Assessing the Impacts of Land use Change on Hard Clam Aquaculture in Old Plantation Creek, Northampton County, Virginia

Matthew J. Strickler

College of William and Mary - Virginia Institute of Marine Science

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Assessing the Impacts of Land Use Change on Hard Clam Aquaculture in Old Plantation Creek, Northampton County, Virginia

A Thesis
Presented to

The Faculty of the School of Marine Science
The College of William and Mary in Virginia

In Partial Fulfillment
Of the Requirements for the Degree of
Master of Science

by

Matthew J. Strickler

2007
APPROVAL SHEET

This thesis is submitted in partial fulfillment of
The requirement for the degree of

Master of Science

Matthew J. Strickler

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ACKNOWLEDGMENTS

First, I would like to thank my parents for all the guidance and support, financial and otherwise, they have given me throughout my life and my time at VIMS. Special thanks also go to my committee, especially Carl Hershner for funding and focusing my efforts, and Julie Herman, for the countless hours she dedicated to teaching me GIS. Additionally, I owe a debt of gratitude to Taiping Wang for all of his help with the modeling components of this study. Thanks also to those who taught me the importance of science, economics, and civic duty, without whom I likely would not care about changing the world for the better, much less have a clue how to go about doing it: Jim Gianniny, Peggy Hays, Liz Ramsey, Ken Ruscio, Jim Casey, and Jim Kahn. Finally, I must thank Pat and Andrew, without whom I would not have enjoyed graduate school nearly as much; and my wife Ashley, for her love and patience as I completed this work.
DEDICATION

To Ann and Dorris Fauber:

for showing me the beauty of nature and teaching me the virtue of hard work
ABSTRACT

One of the main threats to water quality in the Chesapeake Bay is contamination by bacterial loading from point and non-point sources. While only very high levels of fecal bacteria (greater than 200 MPN/100ml) indicate the potential of a health threat to humans from contact with water, lower concentrations (14 MPN/100 ml) make the shellfish from contaminated waters unfit for human consumption. Many nearshore areas that are vulnerable to bacterial contamination also are suitable for the propagation of shellfish, including the hard clam (*Mercenaria mercenaria*). This is especially true on Virginia’s Eastern Shore, where shallow, sheltered waters with optimal salinity and little pollution support a hard clam aquaculture industry that had an economic impact upwards of $48 million in 2004 (Murray and Kirkley, 2005). Over the past decade, however, development pressures on the Eastern Shore have increased, and land has been converted from forests and fields to subdivisions and strip malls at a faster rate than in the past. Even in the absence of a point source of bacteria such as a wastewater treatment plant, bacterial loads from non-point sources associated with increased land development have the potential to degrade water quality to the detriment of marine life and marine resource users. One area where the conflict between aquaculture and other water quality-dependent uses, and development pressure is building is the Old Plantation Creek watershed on the Eastern Shore of the Chesapeake Bay. Using a GIS-based watershed model to simulate land use and associated fecal bacteria loads, linked to a Tidal Prism Water Quality Model to estimate the disbursement of bacteria throughout the water body, this study predicts that if development continues to the maximum buildout allowed under current regulations it would lead to the condemnation of a large portion of the shellfish growing waters in Old Plantation Creek. By coupling this linked watershed-water quality model with an economic Input/Output (I/O) model, it was possible to determine the economic impact of those condemnations to the aquaculture industry and the economy of Virginia.
Assessing the Impacts of Land Use Change on Hard Clam Aquaculture in Old Plantation Creek, Northampton County, Virginia
INTRODUCTION AND LITERATURE REVIEW

In the Chesapeake Bay, as in other estuaries, the land-water interface represents an extremely productive, yet sensitive environment. Tidal marshes, crucial to nutrient cycling and pollution filtration, line the landward side of this transitional zone. Shallow subaqueous lands, lying just beneath the surface of the water, comprise the seaward portion of the nexus and serve as critical habitat for juvenile finfish, as well as for a wide variety of economically and ecologically important benthos including blue crab, eastern oyster, hard clam, and submerged aquatic vegetation (SAV).

Federal and state authorities have recognized that human activities in these areas can have detrimental effects on estuarine water quality, productivity, and biodiversity, and have enacted laws that provide for the regulation of commercial and recreational use of wetlands and shallow waters (§404 Federal Water Pollution Control Act [CWA], §28.2-1200, 1300 Code of Virginia). Similarly, governments have regulated point source discharges of pollutants into state and federal waters (§301 CWA, §62.1-44.5 Code of Virginia). Policy makers justify curtailing these easily identifiable and traceable alterations of aquatic environments on the grounds that doing so protects the public interest in the health, economic, and quality of life benefits that flow from clean, productive waters.

Although existing effluent limitations and permitting processes have not entirely solved the problems of estuarine point source pollution and habitat alteration, they have created a framework within which enforcement officials at the state and federal levels can
have some control over the amount of water pollution generated by locally-based industries, municipalities, and individual private agents. Non-point source (NPS) pollution, on the other hand, has emerged as the largest contributor of many harmful substances to the Chesapeake Bay. Agricultural runoff, atmospheric deposition, and urban and suburban stormwater carry to receiving waters massive quantities of nutrients, sediment, and bacteria, as well as significant loads of chemical pesticides, heavy metals, and hydrocarbons (Chesapeake Bay Program, 2006). This situation has resulted not only from the decrease or slower rate of increase in point source pollution, but also because NPS pollution has proved more difficult to regulate. While §303 of the CWA gives the US Environmental Protection Agency (EPA) the authority to impose total maximum daily loads (TMDLs) of pollutants for water bodies impaired by non-point sources, the responsibility of meeting the TMDL requirement falls first on the state, and ultimately on the local government (§303 CWA).

The Constitution of Virginia states that: “it shall be the Commonwealth's policy to protect its atmosphere, lands, and waters from pollution, impairment, or destruction, for the benefit, enjoyment, and general welfare of the people of the Commonwealth” (Article XI, §2). However, the difficulty of tracking the origins of land-based NPS pollution, along with the resistance of localities and private property owners to state or federal restrictions on the land uses that lead to NPS pollution, have stymied many regulatory efforts. This clash between public interest in water and private rights in land has continually forced lawmakers to accept the inadequate compromise of local assistance and voluntary compliance programs as an alternative for addressing the NPS problem.
In addition to their inability to control existing land uses in the coastal zone, legislators and regulators cannot slow the increase in population and associated land development taking place around the Chesapeake Bay. The number of people living in the Chesapeake Bay watershed more than doubled from 8.1 million in 1950 to 16.6 million in 2005 (Chesapeake Bay Program, 2007). From 1990 to 2000 alone, landowners, developers, and governments converted nearly 250,000 acres of farmland, forest, wetlands, and other open space to impervious surface (Chesapeake Bay Program, 2006). Not only does this changing landscape alter the quality of water flowing off the land during storm events, but it also may change the quantity of runoff as the amount of impervious surface in a watershed increases.

One sign that expanding human populations in the coastal zone are degrading water quality is the increase in fecal coliform bacteria concentrations in the water column. Produced in the guts of warm-blooded animals, fecal coliforms consist largely of the specific bacterium *Escherichia coli* (*E. coli*), but can indicate the presence of other pathogens, including *Salmonella typhi* and *Vibrio vulnificus* (APHA et al., 1985; Huang, 2005). These enteric bacteria reach the water either by direct deposition, or from land via surface runoff and groundwater. Sources of fecal coliform bacteria include municipal wastewater discharge, human septic leachate, wildlife, pets, and livestock (Shen, et al., 2002a). While one would expect the livestock contribution to decrease as human population, impervious surface, and urban and suburban land use increase relative to farmland, loads from municipal point sources and the three non-point sources have the potential to increase.
Public officials have acknowledged the dangers of coming in contact with, or consuming shellfish harvested from bacterially contaminated waters, and frequently close areas to swimming and shellfish harvesting if samples taken from the water exceed maximum safe levels of fecal coliform bacteria. Fecal coliform concentrations are determined using a Most Probable Number (MPN) method (APHA, 1999). The upper limit of fecal coliforms for direct contact is a 30-day log mean of 200 MPN/100ml and the upper limit for shellfish harvest is 14 MPN/100ml, reflecting the human health concerns associated with consuming bacterially contaminated shellfish. For shellfish harvest, no more that 10% of samples from the observation period may exceed 43 MPN/100ml (NSSP, 2003; Huang, 2005). These standards are set by the Virginia Department of Health Division of Shellfish Sanitation (DSS). The health concern arises because filter-feeding shellfish can accumulate pathogens from the water, and because people often consume raw shellfish. In spite of laws dictating that all waters in the Commonwealth remain suitable for shellfish harvest, thousands of acres of Virginia’s tidal waters remain condemned for that purpose because of bacterial contamination (§62.1-44.2 Code of Virginia).

Throughout the world, aquaculture, or the farming of aquatic organisms, is increasingly being adopted as a way to bolster production of seafood in the face of stagnant or declining wild catches (Goldburg et al., 2000). In 2002, cultured finfish and shellfish represented nearly thirty percent of world fisheries production by weight, and generated $60 billion in sales (FAO, 2004). Both the United States and the Commonwealth of Virginia have codified policies to encourage and facilitate the development of the aquaculture industry (16USC2801, §3.1-73.6 Code of Virginia).
Because they can tolerate a wide range of environmental settings and obtain their food from the surrounding water, molluscan shellfish present themselves as a low cost, high return aquaculture investment that does not require the use of wild fishery resources as a feed input. Available evidence also suggests that shellfish aquaculture, except in the most intensive (highest concentration) farms, creates fewer environmental problems than does finfish culture (Davenport et al., 2003). Over the past two decades, the use of near-shore subaqueous land for the extensive commercial culture of hard clams (*M. mercenaria*) has become widespread in the shallow waters of the lower Chesapeake Bay and seaside coastal lagoons. *M. Mercenaria* is an infaunal suspension-feeding bivalve native to the North American coast from the Gulf of St. Lawrence to the Gulf of Mexico (Eversole, 1987). While able to endure widely variable environmental conditions, the hard clam grows best in low energy environments at salinities above 12.5 ppt and at temperatures between 9 and 31°C, peaking at 24-28 ppt and 20°C (Eversole, 1987). In Virginia, these conditions are approached most consistently in the seaside lagoons and southernmost bayside creeks of the Delmarva Peninsula.

Virginia laws and regulations allow for the leasing of the subaqueous land for the purpose of growing shellfish (§28.2-600-650; 4 VAC 20-335-10 et seq.). Many active leases shifted from oyster (*Crassostrea virginica*) to clam production after the arrival of the oyster diseases MSX and Dermo, and before the development of disease-resistant strains of *C. virginica*. In 2004, farm-gate sales of cultured clams were estimated at nearly $24 million for the Eastern Shore alone (Murray and Kirkley, 2005). Proponents of clam aquaculture see it as a potentially sustainable activity, and also as a source of
income for people in rural tidewater communities that have been devastated by declines and fluctuations in the abundance of traditional wild fishery resources.

Nowhere is this sentiment more evident than on the lower Eastern Shore of Virginia, where the core of the clam aquaculture industry is situated. Northampton County in particular has become severely depressed economically as a result of low farm prices and the depletion of aquatic resources on both sides of the peninsula (Petrocci, 2001). However, with cleaner water and higher salinity than the Bay’s western shore rivers, the numerous sheltered tidal creeks and lagoons along the bayside and seaside of Northampton County provide optimal conditions for the grow-out phase of clam aquaculture (Murray and Kirkley, 2005). Many see the emergence of this enterprise as a sign that the Eastern Shore can rebuild its natural resource-based economy and retain its rural character.

At the same time that the aquaculture industry has established itself as a fixture on Virginia’s Eastern Shore, another set of major economic players has taken an interest in the area. In the early 1990s, land developers began targeting Northampton County because of its abundant inexpensive property, relative proximity to the Hampton Roads metropolitan area, and less restrictive land use regulations. While the zoning appeals process has become somewhat more arduous in the last several years, pressure from developers continues to increase, and with few other sources of tax revenue to provide for necessary public services, the local governments often acquiesce to their demands.

