impacts to aquatic habitats, one point is added if more than 50% of the unit is stabilized.

Table 4. Ranking of Additional Modifiers

ADDITIONAL MODIFIERS	SCORE	
	Present	Absent
rare, threatened, endangered species	100	0
aquaculture	1	0
sewer system	0	4
lake pond drainage	-1	0
shoreline modifications		
>50% shoreline in analytical unit stabilized	1	
<50% shoreline in analytical unit stabilized	2	
MAXIMUM POINTS POSSIBLE	107	

Protocol Review

The above section describes the rationale for including various criteria in the protocol. A total of 153 possible points could be assigned to any given analytical unit. The model implies that segments with this score should maintain a high degree o f aquatic health. The model also suggests that development along these segment places an extensive collection of resources and upscale environmental condition at risk.

The minimum number of points a segment may be assigned is 7, with 5 points originating from the original base modifier addressing existing land use. Segments ranked this low are not currently supporting extensive sensitive habitat and may already be experiencing degraded water quality. The model does not conclude that development should be encouraged in these areas. Rather, the model results indicate that development along these waterfront segments would have lesser impacts on overall aquatic health than waterfront development along segments with higher scores.

The maximum number of points a segment may be assigned is 153. Segments accumulating this many points include highly sensitive resources and development should be avoided. An important note regarding this score must be mentioned. One hundred of the 153 possible points are assigned because the segment includes RTEs (Table 4). In the segment classification (Table 5), which divides the point spread into thirds, these 100 points are subtracted from the final score in order to avoid skewed results and balance the distribution.

Qualification of overall rankings divides the point spread into three categories. These categories summarize final scores assigned to each analytical unit. The categorical breakdown divides the total point spread in thirds. The “100" possible points assigned to units that have RTE is first subtracted from the total points spread to reduce inflation of the division. The assignment of categories is based on the designations reported in Table 5.

Table 5. Final Segment Classification

FINAL SEGMENT SCORE(S)	SEGMENT CLASSIFICATION
Habitat plus all Modifiers*	Potential for Impacts to Sensitive Habitat
6-16	low
17-27	moderate
>27	high
Water Quality plus all Modifiers*	Potential for Impacts to Water Quality
7-17	low
18-28	moderate
>28	high

*Modifiers include “Base Modifiers” from Table 1, and “Additional Modifiers” from Table 4.

SECTION III. MODEL APPLICATION

Sample Analysis

The protocol was tested in a small creek located in Lancaster County, Virginia (Figure 3). Lancaster County is currently within the rural waterfront region known as the Northern Neck. Development pressure on the Northern Neck has risen over the years. In particular, the communities along the peninsula are attracting retirees and second home buyers to the waterfront.

Greenvale Creek was selected because of its size and because it exhibits a mix of land uses to test the sensitivity of the model. Greenvale Creek did not support a complete suite of environmental conditions considered in the model, and due to its small size there was a considerable amount of homogeneity among the units. Therefore, the test run did not result in significant variability in analytical units along the shore. A thorough test of the model would be one where the protocol was applied to a larger geographic area (e.g. entire county) where variability in landscape and nearshore habitat conditions are likely.

Model Results

Maps in General : Appendix 1 includes maps illustrating model results for Greenvale Creek. There are 14 designated analytical units in the creek. Each unit is ranked low, moderate, or high impact based on the parameters assessed. There are four fundamental assessments reported. The first assesses the level of impact based on existing land use and selected modifiers reported in Tables 1 and 4. The second assessment considers these baseline conditions and sensitive habitat conditions reported in Table 2. The third assessment considers the baseline conditions and how conditions on the landscape may lead to degraded water quality if development should occur (Table 3). Finally the protocol assesses the overall impact to aquatic resources (sensitive habitat and water quality) given baseline conditions, existing resources, and water quality parameters (Table 5).

Model Output: Since Greenvale Creek is primarily forested, high quality baseline conditions along most of the shoreline is assumed. Therefore, as illustrated in Figure 4, development has the potential to highly impact this baseline condition. Figure 3 breaks down baseline landuse and defined modifiers present on the creek. According to the land use/land cover data used in this analysis (NLCD, 2000) development is present primarily near the mouth of Greenvale Creek. Rules of the protocol reduce the level of potential impact in these units because development has already occurred and aquatic resources are assumed to already be impacted. This is illustrated in Figure 4.

The protocol's evaluation of potential impacts to sensitive habitat considers baseline conditions (Figure 5) combined with existing sensitive habitat resources (Figure 6). The modeled results are illustrated in Figure 7. Waterfront development along most of the creek may impact sensitive habitat. Highly impacted areas are predicted along the eastern shore of the creek. Nearly the entire western shore would have moderate impacts.

