TMDLs for Bacterial Impairment of Shellfish Waters: An Analysis of Options for Coastal North Carolina

By

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Abstract

In North Carolina, more than 100,000 acres of shellfish waters have been closed to shellfishing, many since the Clean Water Act was put in place in 1972. These waters are considered impaired because of levels of fecal coliform bacteria in excess of a set water quality standard. By law, the state must develop a TMDL, or total maximum daily load, for each impaired water body.

In North Carolina, only one TMDL for fecal coliform in shellfish waters has been developed in the State, and it has not been implemented. North Carolina does not offer any guidelines for implementing these TMDLs. The purpose of this project was to use case study TMDLs for nonpoint sources of fecal coliform in shellfish waters to see how they have been implemented and what North Carolina could learn from this.

Land use was analyzed for coastal North Carolina counties, and the counties were categorized based on those land uses as forest, agriculture, or developed. Two case study TMDLs were selected for each category. After reading each case study, the TMDL contact for the state was interviewed about implementation of the case study and general guidelines for implementation in the state. Though some of these case studies were approved as early as 2004, none have been implemented. In addition, each state had different methods for dealing with TMDL implementation.

Other means of improving water quality before TMDL development were also investigated. These included different types of best management practices, action by stakeholders, and watershed management plans. Any of these could be used to prevent water quality impairment or to improve degraded water quality.

Actions can be taken on state and local levels to improve water quality in closed shellfish waters in North Carolina. Locally, sources of fecal coliform should be identified so appropriate best management practices can be selected and implemented. At the state level, requiring TMDL implementation with a specific timeline would increase the probability that water quality will improve as a result of the TMDL process.

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1. Introduction

Over 100,000 acres of waters designated for the harvest of shellfish are closed in North Carolina, either permanently or on a conditional basis (Fowler 2008). These closures are the result of levels of fecal coliform bacteria above the required water quality standards. Waters closed to shellfishing are categorized as impaired and the law requires development of a total maximum daily load, or TMDL, to assess the current pollutant loading and determine the reduction necessary to meet the water quality standard.

In North Carolina, only one TMDL has been completed for fecal coliform bacteria in shellfish waters, and it has not been implemented. The State does not provide guidance on how to implement TMDLs to improve water quality. Furthermore, fecal coliform can be a point or nonpoint source of pollution. Because point sources are known and generally permitted, they are of less concern because they are easier to manage. However, nonpoint sources pose a great challenge to improving water quality because of their diffuse nature. Therefore, this project was undertaken with the goal of gaining information on how other states implement TMDLs for nonpoint source fecal coliform pollution in shellfish waters, and what North Carolina can learn from this.

TMDLs can take several years to be done well, and while waiting for a TMDL to be completed, water quality has likely continued to degrade. Therefore, a secondary goal of the project was to investigate other means of improving water quality without developing a TMDL.

2. Background

2.1 Total Maximum Daily Load

A total maximum daily load (TMDL) assesses the pollutant levels present in a water body. An assessment is made of the current loading of the pollutant to the water body including the sources of the pollutant and how much of the load is coming from each source. This is done using any combination of existing data and gathering new data. The data should have been collected multiple times over a long enough time period to capture seasonal variability in pollutant levels. A computer model is typically used to incorporate the data and determine the pollutant loading and the sources. The TMDL model assesses the maximum allowable load of the pollutant into the water body that will not cause the water quality standards to be exceeded. This total maximum daily loading includes a margin of safety and accounts for seasonal variability (DWQ 2007). From the maximum allowable load and the current loading, a total reduction in pollutant loading can be determined, which the TMDL allocates among the sources. Each determined point source is assigned a specific reduction (or no reduction). Because nonpoint sources do not have a specific origination, they are assigned a portion of the reduction as a group (e.g. John's Hog Farm must reduce its loading by 10% and nonpoint sources must be reduced by 20%).

2.2 Clean Water Act

The Federal Water Pollution Control Act (also known as the Clean Water Act, or CWA) was initially passed in 1948 as a means to protect the nation's waters. When the Act was amended in 1972, it included enforceable standards for water quality and regulations to ensure that those standards are met (Cicin-Sain and Knecht 2000). States play a significant role in setting water quality criteria: They are required to designate uses for each of their water bodies and, with guidance from the EPA, develop water quality standards to ensure those designated uses are possible (Clean Water Act § 303(a)). Common designations include recreational use, drinking water supply, and waters for harvesting shellfish. Each water body use has different standards for permissible levels of pollutants, and these depend on the nature of the primary water use. For example, North Carolina's drinking water standards include limits for more than 20 pollutants including arsenic, chlorine, and dioxin, while tidal recreational waters have measurable limits for one pollutant, enterococcus bacteria (NC Administrative Code 15A 02B.0212; 15A 02B.0222).

Section 303(d) of the Clean Water Act requires states to identify water body segments that are not meeting their water quality standards and include them on the state's list of impaired water bodies (the state's 303(d) list). Impaired water bodies are grouped based on categories of impairment. The EPA specifies five categories to classify all water bodies, and North Carolina uses these and an additional two (DWQ 2006). TMDLs must be developed only for those waters listed as being in EPA Category 5, "Impaired for one or more designated uses by a pollutant(s), and requires a TMDL" (DWQ 2006). The 303(d) list also includes the allowable pollutant load for each Category 5 water body (CWA § 303(d)).