One area that is rapidly becoming an epicenter for potential conflict between developers and aquaculturists is the Old Plantation Creek watershed. As the southernmost of the bayside creeks, it has the high salinities necessary to promote rapid
growth of clams. This location also makes the banks of Old Plantation the some of the first sheltered waterfront property on the north side of the Chesapeake Bay Bridge-Tunnel, and therefore immensely attractive to developers.

Over the last fifteen years, a large portion of the agricultural and forested land in the watershed has been converted to lots for businesses and homes, and for two 18-hole private golf courses. More residential and commercial development is planned for the areas that have already been rezoned, and the remaining open space in the watershed is at increasingly higher risk for conversion as property values continue to rise. This development could have serious consequences for water quality in Old Plantation Creek, as well as for the aquaculturists who depend on good water quality to be able to grow and harvest their clams. While clams can be grown on bottom condemned by fecal bacteria contamination, the cost of the depuration process necessary to make the clams legal for sale is prohibitive, effectively rendering any condemned area worthless to aquaculturists (Michael Peirson, Cherrystone Aqua Farms, pers. comm.).

PROJECT OVERVIEW AND RESEARCH OBJECTIVES

This project used Old Plantation Creek and its watershed as a case study to examine how increases or decreases in natural and anthropogenic land-based pollution might affect hard clam aquaculture through alteration of water quality. Using a watershed model to estimate fecal coliform loading and spatial use suitability data to bound potential clam production, the study addressed how different land use policies in the watershed would affect the number of clams that might be raised profitably in Old Plantation Creek, based on increases or decreases in the extent of areas condemned to
shellfish harvest. In addition, this study attempted to measure the economic impact of changes in the level of clam production to the local and state economies using Input-Output (I/O) analysis. Finally, the results are discussed in the context of Virginia’s existing system of coastal land use decision making. The goal of this project was to apply existing techniques in a manner that helps to reveal the ways in which pollution resulting from individual decisions on private land can affect privately and socially beneficial uses of public trust waters and submerged lands.

There are four major objectives of this research:

(1) Use a GIS-based watershed model to estimate loading of fecal coliform bacteria to Old Plantation Creek for baseline and future land use scenarios;

(2) Link the watershed loading model to a tidal prism water quality model to estimate the spatial distribution of fecal coliform loads within the creek;

(3) Based on these estimates and the water quality requirements for fecal coliform in shellfish growing waters, determine the extent of leased bottom that will be condemned under baseline and future land use scenarios; and

(4) Use an Input-Output (I/O) model to estimate the economic impacts associated with an increase or decrease in available aquaculture grow-out areas in the creek.
MATERIALS AND METHODS

Study area and GIS

Old Plantation Creek is a small tidal inlet with a surface area of approximately 2.5 km$^2$ (Fig. 1). The average depth of the creek is less than 1m and the narrow, winding main channel ranges in depth from 2 to 4 meters (NOS, 1950). The lower and middle sections of the creek are comprised largely of firm, sandy bottom, which supports some eelgrass communities around the creek mouth. Softer sediments dominate the middle and upper reaches. The creek lies on the Chesapeake Bay side of the Delmarva Peninsula, approximately 2.5 miles south of Cape Charles harbor and 8 miles north of the northern terminus of the Chesapeake Bay Bridge-Tunnel complex. The mouth of the creek opens southwestward to the Chesapeake Bay. Northampton County borders the creek to the south and west. The town of Cape Charles annexed the land north of the creek in 1990. Up to that point, agricultural land use dominated the watershed, with some commercial development along the U.S. 13 highway corridor, and private residences interspersed throughout. Only one residential subdivision on the southern shore of the creek existed in the watershed prior to 1990.

During the 1990s, land development in the Old Plantation Creek watershed increased slowly but steadily. A Virginia Beach-based firm purchased the annexed tract from Cape Charles and began work on Bay Creek, a 3,000 unit residential development with two 18-hole golf courses. Because of the association of fecal coliform sources with
certain land uses, these changes could increase loads to Old Plantation Creek. In order to support the watershed-based fecal coliform loading model, land use in the target watershed was characterized, and information stored in a Geographic Information System (GIS). The baseline year of 2002 was chosen for the land use categorization for two reasons. First, this year falls just before the major residential construction boom at Bay Creek. Second, Virginia Base Mapping Program (VBMP) aerial photography from 2002 served as a template for characterizing land use in the watershed (VGIN, 2002).

Land use was digitized from the VBMP digital orthographs using ESRI ArcMAP 9.1 software. The process involved visually identifying land use features on a spatially rectified aerial photograph, and using editing tools in ArcMAP to draw polygons around each distinct tract of land. Like tracts were coded into distinct land use categories in the GIS, creating a digital representation of the area and spatial location of different land uses in the watershed. The watershed boundary was defined using U.S. Geological Survey (USGS) 7.5 minute topographic maps. Subwatershed boundaries for use in the loading model were obtained as shapefiles from VIMS Center for Coastal Resources Management Comprehensive Coastal Inventory (CCI, 2005). (Fig. 2)

There were eight land use categories identified for this study: open water, emergent wetland, beach, forest, golf course, crop land, residential development, and commercial/industrial development (Fig. 3). Each land use has distinct hydrologic and ecologic characteristics, as well as distinct loading coefficients, with residential development assumed to contain 35% impervious surface, and commercial/industrial development assumed to contain 85% impervious surface (Huang, 2005). To support the objective of predicting potential future states of land use in the watershed, information
was collected from the following sources: comprehensive plans, zoning maps and ordinances, plat maps, and building permit records. These materials were provided by the Cape Charles town planner, and the Northampton County Department of Planning and Zoning. The General Assembly requires Virginia localities to develop a comprehensive plan to guide development and to update the plan every five years.

The Comprehensive plan serves to inform local officials and residents about the large scale and long-term goals for the locality, and the general trajectory of planned public and private development (§15.2-2223 Code of Virginia). A zoning map is a visual representation of the restrictions placed on certain parcels of land by the provisions of the zoning ordinance. By assigning land to a certain zoning category, a local government defines the boundaries of potential use. Examining a zoning map and the written restrictions placed on land in certain zones by the zoning ordinance allows one to understand the location and intensity of future development. A plat map shows parcels of land that have been divided and “platted” for building. Comparing the plat map to the zoning map and ordinance, existing development patterns, and recent building permit records can aid in determining the number of structures that could be built on a tract of land zoned for development.

Using this information, a future scenario of “full buildout” was created and entered into the GIS as a separate shapefile. Full buildout characterizes a future state of land use in which land, as it is currently zoned, subdivided, and platted, is developed to its full capacity (Fig. 4). The 2002 baseline and the full buildout scenario represent the upper and lower bounds for the land use component of the analysis that will be conducted using the watershed loading, tidal prism, and economic I/O models described below.
Because of the volatility of the housing and construction markets, no date was estimated for the full buildout scenario. A more detailed description of the GIS development is provided in Appendix B.

Observed fecal coliform concentrations in Old Plantation Creek were obtained from DSS, which conducts a seawater sampling program to test shellfish growing waters for bacterial contamination. To ensure that samples are obtained during all weather conditions, sampling is scheduled one month in advance (VDH DSS, 2007). Sampling occurs approximately once a month at a number of designated stations within Old Plantation Creek, and samples are analyzed for fecal coliform concentration at DSS labs. Fecal coliform concentrations are expressed as most probable number (MPN) of colony forming units per 100 ml of seawater. The sampling stations from which data were obtained for this study are shown in Fig. 1.

**LSPC Watershed Model**

The model used to determine changes in fecal coliform loading rates based on land use changes in the watershed was the Loading Simulation Program C++ (LSPC). This model, developed by the US Environmental Protection Agency (EPA), has been used successfully in TMDL studies for fecal coliform, nutrients, and acid mine drainage (Shen et al., 2002b). The model is precipitation driven, and uses information from an underlying user-compiled Microsoft Access database to simulate watershed hydrology and pollution transport, and ultimately to estimate fecal coliform loads to the water body by subwatershed (Shen et al., 2002b). Data to support this model were collected from a number of sources. All land use and stream network data were obtained from the VBMP.
imagery described above. Hourly rainfall data were collected from a station at Cherrystone Inlet, approximately six miles north of Old Plantation Creek. Since there are no point sources of bacteria in the watershed, this study includes three categories of NPS producers: domestic animals, septic system failures, and wildlife. The watershed contains very few livestock, so no fecal coliform production will be assumed from this source. Fecal coliform production values for NPS were compiled from the existing literature, as shown in Table 1:

Table 1: This table shows the sources of fecal coliform bacteria used in this study and the daily bacterial production associated with each source.

<table>
<thead>
<tr>
<th>Animal</th>
<th>FC/day</th>
<th>Reference</th>
<th>Comments</th>
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<tbody>
<tr>
<td>Dog</td>
<td>5.0E+09</td>
<td>(EPA, 2001)</td>
<td></td>
</tr>
<tr>
<td>Chicken</td>
<td>1.9E+08</td>
<td>(EPA, 2001)</td>
<td></td>
</tr>
<tr>
<td>Deer</td>
<td>2.5E+04</td>
<td>(Kator and Rhodes, 1996)</td>
<td>assume 250 g/day</td>
</tr>
<tr>
<td>Duck</td>
<td>4.5E+09</td>
<td>(EPA, 2001)</td>
<td>average of 3 sources</td>
</tr>
<tr>
<td>Canada Geese</td>
<td>4.9E+10</td>
<td>(EPA, 2001)</td>
<td></td>
</tr>
<tr>
<td>Canada Geese</td>
<td>9.0E+06</td>
<td>(Hussong et al., 1979)</td>
<td></td>
</tr>
<tr>
<td>Horse</td>
<td>4.2E+08</td>
<td>(EPA, 2001)</td>
<td></td>
</tr>
<tr>
<td>Pig</td>
<td>5.5E+09</td>
<td>(EPA, 2001)</td>
<td></td>
</tr>
<tr>
<td>Sea gull</td>
<td>1.9E+09</td>
<td>(Gould and Fletcher, 1978)</td>
<td>mean of four species</td>
</tr>
<tr>
<td>Raccoon</td>
<td>1.0E+11</td>
<td>(Kator and Rhodes, 1996)</td>
<td>assume 100 g/day</td>
</tr>
<tr>
<td>Muskrat</td>
<td>3.4E+07</td>
<td>(Kator and Rhodes, 1996)</td>
<td></td>
</tr>
<tr>
<td>Septage</td>
<td>1.0E+09</td>
<td>(Kator and Rhodes, 1991)</td>
<td>assuming 70/gal/day/person</td>
</tr>
</tbody>
</table>

For the domestic and wild animal categories, only those species for which reliable data were available were included, therefore some fecal coliform production will inevitably be left out of the model. The methods used for calculating animal populations and septic failure rates are detailed below:
Deer populations were calculated using a formula supplied by the Virginia Department of Game and Inland Fisheries (DGIF). An average deer index for the years 1994-2002 was used in the following calculation: 
\[
\text{deer/mi}^2 \text{ of deer habitat} = [(7.74 \times \text{average deer index}) - 0.64].
\]
Using an average deer index of 4.23 for Northampton County, the formula gave a deer density of 32.1 deer/mi^2 (12.394 deer/sq. km) of deer habitat, which was defined as wetlands, forest, golf course, and cropland. Raccoon and muskrat populations were calculated using density information provided by VA DGIF. Raccoons were 10/mi^2 in forest and 50/mi^2 in emergent wetlands. Also, 10% is direct fecal deposition to water. Muskrats were calculated based on an average density of 10/mi^2 of suitable habitat (wetlands, ponds). Dog populations were calculated using a formula from the American Veterinary Medical Association: number of dogs = number of households \times 0.58. Applying this to the area of developed land uses gives a density of dogs by land use in each subwatershed.

While migratory birds can be a significant source of fecal coliform bacteria, mobility and seasonal variability of populations makes their contribution to loading difficult to measure. This study divides populations into winter (October-March) and summer (April-September). Winter counts are based on the Christmas Bird Count conducted by the National Audubon Society (CBC, 2006). Summer counts are based on the North American Breeding Bird Survey conducted by USGS (NABBS, 2004). Each of these surveys has an Eastern Shore transect in close proximity to Old Plantation Creek. Counts of birds from each survey were divided by the area surveyed to generate bird densities. These densities were then multiplied by the area of bird habitat in the target watershed to estimate seasonal bird populations around Old Plantation Creek. Because of
different habitat requirements and fecal coliform production rates, three categories of
birds were examined.