In contrast, the model output for impacts to water quality suggest that water quality impacts would be effected more by development along the sections of the western shore. However, waterfront development along more than 75% of the remaining shoreline has a moderate potential for degrading water quality (Figure 8). The variables factored into this ranking are shown in Figure 9.

The summary map combines all the data assessed and illustrates the potential that waterfront development may have on aquatic resources on Greenvale Creek (Figure 10). This evaluation considers existing landuse, selected modifiers, parameters that influence water quality and existing sensitive habitat. The evaluation divides total possible point spread into thirds after removing the elevated scores associated with RTE, if any. Greenvale Creek appears to be subject to significant aquatic habitat degradation should waterfront development be allowed to continue. Presently development is most extensive in the lower portion of the creek. Wetland and riparian forest buffers are at risk in many of the units. Moderately high k-factors associated with soil erodibility and moderate permeability also contributed points that raise the overall ranking of units for sensitivity to impacts. A data table for Greenvale Creek is available (Table 6). This table includes all the variables and their independent scores along with cumulative and weighted rankings for each unit.

GIS Data: GIS users can view the model output in ArcView. The shape files include the data tables reporting variables, scores, and ranks.

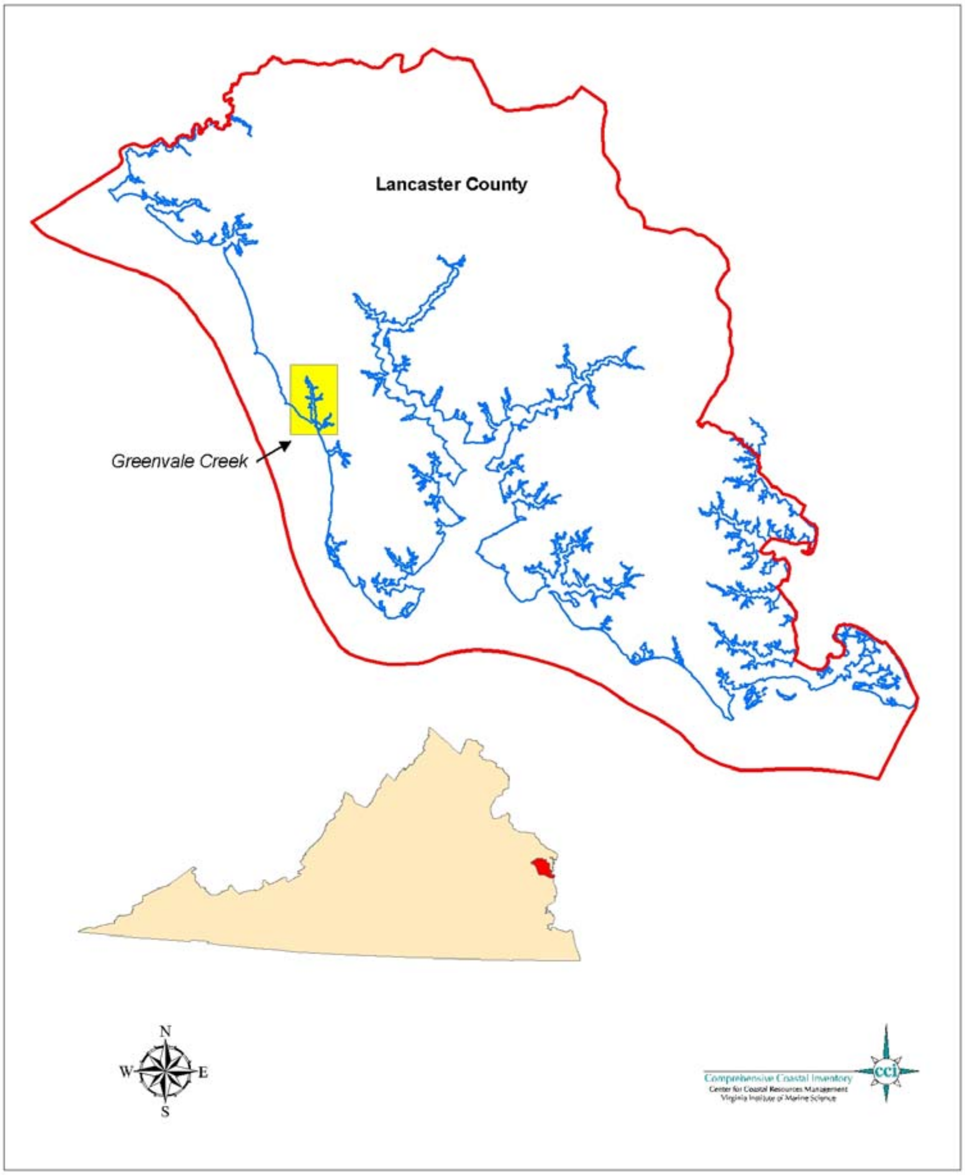

Figure 3. Pilot project area Greenvale Creek, Lancaster County, Virginia.