Each state must submit their 303(d) list to the EPA every two years (EPA 2007a). From the time of submission, the EPA has 30 days to approve or disapprove the water body segments and their TMDLs (CWA § 303(d)(2)). If the TMDLs are approved, the state should incorporate this information into their planning process to meet the goals of the Clean Water Act (CWA § 303(e)). However, if the TMDLs are disapproved, the EPA has 30 days to establish a TMDL. Should a state fail to establish a TMDL in a timely manner, the EPA must do so (CWA § 303(d)(2), EPA 2007b).

Though the Clean Water Act does refer to nonpoint sources of pollution as they relate to TMDLs, the Act was initially intended to reduce pollutant loading from point sources. In the Clean Water Act of 1972, there are references on how to deal with nonpoint source pollution in various scenarios, but there is no comprehensive plan. This changed in 1987 when Section 319 was added to the Act and effectively brought together all parts of the Clean Water Act of 1972 that related to nonpoint source pollution (Cicin-Sain and Knecht 2000). This section includes how a state should go about assessing and managing their nonpoint source pollution and makes grants available to implement management plans for nonpoint source pollutants. In North Carolina, the Section 319 Grant Program is administered by N.C. Division of Water Quality, and offers grants for managing nonpoint source pollution. More information about this program can be found on their website (http://h2o.enr.state.nc.us/nps/Section_319_Grant_Program.htm).

2.3 Fecal Coliform

Fecal coliform (FC) is a bacteria that is found in the guts of all warm-blooded animals. While FC is not usually harmful to humans, it indicates the presence of fecal matter and associated harmful pathogens. Primary sources of FC are wildlife, livestock, pets, and humans. Despite this limited number of sources, fecal coliform can be conveyed to water bodies in numerous ways, as a point and nonpoint source. Point sources of fecal coliform include discharges from wastewater treatment plants, confined animal feeding operations, and some industrial facilities. Nonpoint sources include malfunctioning septic systems, deposition by domestic and wild animals, recreational vessel discharges, land application of manure, and stormwater runoff. Stormwater runoff is the primary conveyance of FC deposited on land into water bodies.

2.4 Shellfish Waters

Shellfish are filter feeders and may concentrate pathogens found in the water in their tissue. When eaten raw or lightly steamed, these pathogens can pose a serious health risk to consumers. During the early 1920s, outbreaks of illnesses were associated with eating oysters, clams, and mussels (FDA 2005). At that time, the FDA established the National Shellfish Sanitation Program which started a national water quality standard for waters where these species are being harvested (FDA 2005). While states may set standards for designated waters within their borders, standards for shellfish waters are implemented nationally because shellfish are often bought and sold on a national level. The current water quality standard for shellfish waters deals with the presence of fecal coliform. If the set standards are exceeded, a water body is considered impaired and is closed to shellfishing until standards are met.

3. Project Goals

The North Carolina Coastal Federation (NCCF) is a nonprofit organization focused on protecting and restoring North Carolina's coast (NCCF 2008). NCCF is currently involved in two TMDLs in the state and anticipates increased future involvement in TMDLs as part of their mission to protect coastal areas. The goal of this project is to give NCCF guidance on implementing TMDLs for fecal coliform and other means of improving bacterial water quality in shellfish waters of the state. Other organizations and government agencies trying to protect and improve coastal water quality may also find this document useful.

4. Project Objectives

The purpose of this project is to gather information on how TMDLs for fecal coliform in shellfish waters have been implemented to improve water quality and how these implementation practices can be translated to coastal North Carolina. The research questions driving this project are as follows:

1. Where TMDLs have been implemented in areas similar to coastal N. C., have the implementation actions been successful at improving water quality? If so, how can these actions potentially be used in coastal N. C.?
2. Where TMDL implementation has been unsuccessful, what contributed to the failure and how can N. C. learn from this?
3. If the cause of impairment to a water body is known prior to doing a TMDL, can water quality be improved without doing a TMDL?

5. Characterizing Coastal North Carolina

5.1 Methods

5.1.1 Selecting Counties

There are 20 coastal counties in North Carolina, all with shorelines on the Atlantic Ocean or one of the many sounds in the state. Because this project focuses on shellfish waters, specifically those with the Eastern oyster (*Crassostrea virginica*), coastal counties without Eastern oysters present in their waters were eliminated from the analysis for this project. This left 10 coastal counties which were used for this project.

5.1.2 Land Cover

In order to find TMDLs in areas similar to coastal North Carolina, I had to define land uses in coastal North Carolina. I analyzed geospatial data for the county boundaries (N. C. Center for Geographic & Information Analysis 2006) and 1996 land cover for the state (EarthSat 1996) using GIS software. Although the land cover data that I used is from 1996, it was the most recent data that was accessible for this project and served as an adequate baseline. Using GIS tools, I excluded major water bodies contained within county boundaries (i.e. large sounds), leaving only the terrestrial county boundaries for the state. I then selected each of the 10 coastal counties individually, and extracted the land cover data for each one. This resulted in a data layer of land cover for each county. I calculated the area of each land cover type using the calculate geometry tool in the attribute table of every data set. I then transferred these tables into Microsoft Excel and determined the percentage of the total area of each land cover type in each county.

5.1.3 Population

Population data for each coastal county being analyzed was obtained from the 2000 U.S. Census. To enable comparison of counties, I converted the total area of each county into square miles and calculated the number of people per square mile for each county.

5.2 Results

5.2.1 Selecting Counties

There are 10 coastal counties with Eastern oysters (Conrad 2007) which are listed below and can also be seen in Figure 1. The analysis of land use and population in North Carolina was limited to these counties.