Gulls were linked to open water, beach, golf course, crop land, residential
developed, and commercial/industrial developed land uses. Species included are ring-
billed gulls, laughing gulls, herring gulls, and great black-backed gulls. Ducks were
linked to open water, beach, wetland, and golf course land uses. Species included are
black ducks, mallards, wood ducks and buffleheads. Canada geese were linked to open
water, beach, wetland, golf course, and crop land uses. Winter counts were higher than
summer counts. However, the presence of large numbers of Canada geese in summer
may indicate the development of a local resident population.

Septic tank count was based on the number of residential and commercial
structures. The future projection is based on full-buildout of lots in existing subdivisions
and full buildout of appropriately zoned land that has not yet been subdivided, according
to minimum lot sizes specified in the zoning ordinance. A septic failure rate of 12.0%
was used, based on US Census Bureau data for Virginia (Huang, 2005).

Linking the location or habitat of each source to a specific land use determines the
fecal coliform load from that land use. The LSPC model then multiplies the fecal
coliform load per area of land use by the total area of that land use in the subwatershed,
summing across land uses to obtain a total fecal coliform deposition for the
subwatershed. This deposition term is tempered by a delivery ratio, which incorporates
the hydrological data as well as on-land and in-water bacterial decay rates, and estimates
a fecal coliform load for each subwatershed. The LSPC modeling process is described in
greater detail in Appendix C.
Tidal Prism Water Quality Model

The Tidal Prism Water Quality Model (TPWQM) developed at the Virginia Institute of Marine Science is a standard tool for estimating the physical dispersal of pollutants loaded into a tidal inlet (Shen et al., 2002b). This model operates on the principle of tidal flushing, which states that water flushed out of an embayment on each tidal cycle will carry with it some amount of the pollutants that had previously entered the embayment (Ketchum, 1951). The tidal prism is the volume of water that enters and leaves an embayment during a tidal cycle (Shen et al., 2002b).

The water body is divided into tidal prism segments, and integrated with the LSPC model by a linkage table included in the associated Access database. Multiple tidal prism segments may be linked to a single subwatershed (Kuo and Park, 1994). Based on the high tide volume and water depth of the inlet, and the tidal prism for each segment, the TPWQM estimates the concentration of the pollutant that will exist in different areas of the water body as a result of the location and amount of pollutant loads. The model makes two estimates per day over the length of the model run, at 11 am and 11 pm. Tide information and tidal prism segments for Old Plantation Creek were provided from data compiled at VIMS (Fig. 2). Appendix D describes the TPWQM process more thoroughly.

Model Calibration

To calibrate the loading and tidal prism models, fecal coliform concentrations observed in different segments of the creek over the study period were compared to modeled results generated with 2002 land cover and precipitation data from 2000-2004.
An in-stream decay rate of 0.5 per day was used, consistent with values for bacterial decay in seawater gleaned from the literature and used in similar TMDL studies (Mancini, 1978; MDE, 2004). The storage capacity of fecal coliform bacteria on land was set to nine times the accumulation rate, representing a bacterial decay rate of 0.1 per day (Wang, 2005). The purpose of this exercise was to establish the model as a reasonably accurate predictor of fecal coliform concentrations in the creek, thus increasing the validity of model results generated under the future land use scenario.

To set the tidal prism segments as units of analysis, the mean of observed fecal coliform concentrations at all sampling sites within each tidal prism segment was used as the segment fecal coliform concentration for each sampling date. Modeled results were obtained for each sampling station for the 2000-2004 study period by averaging the two model output fecal coliform concentrations (morning and evening) for each day of the study period on which a sample was taken. The charts in Figure 8 plot observed and modeled fecal coliform concentrations in three tidal prism segments. Observed and modeled mean fecal coliform concentrations in each tidal prism segment were compared over the study period, using two-sample T-tests to test for a difference in means.

**Input-Output Model**

Input-Output (I/O) analysis is a technique used to measure the impact that an individual economic activity or industry has on a regional economy. An I/O model incorporates not only direct effects generated by the sale of a product, but also indirect effects created by the purchase of inputs essential to production of the target good, as well as induced effects generated by the household expenditures of industry workers (Lindall and Olson, 2006). For example, the sale of cultured hard clams creates revenue
for the aquaculturist, as well as for the seed supplier, net manufacturer, shipping firm, and restaurant owner. The revenue that these linked support and post-production industries generate from the culture and sale of the clam, plus that which other industries receive when the aquaculturist uses his profits to purchase household goods and services, creates a “ripple effect” that, when accounted for, multiplies economic impacts (Schaffer, 1999).

It is important that economic impact differs from value. Social value, often estimated using cost-benefit analysis, estimates the increase in value to society of some action, net of the costs necessary to carry out that action. The purpose of cost-benefit analysis is to determine the most economically efficient option (NOAA Coastal Services Center, 2007). An economic impact technique, like I/O analysis, “does not account for the value of what is given up to achieve the measured level of economic activity, nor does it measure the opportunity cost of the activity...Furthermore, it places no economic value on the non-use values of environmental resources” (NOAA Coastal Services Center, 2007). However, economic impacts are useful on the state and regional level as an indicator of the economic activity associated with an industry.

The I/O model chosen for this study was developed by Kirkley specifically for the Virginia cultured clam industry (Murray and Kirkley, 2005). It incorporates survey-derived production and cost data and produces an estimate of the economic impacts for a given amount of revenue generated by the industry based on regional market linkages and multipliers from the IMPLAN Input-Output model. Since this study focuses on Old Plantation Creek, an area that supports a large proportion, but not all of the hard clam aquaculture grow-out in Virginia, site-specific data were collected. Information about seed planting rates and densities, grow-out times, and dockside sale prices was obtained.
through interviews with aquaculturists using Old Plantation Creek as a grow-out area (Walker, West, and Peirson, pers. comm.). The I/O analysis tool is explained at length in Appendix E.

Use suitability and leases

To determine how much potentially productive subaqueous land would be lost to condemnations occurring in different sections of the creek, a use suitability analysis was needed. Woods (2001) and VIMS-CCRM developed use suitability models for hard clam aquaculture in Cherrystone and Hungars Creeks, two systems similar to Old Plantation Creek (Woods, 2001). Aside from the bacterial water quality criteria, these spatially explicit GIS models used four factors to determine hard clam grow-out suitability: wind exposure; water depth; sediment composition; proximity to SAV. While these criteria are indeed important, interviews with aquaculturists and industry experts related to the current study revealed that none of them make clam culture infeasible on any bottom currently leased in Old Plantation Creek, and that all potentially productive bottom within the creek is currently under lease (Mills, 2001). Also, federal law prohibits aquaculture activity in SAV beds without a permit (§404 CWA). Therefore, the leased area in the creek was chosen as the area suitable for clam production. A subaqueous lease layer was added to the GIS by importing a CAD feature database provided by the Virginia Marine Resources Commission, and rectifying its position relative to other layers using a two-point transformation (VMRC, 2005). A new shapefile was then created by digitizing the leases outlined by the CAD drawing into polygons (Fig. 5). This allows for identification
of the location of leases within the creek, and of the individual or group that holds the lease.

RESULTS

Based on the results of the LSPC-TPWQM exercise shown in Table 2, it is not possible to establish that the observed and predicted means are significantly different. In comparing the modeled fecal coliform concentrations under the future land use scenario to the baseline concentrations, the same statistical test was used. In many tidal prism segments, fecal coliform concentrations are significantly higher under the buildout scenario than they are under the baseline scenario (Table 3).

Table 2: This table presents observations and modeled results for the baseline scenario. The P-values generated by simple T-tests show that there is no significant difference between observed and modeled fecal coliform concentrations in the tidal prism segments for which DSS sampling data exist over the study period. The large standard deviations reflect the fact that bacterial loads are delivered in pulses during precipitation events.

<table>
<thead>
<tr>
<th>Tidal Prism Segment</th>
<th>Number of samples (2000-2004)</th>
<th>Arithmetic mean FC (count/100ml)</th>
<th>Standard deviation</th>
<th>95% confidence interval for FC difference</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 baseline (mod)</td>
<td>53</td>
<td>5.62</td>
<td>6.37</td>
<td>1.06312, -3.48765</td>
<td>0.293</td>
</tr>
<tr>
<td>1 baseline (obs)</td>
<td>53</td>
<td>6.831</td>
<td>5.39</td>
<td>***</td>
<td>***</td>
</tr>
<tr>
<td>2 baseline (mod)</td>
<td>51</td>
<td>16.33</td>
<td>21.42</td>
<td>8.897412, -8.524079</td>
<td>0.996</td>
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<tr>
<td>2 baseline (obs)</td>
<td>51</td>
<td>16.14</td>
<td>22.89</td>
<td>***</td>
<td>***</td>
</tr>
<tr>
<td>3 baseline (mod)</td>
<td>46</td>
<td>34.20</td>
<td>42.37</td>
<td>36.46, -29.64</td>
<td>0.801</td>
</tr>
<tr>
<td>3 baseline (obs)</td>
<td>46</td>
<td>36.46</td>
<td>56.45</td>
<td>***</td>
<td></td>
</tr>
<tr>
<td>6 baseline (mod)</td>
<td>50</td>
<td>16.72</td>
<td>22.45</td>
<td>15.88927, -12.00887</td>
<td>0.099</td>
</tr>
<tr>
<td>6 baseline (obs)</td>
<td>50</td>
<td>10.38</td>
<td>14.72</td>
<td>***</td>
<td>***</td>
</tr>
<tr>
<td>7 baseline (mod)</td>
<td>50</td>
<td>16.94</td>
<td>22.71</td>
<td>***</td>
<td>***</td>
</tr>
<tr>
<td>7 baseline (obs)</td>
<td>***</td>
<td>***</td>
<td>***</td>
<td>***</td>
<td>***</td>
</tr>
<tr>
<td>8 baseline (mod)</td>
<td>50</td>
<td>17.63</td>
<td>22.79</td>
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<tr>
<td>8 baseline (obs)</td>
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<td>***</td>
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<td>***</td>
</tr>
<tr>
<td>9 baseline (mod)</td>
<td>51</td>
<td>12.15</td>
<td>27.57</td>
<td>***</td>
<td>***</td>
</tr>
<tr>
<td>9 baseline (obs)</td>
<td>***</td>
<td>***</td>
<td>***</td>
<td>***</td>
<td>***</td>
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<tr>
<td>10 baseline (mod)</td>
<td>51</td>
<td>23.42</td>
<td>61.91</td>
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<td>***</td>
</tr>
<tr>
<td>10 baseline (obs)</td>
<td>***</td>
<td>***</td>
<td>***</td>
<td>***</td>
<td>***</td>
</tr>
<tr>
<td>11 baseline (mod)</td>
<td>51</td>
<td>31.5</td>
<td>85.1</td>
<td>***</td>
<td>***</td>
</tr>
<tr>
<td>11 baseline (obs)</td>
<td>***</td>
<td>***</td>
<td>***</td>
<td>***</td>
<td>***</td>
</tr>
</tbody>
</table>
Table 3: This table compares modeled results from the baseline land use scenario to modeled results from the future land use scenario. As Table 1 shows, the model is a good predictor of observed conditions, therefore allowing us to draw reasonable conclusions about areas that lack data. Under the buildout scenario, water in the areas of tidal prism segments 1-8 would have higher concentrations of bacteria. As explained earlier, sections 3, 6, 7, and 8 would become condemned to shellfish harvest as a result of these increases.