Other Considerations

This protocol requires that all inputs be available in a geospatial database. Surrogate geospatial data were used when actual data were not available. Still, several desirable elements could not be included. Among them were conditions pertaining to actual water quality parameters measured at local scales. Several parameters pertaining to groundwater and soil properties could not be acquired. Point source discharge sites lend information pertaining to potential water quality. These data were not incorporated in the model but could be. Soil leachability as it pertains to nutrients would be an important development consideration to maintain aquatic health. Efforts have been made to extract these data from Natural Resources Conservation Service (NRCS) soils databases for the Northern Neck. However, sufficient time was not available to extract these data for this demonstration project. Finally impervious surface cover may also lend important information to current water quality conditions within a tributary.

Currently under development is a database to define hubs and corridors defining greenways for preservation. These areas would be appropriate for inclusion in the model as modifiers, and would be ranked to reflect the high potential for development impacts.

Historic erosion rates are an indicator of shoreline stability. While maps illustrating these rates are available, they are not available digitally.

Physical process models would reveal a lot about the dynamics of a waterbody. Particularly, processes related to tidal flushing and circulation determines the residence time of nutrient and sediment input into rivers. Flushing characteristics play an important role in determining water quality. Physical process models are available. Studies being conducted to determine Total Maximum Daily Loads (TMDLs) for all shellfish growing areas in Virginia will rely on these model. Expected completion of these is 2006. Should time permit, outputs should be incorporated into this project if possible.

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APPENDIX 1. Greenvale Creek Pilot Project