- Beaufort
- Brunswick
- Carteret
- Craven
- Dare
- Hyde
- New Hanover
- Onslow
- Pamlico
- Pender

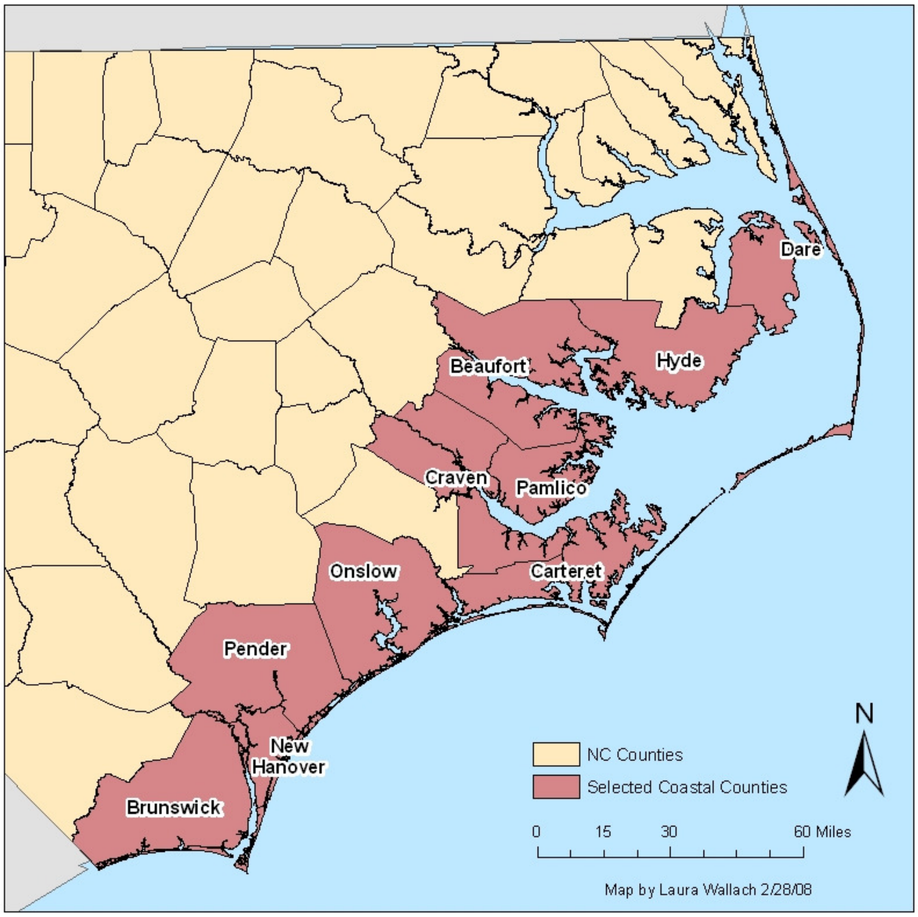

Figure 1. Selected North Carolina Coastal Counties Counties selected for analysis based on the presence of Easter oysters are shown in red.

5.2.2 Land Cover

For all counties, forested land is the most prominent land cover, occupying from 32% to more than 70% of a county's area. In addition to this, seven of the counties have agriculture as the secondary land use, ranging up to 29%. Of the three counties which do not have agriculture occupying the second greatest amount of area, two have bottomland forest/hardwood swamps as their second highest land use and one has high intensity development. I was able to group the counties into three categories based on their dominant land uses: forest, agriculture, and developed. Forest counties have between

60% - 75% forest cover. Agriculture counties have forest cover as the primary land use, but also have 18% - 30% agricultural land cover (including pasture and cropland). All nine of the counties categorized as forest or agriculture have less than 3% developed land cover. The remaining county, New Hanover County, has 17% developed land, so it is considered developed. Table 1 shows the percent of each land use present in selected counties as well as each county's assigned land use designation.

Though New Hanover County had five times more developed land than any other county analyzed, it was kept in the analysis for several reasons. Although the other NC counties examined do not have similar levels of development, many smaller coastal watersheds and cities do, which is not reflected in the county data. A correlation has also been shown between the percent of impervious surface cover (developed land) and bacterial pollution of local waterways from stormwater runoff (Mallin et al. 2000). In fact, when impervious surface cover is greater than 10% in a watershed, Mallin et al. (2000) showed that the bacterial water quality is impaired. Therefore, including a category for developed areas has significance for this project.