<table>
<thead>
<tr>
<th>Tidal Prism Segment</th>
<th>Number of samples (2000-2004)</th>
<th>Arithmetic mean FC (count/100ml)</th>
<th>Standard deviation</th>
<th>95% confidence interval for FC increase</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 baseline (mod)</td>
<td>53</td>
<td>5.62</td>
<td>6.37</td>
<td>10.52, 1.589</td>
<td>0.009</td>
</tr>
<tr>
<td>1 buildout</td>
<td>53</td>
<td>11.68</td>
<td>15.01</td>
<td>***</td>
<td>***</td>
</tr>
<tr>
<td>2 baseline (mod)</td>
<td>51</td>
<td>16.33</td>
<td>21.42</td>
<td>43.90, 7.788</td>
<td>0.006</td>
</tr>
<tr>
<td>2 buildout</td>
<td>51</td>
<td>42.18</td>
<td>60.85</td>
<td>***</td>
<td>***</td>
</tr>
<tr>
<td>3 baseline (mod)</td>
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<td>42.37</td>
<td>120.7, 30.876</td>
<td>0.001</td>
</tr>
<tr>
<td>3 buildout</td>
<td>46</td>
<td>110.00</td>
<td>146.00</td>
<td>***</td>
<td>***</td>
</tr>
<tr>
<td>6 baseline (mod)</td>
<td>50</td>
<td>10.38</td>
<td>14.72</td>
<td>38.66, 7.062</td>
<td>0.005</td>
</tr>
<tr>
<td>6 buildout</td>
<td>50</td>
<td>39.59</td>
<td>51.27</td>
<td>***</td>
<td>***</td>
</tr>
<tr>
<td>7 baseline (mod)</td>
<td>50</td>
<td>16.94</td>
<td>22.71</td>
<td>42.25, 8.981</td>
<td>0.003</td>
</tr>
<tr>
<td>7 buildout</td>
<td>50</td>
<td>42.56</td>
<td>54.35</td>
<td>***</td>
<td>***</td>
</tr>
<tr>
<td>8 baseline (mod)</td>
<td>50</td>
<td>17.63</td>
<td>22.79</td>
<td>39.59, 8.382</td>
<td>0.003</td>
</tr>
<tr>
<td>8 buildout</td>
<td>50</td>
<td>41.62</td>
<td>50.39</td>
<td>***</td>
<td>***</td>
</tr>
<tr>
<td>9 baseline (mod)</td>
<td>51</td>
<td>12.15</td>
<td>27.57</td>
<td>21.434, -5.533</td>
<td>0.244</td>
</tr>
<tr>
<td>9 buildout</td>
<td>51</td>
<td>20.10</td>
<td>39.84</td>
<td>***</td>
<td>***</td>
</tr>
<tr>
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<td>61.91</td>
<td>41.66, -16.450</td>
<td>0.391</td>
</tr>
<tr>
<td>10 buildout</td>
<td>51</td>
<td>36.00</td>
<td>84.1</td>
<td>***</td>
<td>***</td>
</tr>
<tr>
<td>11 baseline (mod)</td>
<td>51</td>
<td>31.50</td>
<td>115.4</td>
<td>56.72, -23.047</td>
<td>0.404</td>
</tr>
<tr>
<td>11 buildout</td>
<td>51</td>
<td>48.3</td>
<td>115.4</td>
<td>***</td>
<td>***</td>
</tr>
</tbody>
</table>

Based on the analysis described above, it is reasonable to expect higher mean fecal coliform levels throughout most of the creek under the full buildout scenario.

Further, waters within tidal prism segments 2,3,4,5,6,7, and 8 would be condemned to shellfish harvest based on failure to meet the 14 mpn/100ml fecal coliform standard.

This determination was only made if the modeled 30-month geometric mean fecal
coliform concentration exceeded 14 mpn/100ml and if the T-test showed that there was a significant difference between the baseline modeled and buildout modeled concentrations. A map of the closed areas is shown in Figure 6. Figure 5 shows areas of leased subaqueous land in Old Plantation Creek. Under the future land use scenario, approximately 186 acres of leased subaqueous land would be effectively rendered valueless as hard clam aquaculture sites, an increase of 151 acres over the current amount of leased area that is condemned. These additional condemnations are the result of both greater bacterial loads and weak tidal flushing in the upstream reaches of the creek.

To calculate the economic impact of taking this acreage out of production, a range of dollar values for clam production per acre of leased bottom was generated using information obtained from industry sources. The dockside price of a hard clam was assumed to be 10 to 15 cents (Peirson, pers comm.; Murray, 2006). A seed planting density of 40-50 thousand clams per 14x50 foot plot was assumed, as was a seed-to-harvest survival rate of 70-90% of planted clams (West and Walker, pers. comm.). Finally, it was assumed that one-third of planted clams would be harvested each year, and that one-half of all leased area of would be left fallow each year (Peirson, pers. comm.). Based on these figures, the revenue lost by taking one acre of suitable subaqueous bottom out of production ranges between $29,040 and $65,341 per year. This range is considered conservative based on the fact that $65,000 has been reported as an annual per acre revenue figure for the hard clam aquaculture industry (Luckenbach, 1999). Given that 151 additional acres of leased area would be condemned, revenue losses would be expected to range between $4,385,141 and $9,866,566, assuming that all 151 acres were being utilized at the intensity noted above. These lower and upper bounds of dockside
clam sales were used as inputs into the I/O model to generate estimates of the economic impact of losing these leases to aquaculture production. The annual economic impact of taking these leases out of production is estimated at between $7.5 and $16.9 million. It is important to note that this is not a one-time loss, but one that will be felt each year that these areas are condemned for shellfish harvest. In addition to looking at new economic losses, the potential positive economic impact of re-opening the leased acreage already closed under the baseline scenario was calculated. Using the same methods described above, it was estimated that the positive economic impact of reducing fecal coliform counts below the condemnation standard in these areas would likely range between $1 million and $2.25 million per year. Appendix E describes the I/O methodology.

DISCUSSION

The results presented above suggest that allowing the continued conversion of land in the Old Plantation Creek watershed from fields and forest to residential and commercial uses has the potential not only to impair water quality in the creek, but also to impose economic hardship upon watermen engaged in hard clam aquaculture. However, the strengths and weaknesses of these results and the modeling exercise as a whole warrant further discussion. While the data used in this study were the best available, they were not the best imaginable. Fecal coliform source data for wildlife were limited to the set of animals for which information on both population and bacterial production rates could be obtained. Thus, sources like cats and many types of birds were omitted. Also, the population data that were used, along with the septic failure rate and
soil types applied, were estimates for the Virginia Coastal Plain, rather than for the target watershed.

Additionally the spatial and temporal resolution of the model could be improved by creating smaller tidal prism segments and reducing the time step of modeled outputs. In this study, the model outputs are fecal coliform concentrations for tidal prism segments that cover large areas. In reality, it is likely that fecal coliform concentrations vary within each tidal prism segment, especially between upstream and downstream areas, and possibly also between deep and shallow water, or between areas directly adjacent to a certain land use feature. As mentioned before, the TPWQM estimates fecal coliform concentrations twice daily. However, because bacterial loading is driven by precipitation, in-water bacterial concentrations are highly variable over time. The fact that hourly precipitation data is available, and therefore that the LSPC model is estimating bacterial load delivery on an hourly basis, means that it would be possible to refine the model to output 24 estimates per day, thus producing a more complete picture of how loading, decay, and tidal flushing affect bacterial concentrations.

Finally, the accuracy of the model could be improved greatly if a more robust sampling program were instituted. As mentioned earlier, the DSS takes approximately one sample per month from each monitoring station within Old Plantation Creek. While the sampling dates are selected randomly, sampling is only conducted on about 3% of all days in a given year. Since bacterial pulses associated with rain events operate on the time scale of minutes or hours, and since bacterial decay and tidal flushing are occurring continuously, the snapshot of water quality given by the current sampling program is a very rough estimate, and the variance of data around any mean will be large. By
narrowing the variance, confidence in predictions could be improved. Further, the chances of identifying areas that should be condemned increase as the number of sampling sites increases. Since this study began, DSS has gathered enough data at additional sites within Old Plantation Creek to produce 30-month geometric means. As a result of this new data, and possibly increases in bacterial loading as well, DSS has identified new areas of the creek that fail to meet the bacterial standard for shellfish harvest (Fig. 7).

Despite its shortcomings, though, this case study has great value in several regards. First, it uses existing, scientifically accepted modeling techniques to make predictions about a key environmental condition. Second, although the available data are not perfect, the approach used here represents actual pollutant levels fairly accurately. Third, the addition of the economic component measures one way in which water pollution can harm the economy.

This study also provides an opportunity to discuss the political, economic, legal, and social/cultural conditions that lead to conflicts between users of land and users of adjacent waterways, and to explore ways in which to resolve these conflicts in a manner that benefits society. The current environmental legal and regulatory system has major flaws which have led to the degradation of many of Virginia’s coastal waters. The combination of population growth with inadequate planning in rural and suburban areas has led to large increases in impervious surface and the proliferation of leaky septic tanks across the Coastal Plain.

A large part of the problem originates from the fact that private property rights in land enjoy favorable legal status relative to the rights of the public to use and enjoy
common pool resources. The underlying causes are economic and, by extension, political: allowing landowners to develop their property as they wish produces calculable economic gains for determinable numbers of people, while protecting coastal water quality usually leads only to hard-to-assess welfare improvements for an indefinite number of potential users. Conversely, placing restrictions on land use to curb NPS pollution and improve water quality for the benefit of the public, members of which have varying and largely unquantifiable interests in environmental protection, would prevent landowners from taking steps that would increase the value of their properties in a very real way. Land developers can present well-supported cases that their projects will provide the community with housing options, construction jobs, and tax revenue in addition to their own profits.

In most cases, advocates of preserving open space and water quality can only make educated guesses at how pollution and habitat degradation associated with development will impact economically important sectors such as tourism and recreational fishing. However, a number of techniques exist that allow for the economic valuation of changes in ecosystem services attributable to policy changes (National Research Council, 2004). The Total Economic Value (TEV) framework allows for the inclusion of both commercial and non-commercial use values, and non-use values, and “helps to provide a checklist of potential impacts and effects that need to be considered in valuing ecosystem services as comprehensively as possible” in support of informed decision-making (NRC, 2004). Under this framework methods such as avoided cost, replacement cost, factor income, travel cost, hedonic pricing, and contingent valuation can all contribute to determining the value to society of ecosystem components and process that are not
exchanges in the market. Unfortunately, it is beyond the capacity of local government, and beyond the scope of this study, to use these tools in a comprehensive cost-benefit analysis, and therefore we do not know the relative impacts of land development versus land conservation.

However, in shellfish aquaculture, Old Plantation Creek does have a tangible, valuable, marketable resource that is negatively impacted by NPS pollution. Therefore, even though we cannot undertake a complete CBA, we can determine how an important local industry will be affected, and how that will impact the regional economy. The results of such an exercise have been presented above.

The purpose of conducting this exercise was not to establish that hard clam aquaculture is the most important or legitimate use of the Old Plantation Creek system. Indeed, this type of aquaculture excludes other uses of submerged land such as crab potting and fishing. Additionally, it changes the biological and chemical makeup of the substrate on which the clams are grown, impairing the structure and function of benthic habitats. Clam aquaculture has also been documented to increase the growth of macroalgae, and respiration of both the clams themselves and the bacteria associated with decay of the macroalgae removes oxygen from the water column. Depending on the physical characteristics of the basin, this could create hypoxic conditions detrimental to other marine life. Finally, the infrastructure and debris associated with the industry is not aesthetically pleasing, and the work crews can be large and noisy, detracting from others’ enjoyment of the water. However, aquaculture is a state-recognized use of a public trust resource, and since it produces a marketable commodity, it allows us to measure part of the value of clean water to the economy. Further, because protection of water quality for
the sake of clam farmers would also benefit other resource users with an interest in clean water, and because of the historically positive effect of filter-feeding bivalves on water quality, sustainably managed shellfish culture has the potential to be a “win-win” for the economy and the environment.

Having established that there is a valuable resource in this water body and that the resource will be negatively impacted by certain changes in land use, which may not be adequately regulated by localities, state level policy makers must develop answers to two questions. First, is protecting waterways from NPS pollution a policy goal under existing law? Given the fact that coastal zone development and associated NPS pollution continue to increase steadily, one might think that Virginia does not have a strong interest in water quality, and that the federally-driven TMDL process under the CWA is the only mechanism for ensuring that coastal waters remain or become clean. However, as noted before, Article XI, §2 of the Constitution of Virginia states that “it shall be the Commonwealth’s policy to protect its atmosphere, lands, and waters from pollution, impairment, or destruction for the benefit, enjoyment, and general welfare of the people of Virginia.” Far from being simply a legal platitude, this provision is central to the mission of the Virginia Natural Resources Secretariat, which oversees the operations of the Department of Environmental Quality, the Department of Conservation and Recreation, the Department of Game and Inland Fisheries, and the Marine Resources Commission. The mission goals of each of these agencies either explicitly include or implicitly depend upon clean water.