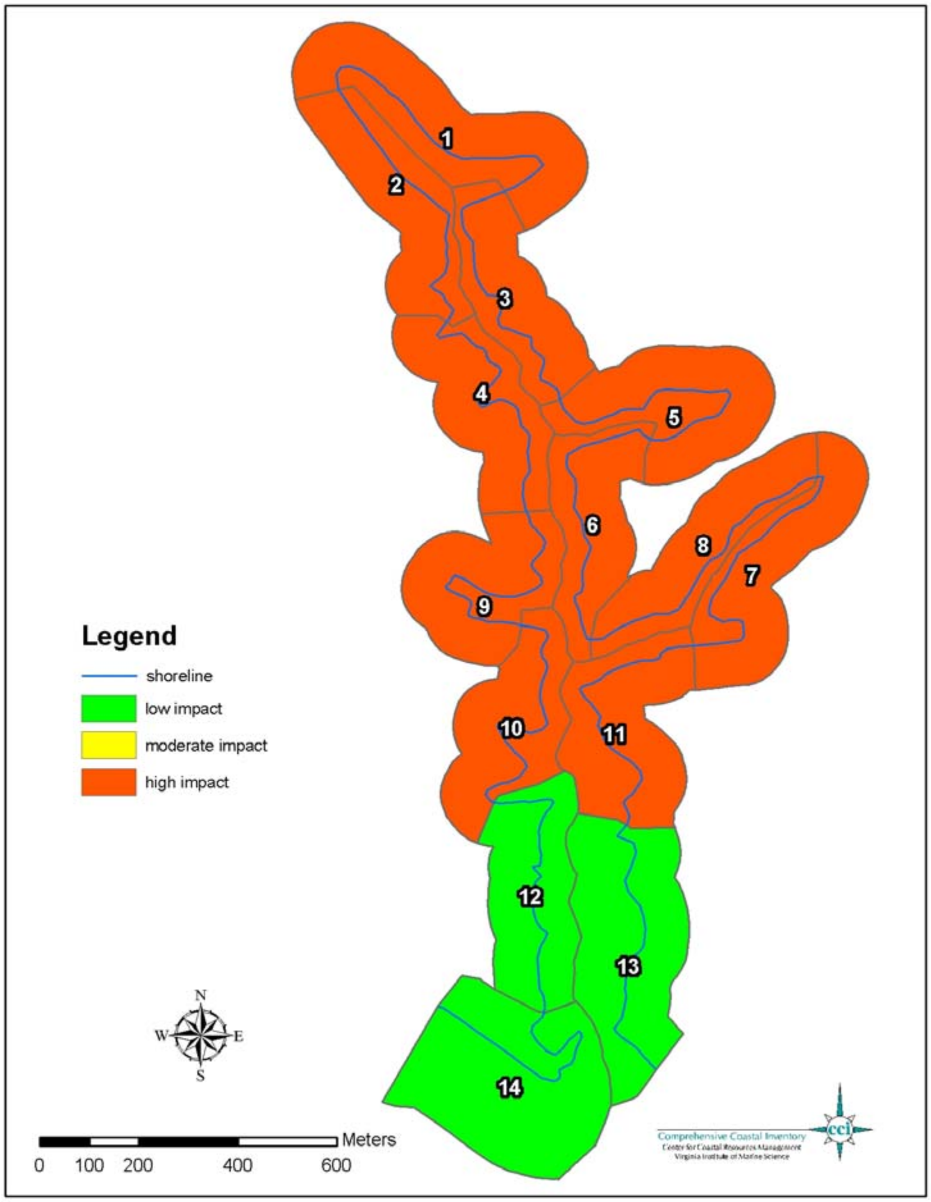

Figure 4. Potential aquatic impacts based on land use and defined modifiers along Greenvale Creek, Lancaster County, Virginia.

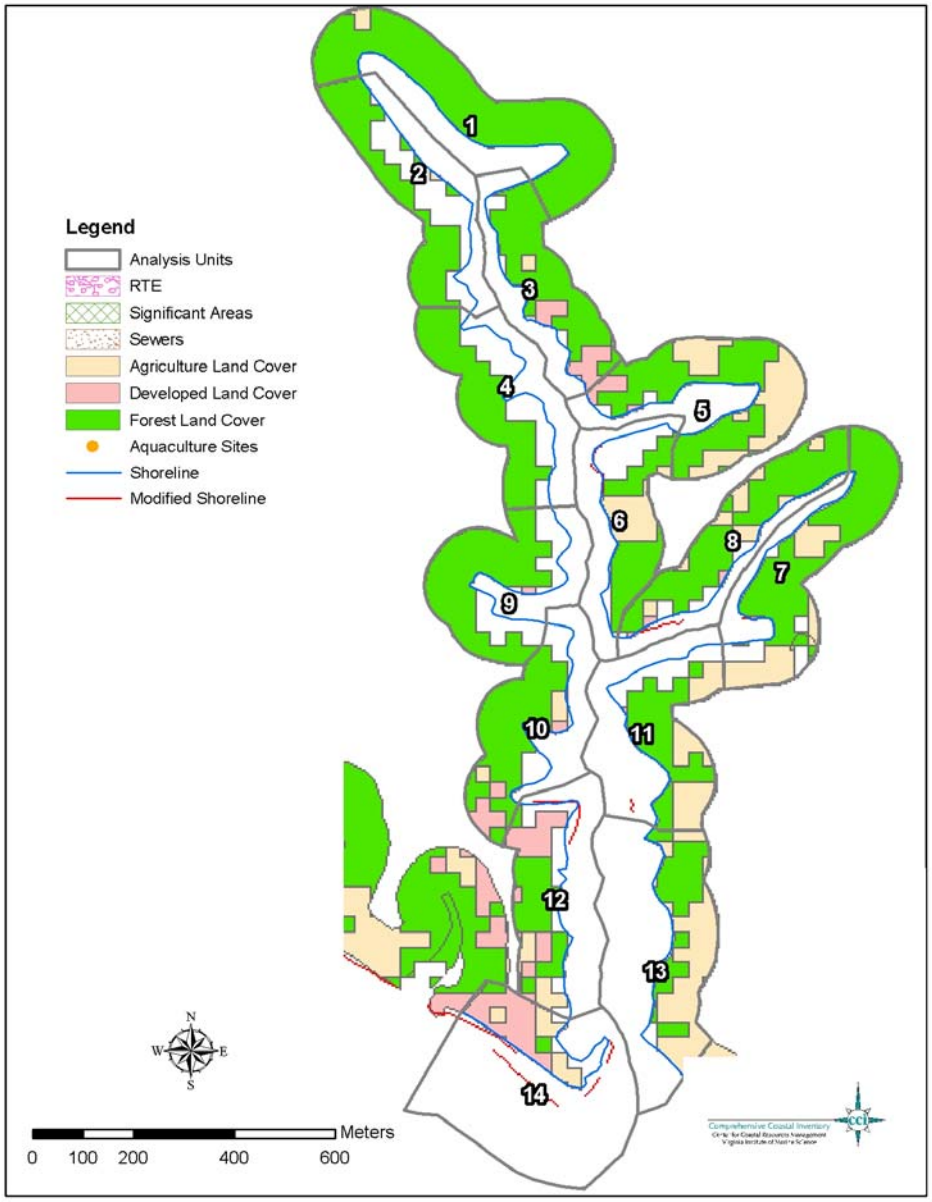

Figure 5. Baseline data - land use and defined modifiers along Greenvale Creek.