Table 1. Land Cover in Selected North Carolina Counties

	Landcover	Percent of County's Total Area				
		Beaufort	Brunswick	Carteret	Craven	Dare
	High Intensity Development	0.36%	1.87%	1.31%	1.03%	1.30%
	Low Intensity Development	0.35%	0.61%	1.08%	1.18%	1.66%
Developed	Total	0.71%	2.48%	2.39%	2.21%	2.96%
	Cropland	28.96%	10.27%	19.98%	14.91%	1.85%
	Pasture	0.94%	3.66%	2.26%	1.96%	0.55%
Agriculture	Total	29.90%	13.94%	22.24%	16.87%	2.40%
	Mixed Upland Hardwoods	2.83%	0.08%	0.90%	1.11%	0.12%
	Bottomland Forest / Hardwood Swamps	13.84%	5.81%	3.65%	18.46%	14.44%
	Needleleaf Deciduous	0.09%	0.36%	0.16%	0.07%	0.05%
	Southern Yellow Pine	38.87%	60.23%	45.30%	44.59%	49.48%
	Other Needleleaf Evergreen Forest	0.10%	0.04%	0.00%	0.00%	3.75%
	Broadleaf Evergreen Forest	0.23%	0.59%	0.13%	0.02%	0.20%
	Mixed Hardwoods / Conifers	1.20%	5.43%	0.87%	1.52%	0.12%
	Oak/Gum/Cypress	0.84%	1.54%	0.18%	0.31%	1.65%
Forest	Total	58.00%	74.08%	51.20%	66.07%	69.81%
	Unmanaged Herbaceous Cover - Upland	0.92%	0.45%	0.57%	0.16%	1.03%
	Unmanaged Herbaceous Cover - Wetland	0.80%	4.24%	12.17%	0.46%	6.94%
	Evergreen Shrubland	4.80%	1.63%	4.71%	6.52%	3.67%
	Deciduous Shrubland	0.86%	0.11%	0.06%	1.19%	0.01%
	Mixed Shrubland	1.89%	1.63%	1.32%	4.29%	7.05%
	Unconsolidated Sediment	0.64%	0.38%	1.72%	0.16%	2.29%
Other	Water Bodies	1.48%	1.06%	3.62%	2.07%	3.83%

Colors show assigned land use designation: yellow is agriculture, green is forest, and purple is developed.

Table 1 (continued). Land Cover in Selected North Carolina Counties

		Percent of County's Total Area				
	Landcover	Hyde	New Hanover	Onslow	Pamlico	Pender
	High Intensity Development	0.24%	13.49%	1.79%	0.57%	0.68%
	Low Intensity Development	0.11%	3.62%	0.91%	0.13%	0.20%
Developed	Total	0.35%	17.11%	2.69%	0.71%	0.87%
	Cropland	22.76%	3.96%	13.52%	18.43%	15.60%
	Pasture	0.36%	7.75%	4.76%	1.10%	2.55%
Agriculture	Total	23.12%	11.71%	18.28%	19.53%	18.16%
	Mixed Upland Hardwoods	0.71%	0.03%	2.04%	7.30%	0.14%
	Bottomland Forest / Hardwood Swamps	10.54%	3.47%	9.90%	6.99%	11.18%
	Needleleaf Deciduous	0.20%	0.55%	0.35%	0.12%	0.50%
	Southern Yellow Pine	32.41%	43.71%	49.19%	45.27%	52.94%
	Other Needleleaf Evergreen Forest	0.94%	0.02%	0.00%	0.00%	0.01%
	Broadleaf Evergreen Forest	0.98%	0.17%	0.91%	0.00%	1.29%
	Mixed Hardwoods / Conifers	1.09%	3.15%	0.85%	0.75%	2.79%
	Oak/Gum/Cypress	0.66%	2.70%	1.09%	1.41%	3.55%
Forest	Total	47.54%	53.82%	64.33%	61.83%	72.40%
	Unmanaged Herbaceous Cover - Upland	0.33%	1.34%	0.89%	0.63%	0.19%
	Unmanaged Herbaceous Cover - Wetland	6.23%	7.89%	1.84%	7.55%	1.09%
	Evergreen Shrubland	7.94%	0.80%	4.12%	1.85%	2.47%
	Deciduous Shrubland	0.07%	0.16%	0.37%	0.73%	0.21%
	Mixed Shrubland	1.96%	0.85%	5.54%	3.80%	3.44%
	Unconsolidated Sediment	0.23%	1.46%	0.72%	0.09%	0.20%
Other	Water Bodies	12.24%	4.86%	1.21%	3.29%	0.97%

Colors show assigned land use designation: yellow is agriculture, green is forest, and purple is developed.

5.2.3 Population

Populations in 2000 for the 10 counties analyzed ranged from more than 5,000 to greater than 160,000. Population densities for the counties ranged from 8 to 802 people per square mile with the average being 151 people per square mile ± 79 (SEM). Excluding New Hanover County, which has a significantly greater population density than the other counties, the average population density is 78 people per square mile ± 22 (SEM). The populations and population densities of each county can be seen in Table 2.

Table 2. Population Data for Selected Counties

County	2000 Population	Population Density (people/square mile)
Beaufort	44958	9.58
Brunswick	73143	85.42
Carteret	59383	118.17
Craven	91436	127.90
Dare	29967	78.26
Hyde	5826	8.50
New Hanover	160307	802.62
Onslow	150355	196.19
Pamlico	12934	38.00
Pender	41082	47.24

Population data was obtained from the 2000 U.S. Census, and population density was calculated from this.

6. Case Study TMDLs

6.1 Case Study Selection

6.1.1 Criteria

Case study TMDLs were selected for their similarities to coastal North Carolina counties. All case study TMDLs were done for fecal coliform bacteria in waters designated for the harvest of shellfish that contain Eastern oysters. Only TMDLs done in areas without point sources of fecal coliform were chosen for case study analysis. This is because nonpoint sources of fecal coliform are the most common sources in coastal North Carolina and are also the most difficult to reduce (Tursi 2007). Population density in the watersheds of selected TMDLs is within the range of population densities observed in coastal North Carolina counties (Table 2). N. C. counties were placed into one of three categories based on their land cover: forest, agriculture, or developed (Section 5.2.2). Two case studies were selected to represent each category.