Knowing that policy makers care about protecting the aquatic environment, the second question becomes “Why has Virginia failed to meet this policy goal, and what
must it do to achieve success?" Answering the first part of this question involves critically examining some of the most fundamental and deeply entrenched relationships between people and property under Virginia and US law. Answering the second part requires consideration of a suite of policy options, including the alteration of some of these relationships.

POLICY PROBLEMS

In politically charged battles such as those over development rights, where one group of stakeholders with a strongly-held preference based on expectations of concentrated private economic gain is pitted against another group for whom the costs and benefits of a certain public policy are substantial but diffuse, the former group often prevails in the public arena. As evidenced by the successes of some interest groups in preserving public resources, the latter group can win (Chesapeake Bay Foundation, 2007; American Canoe Association, Inc. v U.S. EPA, 1999). However, it must demonstrate that its members also have strong rights relative to the issue in question, increase and organizing its ranks, elevate the issue to a higher level importance for a broader audience, and improve information so that more individuals realize that they too reap real benefits from change. This is especially difficult when these battles are fought at the local government level, where officials do not answer to the broader constituencies affected by their decision, and are often reluctant to deny their neighbors the opportunity to utilize their land in a way that maximizes their income. Human nature dictates, and human history reaffirms that local decision makers will hesitate to restrict the rights of one landowner unless there is a serious adverse effect on another landowner.
Private nuisance law exists to address “nontresspassory invasion of another’s interest in the use and enjoyment of land,” but “the plaintiff must prove that the defendant’s conduct is unreasonable and causes a substantial interference with the use and enjoyment of land, or bodily injury” (Glicksman, 2003). Not only is this quite difficult to prove in most cases involving air or water pollution, people with even the most strongly held interests in public lands and waters (i.e., subaqueous leases) lack standing to bring private nuisance suits. Common law also provides for abatement of a public nuisance when a private action “unreasonably interferes with the rights of the public,” but the cause in fact standard is too difficult to meet for cases involving NPS pollution (Glicksman, 2003). Therefore, most decisions of individual landowners have traditionally been both socially acceptable and legally defensible, even if the cumulative effect of these actions has significant adverse impacts on resources the public values. Owners of private land often make land use decisions based on imperfect or incomplete information about the negative externalities of their actions. Even when landowners do have good information, nothing compels them to take public welfare into consideration, or to bear the social costs themselves, rather than imposing them on others. This is the major sociopolitical problem that must be solved in order to eliminate the effects of NPS pollution.

One of the issues at the root of the NPS pollution problem is local oversight of the use of private property. Partly because of the powers reserved to the states by the 10th Amendment of the US Constitution, and partly because direct control at any other level is both politically and practically infeasible, regulation of land use has devolved to local governments through state delegation of police powers. Through the creation of
Euclidean zoning and property tax systems, localities developed the ability to address many of the public health, safety, and general welfare concerns within their own borders. However, because of their geographically narrow interests and limited tool set, local governments do not always account for the effects that their decisions might have on other localities, the state or nation as a whole, or people with an interest in common property resources.

The amount and distribution of certain land uses in a watershed is a second issue critical to limiting NPS pollution. A community needs a certain amount of residential, commercial, and industrial development to be viable, and to supply necessary goods and services to its inhabitants. A somewhat greater level of development is needed to add choice, convenience, and low prices, all of which are driven by competition and greatly improve quality of life. However, at a certain point, the costs of trading off environmental quality and open space for increased residential, commercial, and industrial building exceed the benefits, and quality of life begins to diminish. The trouble lies in two areas. First, there is the problem of science-based assessment versus political assessment of these issues. While we do have indicators (i.e., water and air quality standards, measures of biodiversity and bioproductivity, etc.) to tell us when human activity is damaging ecosystems, it is difficult to compare the monetary costs of this degradation to the losses realized by a property owner whose right to "improve" his land is restricted or denied.

Second, even in instances where we are able to accurately assess the cost of environmental losses, the legal importance of the exercise would be minimal under the current property rights regime in the US and Virginia. Even in watersheds that drain to
already impaired streams or embayments, localities cannot compel landowners to refrain from developing a site. Each property owner has the same rights in land as did others who previously built in this area, regardless of the difference in the marginal social cost of their activities. Even states like Maryland, Washington, and Wisconsin that launched smart growth initiatives in the 1990s involving concentrated building patterns, infill of blighted properties, and low impact development (LID), are still experiencing urban sprawl (MDP, 2007). This happens because the laws operate primarily through providing financial incentives and requiring the submission of comprehensive growth plans by localities, rather than by tackling the fundamental issue of absolutist attitudes toward private property in land.

Virginia lags far behind in undertaking even these types of efforts, choosing instead to allow localities to “preserve large lot zoning to maintain their rural character,” leading to a host of problems, water pollution through septic tank failure among them (Chesapeake Futures, 2003). Currently, the only way localities can aggressively combat NPS pollution through land conservation is by using eminent domain, which requires just compensation and therefore severely limits the amount of land localities can afford to preserve. Even this tool, however, is under fire. A bill introduced during the 2007 session of the Virginia General Assembly would have prohibited the use of eminent domain for conservation purposes (HB 1819, 2007). The fact that states with a decade or more of smart growth planning experience are still struggling to reduce sprawl reveals two things. First, especially given the population growth rates in the northern and southeastern parts of the Commonwealth, Virginia must act quickly to create a governance structure to address inadequacies in land use planning if it wants to prevent
further degradation of water quality and other problems associated with sprawl. Second, a program that enables and provides incentives for local governments to act will not be sufficient.

Because what comes off of the land in Northampton County and other localities affects water quality in the Chesapeake Bay, an estuary from which countless people in different localities and different states derive benefits, local governments will make decisions that undervalue the importance of water quality, even if those decisions are in the best interest of their own constituents. When decisions that have the potential to significantly impact water quality are made by individual property owners and local officials who, in the vast majority of cases, have no incentive to act in the best interest of everyone who benefits from a healthy water resource, the result is a tragedy of the commons (Hardin, 1968). Localities and landowners maximize their utility at the expense of common resource users. While there are some steps that local governments can take to improve water quality in Old Plantation Creek and elsewhere, with NPS pollution the harm is imposed on the public at large, and therefore only the Commonwealth, as representative of the public, has the capacity and authority to impose meaningful restrictions on offending land use practices.

For this reason either control over land use decisions should shift to the level of government that represents all stakeholders, or a new system of rules, based upon a reevaluation of the rights and responsibilities tied to land ownership, should be created to ensure that the decisions of landowners and local governments do not continue to neglect legitimate public interests in private land. Since the former option would impinge upon traditional state responsibilities and require the creation of a massive federal bureaucracy,
the latter is clearly the preferred choice. The following sections will discuss policy recommendations that can help decision makers prevent and remedy situations in which land-based activities degrade water quality to the detriment of those who value it.

POLICY RECOMMENDATIONS

One recommendation that would aid decision makers in identifying potential problem areas and getting a head start on developing solutions is to utilize the modeling framework laid out in this study as a predictive tool in the TMDL process. One of the major flaws in the TMDL process in Virginia is that watersheds have been selected for TMDL studies without consideration for the urgency of an environmental or socioeconomic need for TMDL implementation. The fact that Old Plantation Creek was not identified and treated as a priority TMDL watershed based on the economic importance of the clam aquaculture industry is a significant case of government failure. Further, since it will take spatially explicit predictive approaches to implement effective TMDLs, it would benefit the Commonwealth to utilize GIS-based watershed modeling in its TMDL studies. By honing the GIS-based modeling tool, and perhaps adding additional I/O modules for other water quality dependent uses like oyster aquaculture or recreation, Virginia can do a better job of identifying the watersheds in which the potential for conflict is greatest, and monitoring trends in land use and bacterial loading to know when these conflicts might occur. By targeting its efforts and resources to address the most economically important areas, Virginia can improve the effectiveness of its TMDL program.
Aside from this central recommendation for identifying and monitoring problem watersheds, there are three tiers of action that can be taken at different levels of government to reduce the levels of bacteria, and potentially other contaminants entering our waterways as NPS pollution. The first tier is composed of steps that local governments can take to reduce pollution and raise awareness about the value of in-water activities to the local and regional economy. The second tier includes actions that the Commonwealth could initiate to accomplish the same objectives, while taking political pressure off of localities. The third tier calls on the Commonwealth to attack the problem of coastal NPS pollution at the source, and to renew its legislative commitment to the very progressive legal principles embodied in the Constitution of Virginia.

First Tier

The “low-hanging fruit” in the case of Old Plantation Creek can be gleaned by implementing simple programs at the local level. While local governments can not and should not be expected to solve NPS pollution problems completely on their own, there are some measures they can take to help improve the situation. One easy step toward reducing bacterial contamination associated with NPS pollution is to pass a local pet waste removal, or “pooper scooper” ordinance. This type of program, usually accompanied by a leash law and enforceable through posting of signage and levying of small fines for violators has wide support across the country, is an important step in educating the public and developing social consciousness about the effects our daily activities have on water quality. With the creation of more residential areas, the number of pets increases, making pet waste an even more significant source of bacteria. While
this approach is clearly not feasible for rural areas like Northampton County, Cape Charles could help improve water quality by instituting and enforcing this widely accepted measure. Also, localities could chip away at bacterial loading numbers by eliminating feral animals. While no figures were available for the study area, it is estimated that there are between 60 and 100 million stray and feral cats in the US (Winter, 2002). In addition to their well-documented predation of songbirds and other wildlife, cats that are allowed to roam free will contribute to fecal bacteria loading, especially when they take up residence in urban areas with a high ratio of impervious to pervious surface.

A local-level project that Northampton County could undertake is conducting more frequent surveys of septic tanks located throughout the county. The septic failure rate of 12% used in this paper’s modeling exercise is supported by the literature, but is also alarmingly high. Currently, the Chesapeake Bay Preservation Act (CBPA) regulations require that septic tanks located within Resource Protection and Resource Management Areas be pumped out once every five years, or be certified to be working properly and not need in need of a pump out (9 VAC 10-20-120). There is also an exception allowing the installation of a plastic filter between the septic tank and the drainfield in lieu of the first two requirements. As written, this regulation allows long term, and in some cases, perpetual septic failure to persist unchecked. In the interest of protecting water quality, localities could require mandatory septic tank and drainfield inspections annually. By conducting an initial septic survey, followed by more frequent inspection, maintenance, and pump-out requirements, the County could reduce bacterial loading from human sources. As the number of houses, and thus the number of septic
tanks in the county increases, a lower septic failure rate will be necessary to ensure that bacterial loads from this source do not increase. To cover the increased cost of this program, the county could impose a small annual fee on septic tank owners.

In situations where a larger, more centralized commercial development or residential subdivision is proposed, proffers are a possible tool for ensuring that interests of the community in maintaining or improving water quality are taken into account. In most cases, developers will “proffer,” or agree to finance as a condition of having their project approved, certain public goods or services like school improvements, new roads, or utility infrastructure. Increasingly though, Virginia communities are negotiating proffers of open space, land preservation, and safeguards to environmental quality (Middlesex County Rezoning Submission Requirements, 2007; City of Falls Church Comprehensive Plan, 2005; Albemarle County Proffer Form, 2006). By requesting proffers for watershed protection, coastal communities can offset some of the impacts that large developments would otherwise have on water quality.

Possibly the easiest action that both Cape Charles and Northampton County could take without passing any ordinances, or placing any extra burden on their staffs or constituents is to include a more robust treatment of aquaculture in their comprehensive plans. The comprehensive planning process, mandated to include water quality considerations under the CBPA, requires all tidewater localities to create a comprehensive plan, and review it every five years. The CBPA component of the comprehensive plan is designed to “establish and maintain, as appropriate, an information base from which policy choices are made about future land use and development that will protect the quality of state waters,” and must include land use maps and strategies for
improving water quality (9 VAC 10-20-170). Local governments use the comprehensive planning review process to set priorities for future action on a wide range of issues, including economic development, land use, and environmental protection.