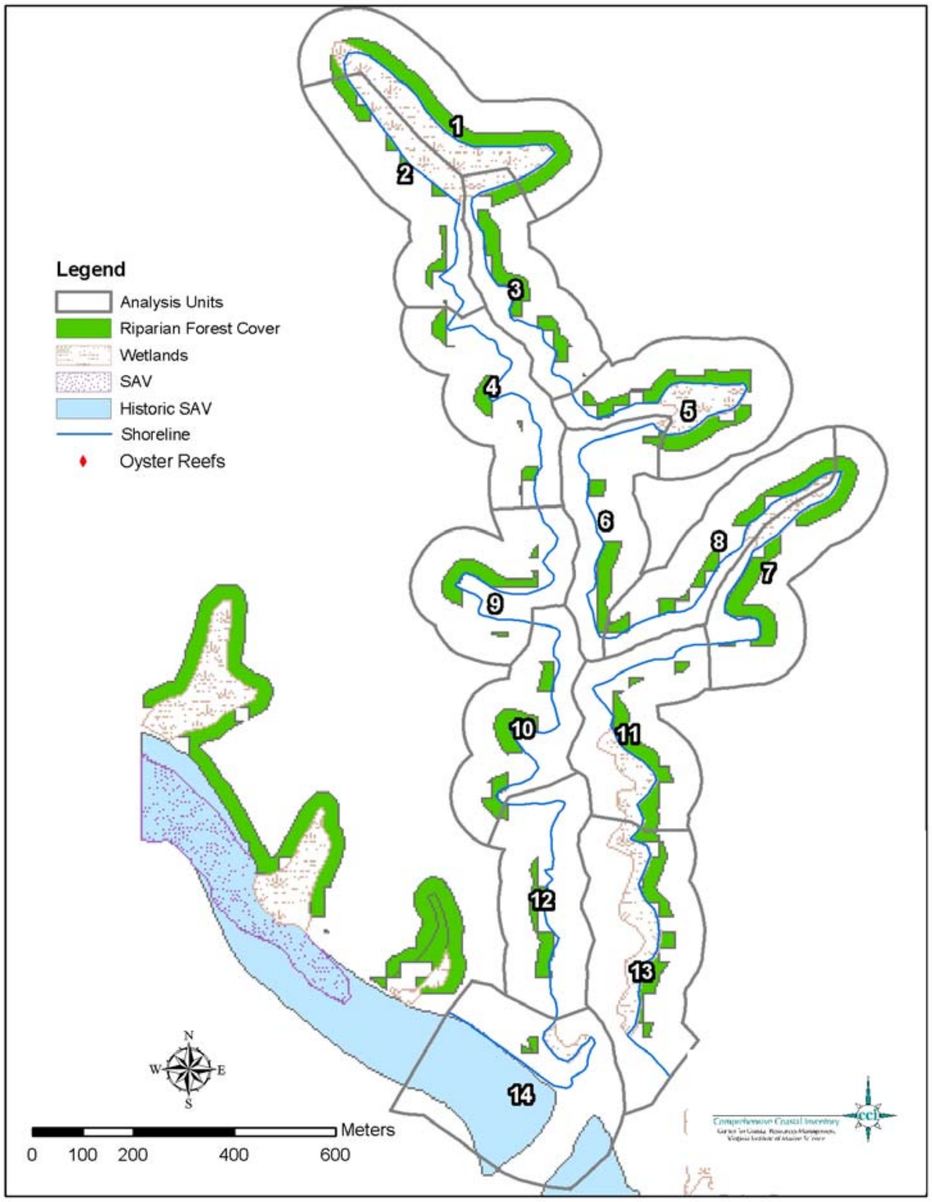

Figure 6. Baseline data - sensitive habitat variables along Greenvale Creek.