6.*1.2 Methods*

Only TMDLs in Maryland, Virginia, and South Carolina were considered because of recommendations from the EPA Region 4 office and the N. C. Division of Water Quality (Simon 2008; Stecker 2008). Each of the three states listed TMDLs on a state website, Maryland and Virginia by approval date and South Carolina by pollutant. Maryland had 90 total approved TMDLs, Virginia had 184, and South Carolina had 70 for fecal coliform. I used a random number generator to choose 10 TMDLs for each state from the total.

Of the initial 30 TMDLs chosen by the random number generation process, 11 were discarded because they were not for fecal coliform. I looked at the remaining TMDLs to determine if they fit the appropriate criteria to be used as a case study. Three TMDLs fit the criteria, and were chosen to be case studies. To find the additional TMDLs needed for case studies, I repeated the process of using the random number generator to select 10 TMDLs from each state and narrowed down those 30 by the criteria previously discussed. This entire process resulted in six case study TMDLs, two each in forest watersheds, agriculture watersheds, and developed watersheds.

For each case study, I noted the watershed characteristics (land uses and population density) and possible sources of fecal coliform present. Looking at the fecal coliform loading from each source and the percent reduction allocated by the TMDL, I spoke with the TMDL contact for each state. In interviewing this person, my main questions involved whether the case study TMDLs from that state had been implemented and what the results have been. I also inquired as to the general TMDL implementation requirements of the state.

6.2 Case Studies – Forest

Forest case studies had 60% - 75% forest cover and less than 10% developed land, similar to those N. C. counties designated as forest (Section 5.2.2).

6.2.1 Ware River Watershed

The Ware River Watershed TMDL (Va. DEQ 2006a) includes sub-watersheds of the Ware River, Wilson Creek, and Mill Run Creek, which occupy 60.6 square miles in Gloucester County, Virginia. The population density of the area was 120 people per square mile in 2000. The main land uses are forest and agriculture, occupying 60% and 15% of the drainage, respectively. Agricultural land uses can be broken down further into crop land, which accounts for 8% of the area, and pasture, which accounts for 7%. 2% of the watershed is considered developed. The remaining 13% of the land area is wetlands and surface water.

The watershed has many potential sources of fecal coliform. Animal sources include chickens, deer, ducks, raccoons, dogs, and geese. A shoreline survey done by the Va. Department of Shellfish Sanitation found 101 deficiencies (sources) that could lead to fecal coliform contamination of waterways. Fifty-five deficiencies related to on-site sewage which includes septic systems as well as straight pipes illegally discharging graywater. Twenty-five deficiencies found were related to animals including livestock having access to waterways or being kept within a short distance of waterways. The remaining deficiencies were related to potential sources (10), industrial facilities (8), and boating (3). Potential source deficiencies are problems reported by individuals but not observed during the shoreline survey.

Bacterial source tracking (BST) was used to determine the likely sources of fecal coliform found in the sub-watersheds. The possible sources the BST can detect are humans, pets, livestock, and wildlife. Fecal coliform contributions were similar in all three sub-watersheds. Humans are the greatest source, contributing from 33% - 39%, followed by pets with 23% - 30%, then wildlife with 22% - 25% and finally livestock, contributing 12% - 16%. An implicit margin of safety was used in calculating the current fecal coliform loadings. The water quality standards for shellfish waters have requirements for a geometric mean and a 90th percentile value. The value that showed the highest loading, in this case the 90th percentile value, was used to calculate the current loading and allocate reductions.

Human, livestock, and pet sources of fecal coliform are considered controllable sources, and target reductions are typically allocated to these sources before wildlife. In this TMDL, 100% reductions were allocated to humans and livestock in all three sub-watersheds. Any remaining reductions needed were allocated to pets, which amounted to 10% in the Ware River watershed, 19% in the Mill Run Creek watershed, and 100% in the Wilson Creek watershed. The Wilson Creek watershed is the only sub-watershed to also have a reduction allocated to wildlife sources (30%). The fecal coliform sources and reduction allocations in each sub-watershed are in Appendix A.

The state of Virginia requires TMDLs to be implemented but does not have a timeline for this requirement. Though this TMDL was approved by the EPA in 2006, it has not yet been implemented. The creation of an implementation plan for this TMDL is scheduled "for the future" (Martin 2008). The BST showed humans to be the greatest source of FC, likely from septic system failures as the shoreline survey found. One way to implement this TMDL would be to reduce the loading from failing septic systems, especially those noted in the shoreline survey. The Va. Department of Environmental Quality does not have the authority to regulate septic systems; however they have used cost sharing programs in the past to encourage homeowners to help implement TMDLs (Martin 2008). In the Ware River watershed, a cost share program for residents with septic system violations to repair or replace those systems could considerably lessen the FC loading from humans. In Virginia, the money for a cost share program to implement TMDLs comes from Clean Water Act Section 319 grants and from a Virginia state "Water Quality Improvement Fund" which has money earmarked specifically for nonpoint source pollution problems (Martin 2008).

6.2.2 Corrotoman River Watershed

There are nine sub-watersheds of the Corrotoman River evaluated in this TMDL (Va. DEQ 2007), all of which are in Lancaster County, Virginia, and occupy 49.14 square miles. The population density of the drainage was 101 people per square mile in 2000. Forest is the primary land use, accounting for 70.85% of the area. Agriculture accounts for 21.8% of the land use including 12% as cropland and 9.8% as pasture. Development accounts for 0.96% of the land use. The remaining 6.39% of the land cover is transitional land, wetlands, and surface water.