Northampton County and Cape Charles inserted language referencing aquaculture during their 2006 comprehensive plan reviews, finally recognizing it as an important component of their economic futures. While comprehensive plan inclusion affords aquaculturists no legal protections or rights of any kind, it does increase the visibility of the industry, and elevate concerns about the affects of diminished water quality on their livelihood to the highest level of local government debate. However, simply recognizing that aquaculture exists, is water quality dependent, and is important to the local economy does nothing to prevent the continued degradation of shellfish growing waters. By creating an aquaculture overlay district on their zoning maps, Northampton County and Cape Charles could introduce a new set of zoning restrictions on properties adjacent to subaqueous leases, or to watercourses with subaqueous leases. Such a policy could serve as a vehicle for instituting land use conditions that would have major positive implications for water quality in Old Plantation Creek and other areas crucial to the aquaculture industry, while not unnecessarily restricting land use adjacent to harbors, the mainstem bay, or navigation channels.

Second Tier

In addition to enabling and/or funding some of the work in Tier One above, the Commonwealth should take a more active role in preventing degradation of state waters, simply because local governments lack the capacity to be protective of everyone’s
interest in the resource. The easiest way for the Commonwealth to act is to strengthen existing provisions designed to reduce NPS. One of these tools is the Chesapeake Bay Preservation Act. Under the CBPA, property owners in tidewater localities must maintain a 100-foot forested buffer between tidal wetlands and shores adjacent to any water body, and any non-agricultural or silvicultural land disturbance (VAC 10-20-80). While this law is not retroactive (i.e., doesn’t require people to remove existing structures or create buffers where they previously did not exist), it is designed to protect water quality by keeping coastal development at a distance from the water, and to maintain a biogeochemical buffer strip between the water and areas of impervious surface in the watershed.

Rather than usurp traditional land use authority, Virginia has delegated enforcement of this law to localities. The CBPA resource protection area (100-foot buffer) must be incorporated onto the zoning map, and is intended to be off limits to development. However, exceptions are allowed through the normal zoning variance process, with the local board of zoning appeals (BZA) having the final authority. A review of records from the Northampton County Department of Planning and Zoning shows that the BZA grants many of these exceptions, undermining the effectiveness of the law, and that penalties for violations are minimal. Further, the number of building permits issued in Northampton County has increased in recent years, and if this trend continues the number, if not the percentage, of zoning variances granted also will increase.

Until now, the Department of Conservation and Recreation’s Chesapeake Bay Local Assistance (DCR-CBLA) office has played mainly an advisory role, with a small
number of staff covering a large geographical area and offering mostly technical assistance to localities regarding implementation of the CBPA. Amending the CBPA to give DCR-CBLA the authority to review and veto BZA variance decisions, and to review and amend local enforcement actions (or the lack of action) by increasing penalties is one option for utilizing an existing framework to limit impervious surface in areas that are most likely to deliver large bacterial loads to receiving waters. This change would improve accountability at the local level, while simultaneously affording local officials some political cover for tough decisions that err on the side of conservation.

Another way to make the economic importance of aquaculture more visible, and by extension improve the case for clean water, is to afford aquaculturists and their operations some legal protections. Although it is regulated by governmental entities traditionally associated with management of wild fisheries, aquaculture is generally recognized as a form of agriculture, and is defined as such under both Virginia and Federal law (Code of Virginia §3.1-73.6;16 USC 2801). In Virginia, the Right to Farm Act states:

In order to limit the circumstances under which agricultural operations may be deemed to be a nuisance, especially when nonagricultural land uses are initiated near existing agricultural operations, no county shall adopt any ordinance that requires that a special exception or special use permit be obtained for any production agriculture or silviculture activity in an area that is zoned as an agricultural district or classification...No county, city or town shall enact zoning ordinances which would unreasonably restrict or regulate farm structures or farming and forestry practices in an agricultural district or classification unless such restrictions bear a relationship to the health, safety and general welfare of its citizens (Code of Virginia, §3.1-22.28)

The purpose of this law is to prevent farms in areas prone to the pressures of suburban fringe and second home development from being effectively shut down by citizens and local governments that decide farm operations diminish their quality of life. Aquaculture faces the same pressures, as evidenced by actions brought against would-be leaseholders in North Carolina that resulted in the imposition of an ongoing leasing moratorium in
Core Sound (North Carolina Sea Grant, 2002). By issuing an advisory opinion clarifying that the Right to Farm Act applies to aquaculture, the Virginia Attorney General could not only give clam growers the same rights as corn growers, but also could make a bold statement about the importance of aquaculture and the conditions necessary to support it (i.e., clean water and responsible coastal development), to the benefit of all who seek sustainable use of the Commonwealth’s coastal resources.

Studies have shown that as the amount of impervious surface in a watershed increases, NPS pollutant loads to and pollutant concentrations within the receiving water also increase. A study of five tidal creeks in North Carolina established a very strong correlation between the percentage of impervious surface in the watersheds and the area of the water body condemned for shellfish harvesting, even stronger than the correlations for both population and percent developed area (Mallin, 2000). This study also found that 10% impervious surface in a watershed was the threshold for some condemnations in the upper reached of creeks, and that 20% impervious surface was the threshold for condemnation of the entire inlet. Similar research conducted in South Carolina concluded that impervious surface was the “ultimate stressor” to tidal creek systems, identifying not only increased bacterial concentrations at the 10% impervious threshold, but also alteration of chemical processes and food webs at the 20% threshold (Holland, et al, 2004).

In the Old Plantation Creek baseline land use scenario, 6% of the land in the watershed is impervious surface. In the buildout scenario, impervious surface increases to 16.9%. Table 4 shows the comparison between the baseline and buildout scenarios for each subwatershed:
Table 4: This table includes the percentage of impervious surface for the Old Plantation Creek watershed and its six subwatersheds. Note the increases in impervious surface from the baseline land use scenario to the buildout scenario.

<table>
<thead>
<tr>
<th>Subwatershed</th>
<th>Baseline scenario</th>
<th>Buildout scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10.5</td>
<td>36.1</td>
</tr>
<tr>
<td>2</td>
<td>6.4</td>
<td>27.1</td>
</tr>
<tr>
<td>3</td>
<td>4.4</td>
<td>4.4</td>
</tr>
<tr>
<td>4</td>
<td>1.9</td>
<td>18.2</td>
</tr>
<tr>
<td>5</td>
<td>3.6</td>
<td>3.6</td>
</tr>
<tr>
<td>6</td>
<td>5.3</td>
<td>5.9</td>
</tr>
<tr>
<td>Entire watershed</td>
<td>6</td>
<td>16.9</td>
</tr>
</tbody>
</table>

Ideally, then, from a management standpoint, it is important to minimize the amount of impervious surface in our coastal watersheds. While economic development and population growth are generally associated with the building of hard structures to house people and businesses, and are therefore considered at odds with maintaining open space for purposes such as stormwater infiltration, ways exist to reconcile these two seemingly contradictory objectives. Indeed, localities in many places, including Virginia, have a variety of tools at their disposal that can play a role in limiting the amount of impervious surface that new development adds. For example, in most localities across the country, the local government imposes restrictions in the zoning code regarding the percentage of a residential lot that may be covered by a building footprint. While this tactic is most often used as a way to prevent people from building large homes in modest neighborhoods, and thereby dramatically increasing the value, assessments, and taxes on nearby properties, it could also be employed for environmental protection. Setting limits for the percentage of a lot that may be covered by impervious surface, especially in an area with water quality-dependent industries like aquaculture and ecotourism, is a legitimate use of the Commonwealth’s police powers.
By developing a formula, possibly with the help of the modeling tool used above, the Commonwealth could prescribe limits on impervious surface for each coastal watershed. Importantly, these limits would not necessitate a ban on new construction. Technological advances have made it possible for a sustainable amount of development to proceed with minimal impacts to the quantity and quality of stormwater entering receiving waters. Hard yet pervious surfaces like “pervious pavement” can be used for sidewalks and roads, and improved structural and non-structural stormwater BMPs also can help. Possibly in conjunction with its recently developed nutrient trading schemes, Virginia could establish a market-based trading mechanism for impervious surface offsets within watersheds or subwatersheds, giving credits for the use of pervious paving, green roofs, and land conservation. Not only would this reduce NPS pollution, it would promote innovation in building and community design, as well as in LID-associated products.

Third Tier

While the proposals above could have significant positive effects on water quality and sustainable aquaculture, they do not directly address the central problem of the disconnect between rights and responsibilities associated with privately held land, and the impact that this has on public trust resources. The view of private land championed by property rights advocates is reflected by the Blackstonian bundle of land entitlements, named after 18th century English jurist William Blackstone, who famously defined property as “that despotic dominion that one man claims and exercises over the external things of the world, in total exclusion of the right of any other individual in the universe,”
(O’Drischoll and Hoskins, 2003). This type of property regime “presupposes impeccably demarcated parcels whose boundaries extend upward to the heavens and downward to the depths of the earth, and owners with unbridled powers and privileges to use, transfer, and even abuse the land” (Bell and Parchomovsky, 2004). While this view of property rights is still promoted by many Americans, the fact that it predates, and is too inflexible to accommodate improvements in the scientific understanding of such processes as coastal storm buffering, groundwater flow, and eutrophication, makes it unconstructive in the modern policy environment.

However, even the mainstream American view of land rights, that “every individual has as much freedom in the acquisition, use, and disposition of his property, as is consistent with good order, and the reciprocal rights of others,” has not led to a system in which the general public has legal recourse against a landowner who contributes, through the course of otherwise legal behavior, to despoiling a public resource (Kent, 1826). The concept of land rights as a “bundle of sticks,” with each stick representing a narrowly defined right possessed by the landowner, has found general acceptance in the American legal community and has been applied to some extent through the use of certain zoning schemes. However, landowner actions continue to lead to the degradation of public resources. The following sections propose three ways to further deconstruct the bundle of sticks, and they may be used in combination: economic incentives and disincentives, privatization of the commons, and improved stewardship of the public trust.
Economic Incentives and Disincentives

Through restrictive zoning, localities have had some success in limiting the use and development rights of landowners for the benefit of neighbors and the public at large. This has been especially true of state and local land use restrictions instituted to fulfill requirements of the US Coastal Zone Management Act. However, there has been a backlash against land use restrictions for environmental protection, especially since the Supreme Court’s landmark 1992 decision in *Lucas v South Carolina Coastal Council.* In order to reduce NPS pollution and manage the coastal zone responsibly without raising the specter of a 5th Amendment takings claim, localities must apply a new set of strategies, which often includes incentivizing sound land use. As a Dillon’s Rule state, however, Virginia does not allow its local governments to devise and institute their own instruments of public finance. Therefore, the General Assembly would need to pass one or more enabling statutes that would give local governments a greater degree of flexibility in how they pay for the provision of public services or would authorize them to pursue specific options outlined in the statute. Two options that Virginia should consider are impact fees, and tradable development right schemes.

In many areas of the country, impact fees have been a huge success both as a mechanism for generating revenue, and as a way to limit the environmental impacts associated with new land development, especially in providing money to offset the cost of increasing water treatment plant capacity. More recently, though, states are turning to impact fees in an attempt to counter NPS pollution. In Vermont for example, impact fees of $30,000 per impervious acre are based on the estimated cost of providing adequate stormwater treatment, and the revenue is used to fund pollution load reduction projects.
within the same watershed (Vermont Department of Environmental Conservation, 2004). A bill that easily passed the Maryland House of Delegates in 2007 before failing to receive a vote in the Senate would have created the “Chesapeake Bay Green Fund,” to finance water pollution reduction initiatives by requiring developers to pay, with some exceptions, a fee of $2 per square foot of new impervious surface (HB 1220, 2007).

In addition to funding programs designed to offset development-related pollution, impact fees offer a disincentive to developers that would otherwise utilize their property in a manner detrimental to the public. If programs are carefully tailored, and fees are set high enough, aversion to fees has the potential to lead to the downsizing and relocation of projects originally proposed for construction in environmentally sensitive areas. Further, the possibility exists to create geographically defined tiers of fees, based on proximity of impervious surface to waterways, aquifer recharge areas, or even the slope of the land.

Under Virginia law, localities may impose impact fees to offset the costs of providing transportation infrastructure to new developments (§15.2-2319, Code of Virginia). Extending this law to allow or require impact fees for extension of water and sewer infrastructure, and for impervious surface, would be an important step toward internalizing the external costs of NPS pollution. Not only would this legislation have an enormous practical impact by improving water quality, it would represent an important philosophical step by codifying the polluter pays principle.