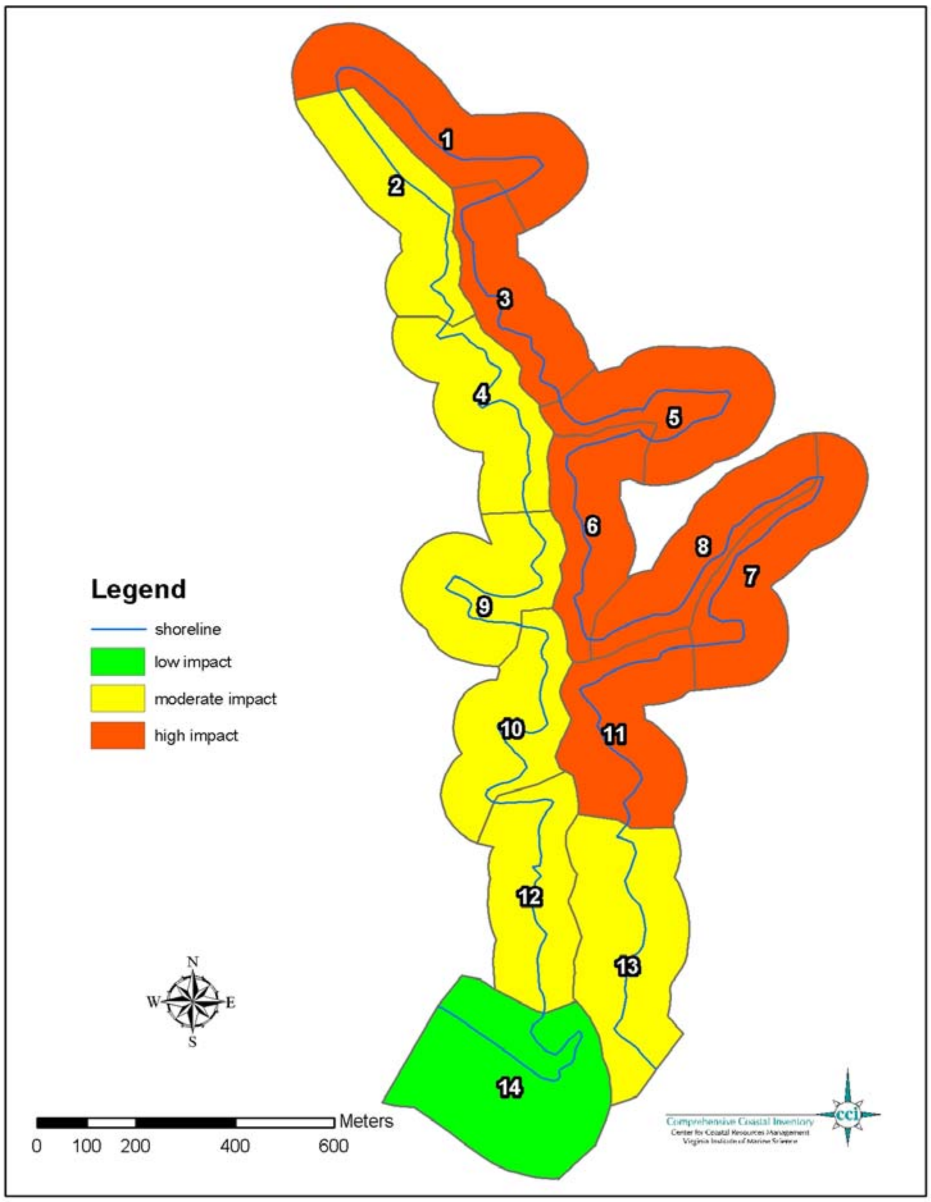

Figure 7. Potential impacts to sensitive habitat along Greenvale Creek.