Humans, pets, livestock, and wildlife are all potential sources of fecal coliform in the watershed. Animal sources in the watershed are primarily raccoons, deer, dogs, ducks, and geese. There are 2,572 septic systems in the watershed. A Va. Department of Shellfish Sanitation shoreline survey found 81 deficiencies that could contribute fecal coliform to waterways. Twenty deficiencies were related to animals having direct access to waterways or being kept within a short distance of waterways, 15 were related to on-site sewage (septic system and straight pipe issues) and 14 were related to boating. Twenty-one deficiencies were noted as being potential sources where a deficiency was reported by a resident but not observed during the shoreline survey. Additional deficiencies included solid waste dumpsites (6), and industrial facilities (5).

Bacterial source tracking was used to categorize the likely sources of fecal coliform as humans, pets, livestock, or wildlife. Livestock were the dominant source in eight of the sub-watersheds, contributing from 28% - 55% of the fecal coliform present. In all, controllable sources (humans, pets, and livestock) were responsible for the majority of fecal coliform in the waterways, with wildlife accounting for the smallest contribution in seven of the sub-watersheds, with a range of 5% - 19%. An implicit margin of safety was used in calculating the current fecal coliform loadings. The water quality standards for shellfish waters have requirements for a geometric mean and a 90th percentile value. The value that showed the highest loading, in this case the 90th percentile value, was used to calculate the current loading and allocate reductions.

The load reductions needed were allocated to humans, then livestock, pets, and finally to wildlife. One sub-watershed required 100% reductions to all controllable sources as well as 10% to wildlife. Six sub-watersheds required 100% reductions to humans and livestock, and reductions allocated to pets ranged from 10% - 93%. The remaining two sub-watersheds required a reduction in human sources of 100% and allocated 67% and 97% to livestock. The fecal coliform sources and reduction allocations in each sub-watershed are in Appendix A.

The TMDL recommends that the first part to implementing it should be to establish a no-discharge zone in the entire Corrotoman River drainage because of high vessel traffic. It is noted that while the discharge of untreated human sewage is illegal under the federal Clean Water Act and Virginia state law, discharges from Coast Guard approved Marine Sanitation Devices are allowed. This can contribute to the fecal coliform impairment of the waterways under consideration because while Marine Sanitation Devices are adequate for discharge into open coastal waters, they do not sufficiently treat sewage for discharge into small watersheds and embayments (Va. DEQ 2007).

The state of Virginia requires TMDLs to be implemented, but with no specific timeline. This TMDL was approved by the EPA is 2007 and has not yet been implemented, though it recommended the creation of a no-discharge zone in the Corrotoman River. The EPA has been supportive of no-discharge zones as a means to reduce fecal coliform loading from recreational vessel discharges, but there has been some resistance in the state from local stakeholder groups, towns, and commercial vessel operators (Martin 2008). A no-discharge zone typically takes 9-15 months to implement, and part of this time is spent on an intensive outreach campaign to garner support for the designation (Martin 2008).

No-discharge zones have only recently been used to protect water quality in the state and reverse impairment. To date, only one water body in Virginia, Lynnhaven Bay, has been designated as a no-discharge zone due to the results of a TMDL and a commitment to improving water quality from the nearby town of Virginia Beach. Because of this designation and other implementation measures, parts of the Bay which had been closed to shellfishing since the 1930s have been reopened (Martin 2008). The use of no-discharge zones is currently being considered in other impaired water bodies with high recreational vessel traffic (Martin 2008).

In the Corrotoman River Watershed, establishment of a no-discharge zone would only decrease FC loading from human sources, and livestock were found to be the largest single source of fecal coliform in eight of the nine sub-watersheds. Virginia's "Guidance Manual for Total Maximum Daily Load Implementation Plans" (Va. DEQ 2003) suggests several best management practices (BMPs) for reducing bacterial loading from different sources. Suggestions for reducing loading from livestock including lagoon pump outs, management of the storage location and use of animal waste, and fencing to exclude livestock from waterways. For a list of possible best management practices for bacteria and their descriptions from the guidance manual, see Appendix B. In this case, the best management practices implemented would depend on how the FC from livestock is getting into the water bodies as well as the willingness of landowners. Specific sources of fecal coliform derived from livestock should be located, and the shoreline survey done for this TMDL notes 20 such sources. Because these are now known to be potential sources of fecal coliform into the waterway, these locations should be targeted for BMP development first. However, the Virginia Department of Environmental Quality does not have the authority to require private land owners to implement best management practices. Through educating landowners about the results of the TMDL and the possible implementation measures, as well as making a cost share program available, the livestock sources of fecal coliform can be reduced.

6.2.3 Discussion

The Ware River Watershed and Corrotoman River Watershed TMDLs have not yet been implemented. However, Virginia requires TMDL implementation, giving assurance that these will be implemented at some point in the future. The sources of fecal coliform differed between the two forest case studies, with the Ware River watershed being dominated by human sources and the Corrotoman being dominated by livestock. However, because human sources are present in both TMDLs, reducing those sources can be one step in the implementation process. Having residents fix septic system failures could help improve water quality in the Ware River watershed. The Corrotoman River may be designated as a no-discharge zone in the future to limit human sources of FC from recreational vessel discharges. Livestock was found to be the single largest source of fecal coliform in the Corrotoman River TMDL, so reducing livestock sources through best management practices could also help improve water quality. In both cases, shoreline surveys done in conjunctions with the TMDLs found many deficiencies. The shoreline surveys also noted the locations and details of each deficiency, which will make it easier to correct those deficiencies as a first step in implementing these TMDLs.