Another economic tool used by many localities interested in limiting the environmental damage caused by development is the transfer of development rights or tradable development rights (TDR). Like purchase of development rights (PDR) schemes, most frequently employed as conservation easements, TDRs isolate a right from
the bundle of sticks. Unlike PDRs, however, these programs do not require a large investment from government to make land purchases, but instead use a market mechanism to channel development to areas where it will benefit the community. By allocating a finite number of tradable credits to landowners in areas zoned for development and areas zoned for open space, localities can create a market through which landowners may opt to trade their right to develop in an area with restrictive zoning for rights to develop or redevelop land in areas with purposely lax zoning designed to allow for building to the traditional sense of “highest and best use” (Pruetz, 2002). TDRs allow localities to offer incentives to developers to give up their right to build on a certain site in exchange for the right to build on another site that better suits the locality’s land use plan and existing infrastructure, but is at least equally as attractive to the developer.

The purpose of TDRs is to balance the public interest in land preservation with the private interest in land development without taking the economic value of the land from the landowner, and without requiring a major taxpayer-financed expenditure. It is important to note that in TDR programs, not only the amount, but also the location of development is important. It is necessary to ensure that concentrated development (and, by extension, concentrated pollutant loads) does not occur adjacent to areas that are ecologically sensitive or lack assimilative capacity.

Privatization of the commons

A different type of economic tool that the Commonwealth could use to reduce bacterial pollution of systems like Old Plantation Creek is the extension of stronger and
more certain (i.e. statutorily defined) property rights to aquaculturists holding leases of subaqueous land. Free market environmentalists claim that by auctioning off use rights to a certain portion of a renewable natural resource, the government gives the user an incentive to maximize resource production over the long run, or sustainably. Through its subaqueous leasing program, and more recent legislation for leasing the water column, Virginia has gone half way toward creating the ideal privatization scheme, and the results are promising. There are currently nearly 90,000 acres of subaqueous land leased to individuals in the Commonwealth for the purpose of shellfish propagation (VMRC, 2005). Virginia’s sales of 178 million cultured hard clams in 2005 ranked first in the US, and sales of cultured native oysters increased more than threefold from 2004 to 2005, to nearly 3 million oysters (Murray, 2006). Currently though, the use rights attached to leases are not coupled with rights protecting the “property” (planted clam seed, leased bottom, and clean water) from damage caused by diffuse sources of pollution. For this reason, aquaculturists have no guarantee that their leases will be available for use indefinitely.

To complete the move toward a privatization scheme that incentivizes sustainable use, Virginia would need to develop a law that identifies areas critical to the aquaculture industry, and requires local governments ensure that these areas remain free from bacterial condemnation. Zoning for aquaculture, a concept first proposed for this specific context by VIMS-CCRM, would add certainty and investment security to the aquaculture industry, while maintaining a level of water quality that is beneficial to other instream uses, and reducing user conflicts (Shallow Water Resource Use Conflicts, 1999).
In exchange for having existing productive leases deemed Aquaculture Priority Zones, and thereby adding the sticks of exclusion and nuisance protection to their bundle of rights, aquaculturists would make several concessions to ensure that the public interest in submerged land would not be violated. These concessions could include allowing other leased land to revert to the commons, agreeing that all unleased land remain common, and paying higher per-acre lease rates or royalties to support administration of the system and for additional enforcement, monitoring, and local government assistance. The current leasing system doles out submerged bottom at the annual rate of $1.50 per acre. This has led to a situation in which some individuals illegally sublet their leases at up to $6,000 per acre annually (Dr. Michael Peirson, Cherrystone Aqua Farms, pers. comm.). This amounts to speculation in a public resource, a situation in which people can afford to hold leases on the chance that they may be able to extract an economic rent in the future. Increasing lease rates capture the land rents associated with leased areas and reallocating these proceeds to the public through programs or projects that benefits society as a whole is necessary to allow shellfish aquaculture to continue in a manner consistent with public trust principles.

Also, the industry would need to agree to a set of mandatory best management practices (BMPs) for Aquaculture Priority Zones. These BMPs could include removal of abandoned predator exclusion netting and other industry-related debris, and if necessary, measures designed to keep the intensity of aquaculture activities within the ecological carrying capacity of the water body. By giving aquaculturists a real sense of ownership of and responsibility for the grow-out areas they are utilizing, the Commonwealth can make them champions of water quality measures and encourage stewardship of the resource,
building toward long term sustainability measured by indicators that could also be
developed using funds from the increased lease rates.

Finally, and most importantly, Virginia could utilize the strongest tool it has for
protecting its coastal waters and subaqueous resources by recommitting to an active and
progressive application of the Public Trust Doctrine (PTD). The PTD is part of the
common law tradition transported from England to colonial America, but its origins date
to Justinian’s Rome. Originally established as a way to address disputes over nearshore
submerged lands and to ensure that uses of these lands benefited the public, the PTD has
been an important legal principle throughout the history of Virginia and many other
states. In short, the PTD guarantees that the state will protect resources held in common
for the benefit of the people from overexploitation or degradation, theoretically creating a
better balance between the rights of private land owners and public resource users
(Butler, 1988).

In his famous 1970 treatise The Public Trust Doctrine in Natural Resource Law:
Effective Judicial Intervention, Joseph Sax proposes that the PTD can be a useful tool for
the judiciary to ensure that governments do not misappropriate public resources to private
parties without due consideration of the public interests in those resources (Sax, 1970).
Sax states that “a comprehensive approach to resource management problems...must
contain some concept of a legal right in the general public; it must be enforceable against
the government; and it must be capable of an interpretation consistent with contemporary
concerns for environmental quality,” and argues that the PTD meets all three of these
criteria (Sax, 1970). In the most significant public trust ruling since Sax’s paper,
National Audubon Society v Superior Court (Mono Lake), The California Supreme Court
invoked the PTD to rule that water diversions from the tributaries of Mono Lake could not be so great as to damage trust resources within the lake (Mono Lake, 1983). In the words of one observer:

> "the Mono Lake decision refused to allow decisions made by past generations to shackle allocations of water resources by this generation... The public trust doctrine, as interpreted by the Mono Lake court, means that the state has the ability and responsibility to supervise water uses according to both yesterday's traditions and today's values. After Mono Lake, the former can no longer overwhelm the latter. Instead, the state must consider and accommodate both.." (Blumm and Schwartz, 1995)

Application of this accommodation principle would require states to periodically reevaluate current allocations of trust resources against the evolving best interests of the public, and to adjust the way in which these resources are treated if science or economics warrant such action. While Sax’s analysis focuses on the courts, this decision shows that public trust principles and are important considerations for state legislatures, executive branch resource managers, and local governments.

The principles of the PTD are reflected in two sections of Article XI of the Constitution of Virginia: Section 1 which contains the aforementioned language regarding the protection of environmental quality for general welfare, and Section 3, which holds that “the natural oyster beds, rocks, and shoals in the waters of the Commonwealth...shall be held in trust for the benefit of the people of the Commonwealth, subject to such regulations and restrictions as the General Assembly shall prescribe.” The General Assembly, however, has not passed laws stringent enough to meet the Constitution’s grand statements. The 240,000 acres of Baylor Grounds, or surveyed public oyster grounds, beneath Virginia’s waters have been severely mismanaged and over-harvested. Even now, in an age when we understand that the public value of oyster reefs as a critical factor in improving Bay water quality and habitat
for commercially and recreationally prized crustaceans and finfish far exceeds their private value as a fishery resource, the General Assembly and VMRC continue to permit wild harvest.

The true beauty and effectiveness of the PTD is the fact that it is a doctrine of degrees. Surely, the public is well served by having ports and wharves out over the bottom, even if privately owned, because they contribute to the economy. But it would be difficult to justify saying that the trust is served by allowing every property owner to build a wharf. Likewise, it wouldn't serve the public to allow all of the subaqueous land to be used for any one purpose, whether it is aquaculture, conservation, or another activity. The PTD demands balance. It is the legal authority that not only allows states to implement the optimal solution once the optimization problem has been solved, but in the interim also to put in place measures that increasingly serve the public interest as our understanding of the relationships among ecosystem components, and between ecosystems and economic systems progressively improves.

Unfortunately, the Virginia Supreme Court has been hesitant to expand the role of the PTD either through its common law tradition, or as it appears in the Constitution of Virginia. Two cases, Commonwealth v. City of Newport News, and Robb v. Shockoe Slip Foundation, stand as important precedents in Virginia public trust law. In Newport News, a case decided in 1932, the Court ruled, in essence, that allowing public use of the waters of the James River for sewage disposal constituted a legitimate exercise of legislative authority, in the absence of a Constitutional mandate to the alternative (Kelly, 1989). The Court also ruled that the legislature was free to dispose of the right of fishery
affected by sewage disposal, in this case, the right to grow and harvest oysters (*Newport News, 1932*).

In Shockoe, a case involving preservation of historic resources, the Court ruled that Article XI of the Constitution of Virginia was not self-executing, meaning that it did not lay out a mechanism for enforcing the duties it imposed upon society and government, and therefore did not mandate judicial review or specific legislative action (Shockoe, 1985). While both of these cases show the reluctance of the Virginia Supreme Court to use the PTD in the manner Sax envisioned, they also make the following very clear: in Virginia, the legislature has enormous authority over how public resources are used, and the courts are deferential to its prioritization of public uses. Given the increase scientific understanding of ecosystem function and its importance to public health and the economy, as well as the technological and management advances in pollution control and prevention, priority uses of public trust resources are shifting. The Virginia General Assembly has the responsibility to recognize this fact, and the authority to act upon it by incorporating PTD principles into environmental and natural resource laws.

Though resuscitating the PTD does not take a lot of imagination, or necessarily a lot of legislation, it does take an enormous amount of education and political will. Convincing legislators that public interest in private land is legitimate and strong enough to allow for property rights restrictions will be difficult. Similarly, educating citizens about the public trust concept will be a challenge. However, the fact that the PTD provides an established, legally defensible framework for protection of water quality, habitat, and ecosystem function, while also allowing for sustainable development of
natural resources makes it the most attractive tool for repairing the damage that pollution and resource exploitation have done to Virginia’s coastal environment.

A Federal Government Role?

Land use and public trust resource management have traditionally been under the purview of local governments, as creatures of the Commonwealth of Virginia. Aside from issues with federalism and political realities, a greatly increased federal government role in managing the land use of private property owners and subaqueous leaseholders is unnecessary. There are, however, some ways in which the federal government can help state achieve environmental management goals. Through the TMDL process, federal officials have tools to help localities and states improve watershed and coastal zone management to meet standards. In particular, the TMDL process should move forward more quickly, and be pursued aggressively, even if the face of what will surely be a large number of lawsuits charging that local and state land use restrictions designed to implement TMDLs violate 5th and 14th amendment rights. However, the US government can handle these challenges while allowing the states to implement necessary programs.

The Coastal Zone Management Act acknowledges that “land uses in the coastal zone, and the uses of adjacent lands which drain into the coastal zone, may significantly affect the quality of coastal waters and habitats, and efforts to control coastal water pollution from land use activities must be improved” (§302 CZMA). To address this problem, the Secretary of Commerce (through NOAA) provides funding for states to implement approved management programs for coastal resources. The plans submitted by the states must meet certain minimum requirements in order to be approved, including
a strategy for reducing coastal NPS pollution. States, localities, and Federal agencies are required to coordinate in developing and implementing NPS pollution reduction strategies with not only the rest of the coastal management program, but also with water quality standards, NPS reduction plans, and wastewater treatment grants under the Clean Water Act (§306b CZMA). What is lacking, however, is a concerted coordination effort between coastal NPS reduction strategies and the TMDL development and implementation process for coastal waters. Funding under the CZMA can be used for planning assistance and land acquisition, both of which should be targeted to localities in which land development has the greatest potential to degrade the environment to the detriment of resource users.