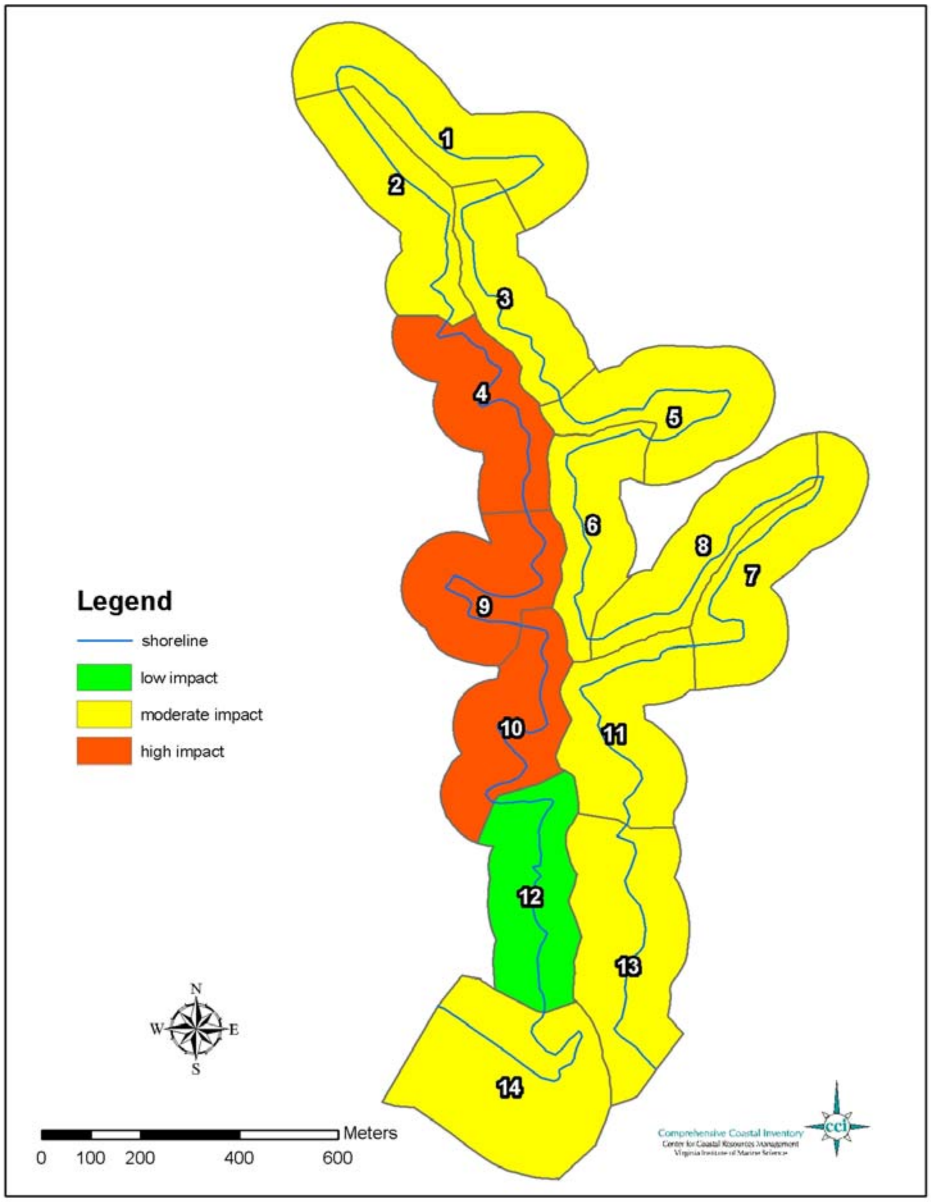

Figure 8. Potential impacts to water quality along Greenvale Creek.