6.3 Case Studies - Agriculture

Case studies selected for the agriculture category had 18% - 40% agricultural land cover. Because forested land is the most dominant land use in coastal NC counties, agriculture case studies with forested land accounting for the single greatest land use were chosen. Developed land in these case studies was limited to 10% or less of the area.

6.3.1 Messongo and Guilford Creeks

The TMDL done for Messongo and Guilford Creeks also includes Youngs Creek (Va. DEQ 2006b). The three sub-watersheds are adjacent to one another and are located in Accomack County, Virginia. The total drainage area for this TMDL is 47 square miles. The population density within the drainage area was 56 people per square mile in 2000. Forest is the single greatest land use, occupying 35% of the area. Agriculture accounts for 20% of the land use in the area, with 11% as cropland and 9% as pasture. 1% of the land area is developed. The remaining 44% of the area is barren land, wetlands, and surface waters.

Animal sources of fecal coliform include primarily chickens, dogs, ducks, raccoons, geese, and deer. There are 773 septic systems in the area, any of which could be potential sources of fecal coliform due to failure. A shoreline survey performed by the Va. Department of Shellfish Sanitation found only two possible fecal coliform sources: an animal pen within 75 feet of receiving waters and a trash dumpster. While the shoreline survey notes that the dumpster is regularly maintained and emptied (and therefore not a likely source of FC), the animal pen is a potential source of fecal coliform.

Bacterial source tracking was used to determine the likely sources of fecal coliform found in the creeks (humans, pets, livestock, or wildlife). Each of the three sub-watersheds had a different breakdown of the likely sources. However with the exception of no contribution from livestock in Messongo Creek, each possible source was responsible for 17% - 54% of the fecal coliform in each watershed. An implicit margin of safety was used in calculating the current fecal coliform loadings. The water quality standards for shellfish waters have requirements for a geometric mean and a 90th percentile value. The value that showed the highest loading, in this case the 90th percentile value, was used to calculate the current loading and allocate reductions.

Human, pet, and livestock sources are considered controllable sources while wildlife is not, so necessary reductions are generally allocated to these controllable sources before they are allocated to wildlife. Here, all controllable sources in each sub-watershed were allocated 100% reductions while wildlife was allocated 54% - 89% reductions. The fecal coliform sources and reduction allocations in each sub-watershed are in Appendix A.

The state of Virginia requires TMDLs to be implemented but does not have a timeline for this requirement. This TMDL was approved by the EPA in 2006, and has not yet been implemented. Because sources were split evenly between humans, pets, livestock, and wildlife, there are a variety of ways to reduce fecal coliform loading. Virginia implements TMDLs in an iterative process, beginning with reducing sources that have the greatest impact on water quality (Va. DEQ 2006b). A list of best management practices often used in Virginia and their descriptions can be found in Appendix B. TMDL implementation is voluntary for private citizens and landowners, so the BMPs implemented on private lands depend on the sources and the willingness of the landowner. Virginia Department of Environmental Quality often implements a cost share program in conjunction with a public education program to encourage citizens to use BMPs to improve water quality (Martin 2008).

6.3.2 St. Clements Bay

The St. Clements Bay TMDL (MDE 2004a) includes sub-watersheds for St. Clements Bay, Canoe Neck Creek, and St. Patrick Creek, all of which are located in St. Mary's County, Maryland. The drainage area covered by this TMDL is 604.25 square miles. The population density in 2000 was 9 people per square mile. The predominant land use in the area is forest, covering 49.64% of the sub-watersheds. Agriculture follows closely behind, accounting for 36.02% of the area. 9.15% of the area is developed. Wetlands and surface water account for the remaining 5.19% of the area.

Animal sources of fecal coliform in the watershed are split into wildlife, livestock, and pets. The wildlife sources include beavers, deer, geese, ducks, muskrats, raccoons, and wild turkeys. Livestock sources include cattle, sheep, chickens, and horses while dogs are the only pet source considered. There are 2,194 septic systems in the area that are assumed to be the source of any human contribution of fecal coliform.

Though this TMDL does not use BST to determine the sources of fecal coliform, they are deduced based upon data for the numbers and types of animals in the area and the amount of fecal coliform generated by each as well as the number of septic systems and a calculated failure rate. Livestock was found to be the source of 85% - 95.1% of the fecal coliform in all three sub-watersheds, followed by 3.5% - 12.3% from wildlife, less than 3% from pets, and 0.1% from humans. An implicit margin of safety was used in calculating the current fecal coliform loadings. The water quality standards for shellfish waters have requirements for a geometric mean and a 90th percentile value. The value that showed the highest loading, in this case the 90th percentile value, was used to calculate the current loading and allocate reductions.

In this TMDL, the reductions needed were calculated and split evenly between all controllable sources, with no reductions needed from wildlife sources. St. Clements Bay required a 24% reduction to all controllable sources, Canoe Neck Creek a 34.4% reduction, and St. Patrick Creek an 82.9% reduction. The fecal coliform sources and reduction allocations in each sub-watershed are in Appendix A.

This TMDL has not yet been implemented. TMDL implementation is not required in Maryland, so there is no guarantee that this will be implemented in the future. However, Maryland Department of the Environment has been working to incorporate measures for reducing pollutants into local government planning and existing regulatory programs (George 2008). This is most applicable in areas such as the St. Clements Bay drainage where a small percentage of the watershed is developed and there is a large potential for future development.