Other major functions of the federal government in this policy environment should be information provision and education. By funding research on ecosystem services valuation to inform coastal zone management, and developing guidelines for effective NPS pollution controls to employ during TMDL implementation, the US government can give states what they need to optimize the balances between resource use and conservation, and between public and private rights in property and commons. Further, by developing this study’s methodology into a predictive tool for the TMDL process, and by requiring standardization of TMDL study methodology to techniques that allow both current assessment and forecast modeling, the federal government could help states address potential problems before they become serious environmental and economic concerns.
CONCLUSIONS

This case study was designed to describe a linked biological-physical-economic modeling tool, and to apply a basic version of that tool in a manner that would reveal one aspect of the social cost of allowing uncurbed NPS pollution from excessive land use change, and identify the problems that led to the creation of this externality. The LSPC model was used to estimate bacterial loads delivered from the watershed to the water body. The TPWQM distributed these loads throughout the water body by simulating tidal flushing, and estimated bacterial concentrations for different areas within the creek. Based on the results presented above, the combined LSPC and TPWQ models generated a reasonable reflection of monitored conditions in Old Plantation Creek over the study period, as it was not possible to establish that the observed and predicted means for fecal coliform concentration were significantly different.

By comparing fecal coliform concentrations modeled under the baseline land use scenario to those modeled under the buildout land use scenario, it was possible to show that additional areas of the creek, including over 150 acres of shellfish leases, could become condemned to shellfish harvest if the amount of impervious surface and the number fecal coliform sources in the watershed continue to increase. While not all of this acreage is currently being used for hard clam aquaculture, it is suitable for that purpose, and therefore was included in the economic impact analysis.

Using an Input-Output analysis and data obtained from the literature and industry sources, the economic impact of these condemnations was calculated. This exercise estimated that annual economic impact of taking these leases out of production at $7.5 to $16.9 million. It is important to note that NPS pollution has negative affects on other
valuable in-water activities such as oyster aquaculture, and commercial and recreational fishing, which were not calculated in this study. It is also important to note that the economic impacts of preventing bacterial condemnations were not calculated. Finally, while it is assumed that shellfish have a positive effect on water quality, the potential negative effects of aquaculture industry practices or concentrations of clams that exceed the carrying capacity of Old Plantation Creek were not considered.

Based on the results of this application, recommendations were made for actions that could help solve the problems identified. One of these problems was the fact that even though this model is the state of the art, it must be refined through collection of better data and a more complete knowledge of variable components in order to improve its predictive accuracy and increase its value in informing public policy. However, it is clear that taking steps to do so will be beneficial to the TMDL process.

Other problems included finding ways to address NPS pollution in Old Plantation Creek, both by using measures to restrict what flows off of the land, and by giving instream users rights and incentives to protect their investments; and finding ways to ensure that allowing public submerged lands to be used for private aquaculture operations benefits the public. Most significant, however, is the need for a fundamental reevaluation of property law in the US and Virginia that takes into account the marginal social costs of each additional alteration of the natural landscape, recognizes that impacts are cumulative, rather than discrete, and strikes a more sustainable and democratic balance between the private and public interests in privately held land. Such a review would have major positive ramifications for NPS pollution control, habitat conservation, and protection of biological diversity and productivity, while also addressing the root causes.
of other quality of life issues like air pollution, traffic congestion, and property tax rates. By making a concerted effort to bring the Public Trust Doctrine to the forefront of aquatic resource management, the Commonwealth can shift the burden of proof of harm from the shoulders of the public to those of private interests, thereby incorporating themes of precaution and sustainability into mainstream political debate.
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Appendix A: Figures

Figure 1: Location of Old Plantation Creek within the Chesapeake Bay watershed (left) and the general shape and orientation of the inlet (right).
Figure 2: Old Plantation Creek’s subwatersheds, and the tidal prism segments within the inlet itself. One tidal prism segment can receive pollutant loads from multiple subwatersheds. The linkages displayed here are incorporated into the LSPC and Tidal Prism Water Quality Models.
Figure 3: Land use in the baseline model scenario. This layer was digitized from 2002 VBMP aerial photographs. The land use categories listed in the legend are associated with specific types of bacterial sources and have unique loading rates. Also shown here are the DSS monitoring stations from which fecal coliform data were collected, and the location of these stations relative to the tidal prism segments used in the model.
Figure 4: Projected land use for the buildout scenario used in the modeling exercise. The increases in developed areas predicted for the northern portions of the watershed are based on current zoning designations. The DSS monitoring stations and tidal prism segments are also shown here.
Figure 5: Extent of submerged land in Old Plantation Creek that is currently under lease. While not all of these leases are currently being used for shellfish aquaculture, they are suitable for the purpose if the waters above them are not contaminated by excessive concentrations of bacteria.
Figure 6: Extent and location of bacterial condemnations projected for Old Plantation Creek land use changes from the baseline scenario to the buildout scenario.
Figure 7: Areas of Old Plantation Creek condemned to shellfish harvest as of July 9, 2007. Section A has increased in size since 2004, and Section B is entirely new. In both these sections, data from new sampling stations became available too late to be included in this study.
Figure 8: These charts compare observed and modeled fecal coliform concentrations for three tidal prism segments in Old Plantation Creek over a portion of the study period.
APPENDIX B: GIS Development

The first requirement for the linked modeling exercise conducted in this study is the spatially explicit characterization of land use in the target watershed. Many similar studies have relied on the National Land Cover Dataset (NLCD), an existing GIS data layer compiled by the Multi-Resolution Land Characteristics Consortium in 2001, as the baseline for their analyses. This approach saves a great deal of time, and is widely accepted. When researching the study area for this project, however, it became apparent that the NLCD was not sufficiently precise or accurate. Because the NLCD is produced automatically using satellite remote sensing and only has a resolution of 30 meters, ground-truthing in the study watershed revealed that the dataset often mischaracterizes the land cover in some areas, particularly along borders between different land uses and in areas of mixed use. In a small watershed like that of Old Plantation Creek, a proper land use assessment is critical because even small inaccuracies can have a significant impact on both the relative percentages of each land use in the watershed, and on the total amount of fecal bacteria loading. This problem was addressed by using aerial photographs from the Virginia Base Mapping Program (VBMP) as a reference for creating a data layer for land use in the study watershed. These photographs, taken in 2002, have a 0.5 foot to 2 foot resolution, depending on the altitude at which the photographs were taken, and thus allowed for an excellent characterization of land use. This was a time-consuming process that started with importing the VBMP photograph to ArcMap 9.1 and overlaying the watershed boundary on the photograph. Then, each separate area of each land use category was manually delineated at the resolution
necessary to determine the boundary between it and the adjacent parcels. The result of this process was a land use layer comprised of nearly 400 polygons, each of which could be identified by attributes such as land use category, area, perimeter, subwatershed, and, of course, its “place in space,” or coordinates.

Areas of uncertainty were subject to ground-truthing in 2005 and 2006. These site visits revealed changes in land use and in fecal bacteria source associations. For example, a small number of goats (n<30) and horses (n<10) have been introduced to the watershed since 2002. However, since there was no method for determining a pattern for extrapolating these additions to future scenarios, these sources were excluded from the analysis altogether, rather than included in both the baseline and future land use scenarios. Despite these omissions, it is clear that the newly created land use layer from the VBMP is a great improvement over the NLCD for modeling Old Plantation Creek.
APPENDIX C: LSPC Model

The LSPC model used to simulate fecal coliform bacteria loads has four main components: land use classifications, fecal coliform sources associated with land uses, physical features of the land, and precipitation. Within each of these main components, a number of characteristics exist that describe the specifics of the watershed. For the land use category, many of these specifics are contained in the GIS developed above. For example, the GIS stores information regarding the size of each parcel of each different land use, the proportions of each subwatershed that are comprised of each land use type, and proximity of each parcel to water. As mentioned before, the land use layer created for this study is far superior in quality to those normally used for TMDL studies.

In setting up the LSPC model, data from the GIS, along with data for the other three main components, were entered into a Microsoft Access database. The GIS information, including subwatershed boundaries and stream reaches, is uploaded via the model’s GIS interface. The bacterial loading figures, along with precipitation data, land use, and physical features such as land slopes, stream widths and depths, bacterial decay rates and the start and end dates for each model run were entered manually. The database also contains a number of default parameters such as soil type, infiltration rate, and percentage of impervious surface for individual land use categories.

Determining the sources of fecal coliform bacteria associated with land use was a fairly simple process. However, even though the data sources were the same as those used in similar studies, and the methodologies used to derive estimated numbers of animals and to calculate loads were defensible, more complete data would definitely
improve the predictive effectiveness of the model. While the lack of data for species that surely contribute to fecal bacterial loads (rodents, feral cats, concentrated resident bird populations) is a condition that should be improved, this task was far beyond the scope of the current study, which sought only to test a new application of existing methods, rather than to improve upon those methods.

Once the raw data were collected and calculations were made, processed data were entered into the databases. During a model run, the model draws on the database for inputs necessary to estimate the chosen parameter(s), in this case, fecal coliform loads delivered to a water body from a specific subwatershed over specific time period. The linkage of the GIS to the LSPC model and its underlying Access database allows for the adjustment of parameters to test different scenarios. While it would have been possible to test formally the sensitivity of the model to changes in numerous variables, this study opted to examine only one baseline scenario and one future scenario, which is a sufficient analysis from which to draw the conclusions presented above.
APPENDIX D: Tidal Prism Water Quality Model

The TPWQM represents the final linked piece of the scientific puzzle. By simulating tidal flushing, the TPWQM distributes the bacterial loads generated by the LSPC model throughout the water body. This allows one to estimate the in-water concentrations of bacterial pollution not just at a single point in time, but also over time, and relative to precipitation events. By entering data into the Access database for the tidal prism, that is, the volume of water that enters and leaves the embayment over the course of a tidal cycle, along with data on the bathymetry of the basin, it is possible to estimate how a certain load of bacteria flowing off of the land will disperse and decay in tidal waters.

The first step in this modeling process is the creation of a tidal prism segment layer for integration into the GIS. As mentioned above, this had already been accomplished, so the existing layer needed only to be added on. Old Plantation Creek was divided into 11 tidal prism segments and the segments become smaller toward the headwaters of the creek, reflecting the diminishing influence of tidal flushing in these reaches. One tradeoff of note is that while smaller and more numerous tidal prism segments allow for a more granular look at model results, larger tidal prism segments have a greater probability of containing one or more observation stations with which to compare modeled results.

The next step is to calculate the low tide volume and the tidal prism. These calculations were relatively simple, requiring only knowledge of the surface area of the
creek, the tidal range, and the average depth at mean low water. Bathymetry data were obtained from a National Ocean Service (NOS) bathymetric survey (NOS, 1950).

Finally, in preparation for a model run, these data were entered into a linkage table within the LSPC model’s Access database. This table connects each tidal prism segment to the subwatershed(s) from which it receives runoff, and therefore a bacterial load. This final step allows one to estimate the concentration of fecal coliform bacteria, and, if desired, other pollutants in the waters of each tidal prism segment over a user-defined time period. Additionally, by changing parameter values for land use, decay rates, bacterial sources, or physical features one can estimate pollutant concentrations under a host of different scenarios.
APPENDIX E: Input/Output Model

The economic portion of this analysis was conducted by using the results from the environmental models described above, as well as knowledge about production methods and the value of sales in the hard clam industry, as inputs to an Input/Output (I/O) model. Information compiled through a series of interviews with aquaculturists, and from survey results that supported creation of the I/O model were used to determine both the per-acre value of submerged land in Old Plantation Creek, and the total dockside value of clams harvested from the Creek under standard production conditions.

By knowing the per-unit economic value of submerged land for one use, production of hard clams, and by knowing the number of units that will be taken out of production as a result of pollution, it is possible to estimate the direct loss of revenue to the aquaculture industry as a result of bacterial condemnation of a grow-out area. In addition, there are multipliers built into the I/O model to account for indirect and induced economic effects. The I/O model interface, which used Microsoft Excel as a platform, is shown below (Fig. 1).

Figure 1: I/O Model main interface
While it is not formally linked to the LSPC’s Access database, and therefore not technically a component of the scientific model, the I/O model is the key to making this analysis policy-relevant. Although this technique does not capture the economic value of submerged lands and clean water in terms of a full range of inputs to production and ecological services, and therefore, is not sufficient for conducting a cost-benefit analysis of the tradeoffs between coastal development and environmental protection, it does show that degradation of the aquatic environment can cause very real, very direct economic hardship. In an industry such as clam aquaculture, where the conditions necessary for optimal growth limit the areas in which the trade can be practiced, maintaining existing grow-out areas is a key to sector growth and sustainability.