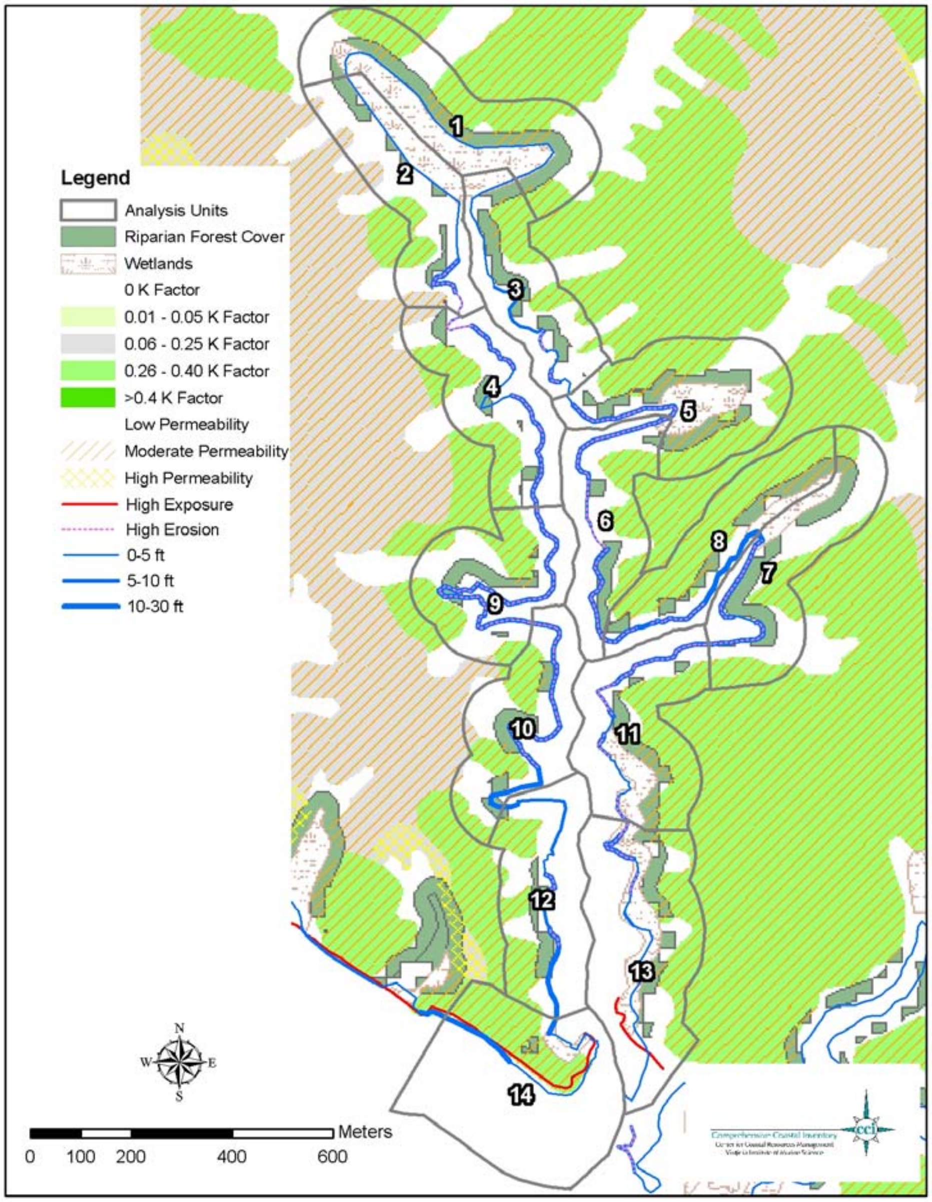

Figure 9. Baseline data - water quality variables along Greenvale Creek.

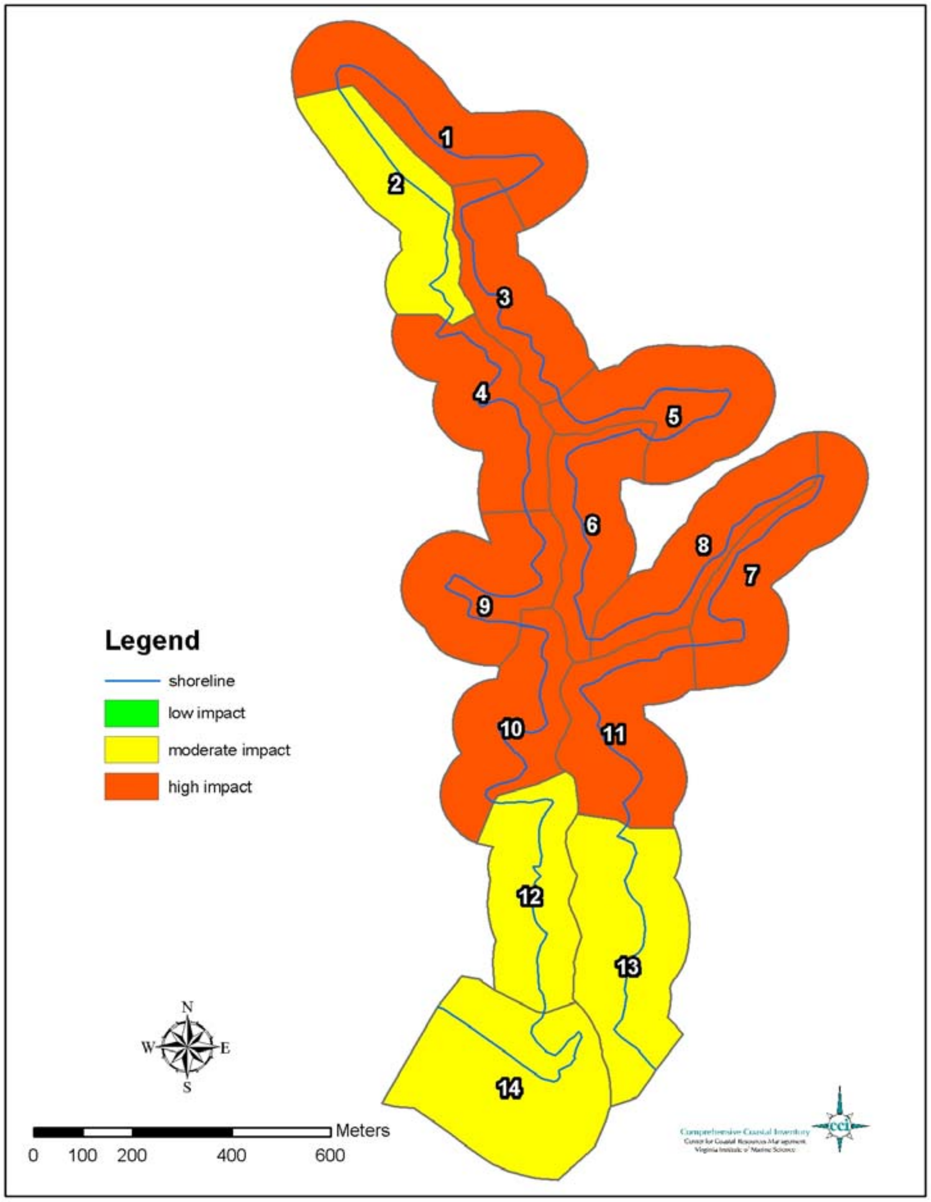

Figure 10. Combined potential impacts to aquatic resurces on Greenvale Creek.