Maryland Department of the Environment has developed a guidance document for local governments looking to protect water quality through existing programs and regulatory framework, "Maryland's 2006 TMDL Implementation Guidance for Local Governments" (MDE 2006). This guidance document gives "broad strategic direction" for implementing TMDLs rather than being a "how to" manual (MDE 2006). The state of Maryland has only recently begun to develop TMDLs for bacterial impairment, and has been looking to Virginia's "Guidance Manual for Total Maximum Daily Load Implementation Plans" (Va. DEQ 2003) for "how to" ways to reduce bacterial loading on impaired water bodies (George 2008). According to Virginia's guidance manual, some means to reduce fecal coliform from livestock sources include using fencing to exclude livestock from waterways, lagoon pump outs, and management of the storage location and use of animal waste. The sections of Virginia's guidance manual which have descriptions of these BMPs and others for controlling livestock sources of fecal coliform are in Appendix B. Before BMPs can be used to implement the TMDL, locations of sources of fecal coliform should be found and BMP implementation should be focused on these areas. A shoreline survey or meetings with local residents can assist in this task.

6.3.3 Discussion

Neither of the agriculture case studies has been implemented yet. Virginia requires TMDL implementation, assuring that the Messongo and Guilford Creeks TMDL will be implemented in the future. However, Maryland does not require TMDL implementation, giving no assurance that the St. Clements Bay TMDL will be implemented. The sources of bacteria differed between the case studies. The Messongo and Guilford Creeks TMDL found that fecal coliform loading was split fairly evenly between all sources, while livestock were responsible for 85% or more of the loading in St. Clement's Bay. There are several possible BMPs for limiting livestock sources of bacteria in both cases, and other BMPs for limiting human and pet sources in Messongo and Guilford Creeks. A shoreline survey in the Messongo and Guilford Creeks TMDL did not yield significant findings, so local knowledge should be used in determining the locations of sources of fecal coliform in the drainage. The St. Clements Bay TMDL did not use information from a shoreline survey; this might be helpful in determining spatial locations of bacteria sources to the water bodies and should be done before determining how to reduce the bacteria loading.

6.4 Case Studies – Developed

The main criteria of concern when selecting developed case studies was that they have at least 17% developed area. This is because Mallin et al. (2000) has shown a correlation between greater than 10% impervious surface cover and impaired bacteriological water quality. Developed land varies in its percent of impervious surface cover, and the specific values for the amount of impervious surface cover were not given in the potential case study TMDLs. Therefore, considering TMDLs done in areas with greater than 17% developed area is thought to capture at least 10% impervious surface cover.

6.4.1 Church Creek

The Church Creek TMDL (MDE 2004b) was done for the Church Creek watershed in Dorchester County, Maryland. The watershed occupied 4.54 square miles and had a population density of 67 people per square mile in 2000. Forest accounts for 29.8% of the area with agriculture occupying 39.9%. Developed land occupies 17.7% of the area. Wetlands and surface water account for the remaining 12.6% of the area.

Animal sources in the watershed have been categorized as wildlife, livestock, or pets. Wildlife sources present include beavers, deer, geese, ducks, muskrats, raccoons, and wild turkeys. Livestock sources found in the Church Creek drainage include cattle, sheep, chickens, and horses. Dogs are the only pet source of fecal coliform considered in this TMDL. There are 134 septic systems in the drainage, any of which are a potential human source of fecal coliform.

The current loadings of fecal coliform in the watershed were calculated by using the data from the different types of animals present and how much fecal coliform each produces daily. A similar technique was done to incorporate humans into the current loading by using the number of septic systems in the area and a calculated rate of septic system failure. The current loadings were found to be primarily wildlife (82.7%), followed by pets (14.2%), livestock (2.8%), and humans (0.3%). The margin of safety for this TMDL was implicit, using a low decay rate for fecal coliform in calculating the TMDL. By doing this, the current loading and necessary reductions are more conservative.

The target reductions were first allocated among controllable sources, with a 95% target reduction being assigned to each humans, pets, and livestock. It was calculated that further FC reductions would be needed, so a 63.7% reduction was also allocated to wildlife. The fecal coliform sources and reduction allocations in each sub-watershed are in Appendix A.

This TMDL was approved by EPA is 2004 and has not yet been implemented. TMDL implementation is not required in Maryland, so there is no guarantee that this will be implemented in the future. Maryland Department of the Environment has been working to incorporate measures for reducing pollutants into local government planning and existing regulatory programs (George 2008). This does not have the same potential to improve water quality here as it would in a less developed drainage because these existing programs are focused on new development and land use changes, not retrofitting existing areas to minimize their pollutant contributions. However, almost 70% of the drainage is currently forest and agriculture, and these existing programs and regulations will be useful if any of that 70% undergoes land use changes in the future.

Maryland has only recently begun to develop TMDLs for bacterial impairment, and has been looking to Virginia's "Guidance Manual for Total Maximum Daily Load Implementation Plans" (Va. DEQ 2003) for ways to reduce bacterial loading on impaired water bodies (George 2008). However, this manual does not suggest means for reducing wildlife sources of fecal coliform. In fact, this TMDL specifically says that "neither the State of Maryland, nor EPA is proposing the elimination of wildlife to allow for the attainment of water quality standards" (MDE 2004b). The State does expect that implementation measures to reduce fecal coliform from nonpoint sources will also reduce fecal coliform loading from wildlife to some extent (MDE 2004b, George 2008). For example, vegetated buffers meant to slow down stormwater runoff and filter out pollutants, will work for FC from wildlife as well as other sources. Appendix B has a list of BMPs suggested by Virginia's "Guidance Manual for Total Maximum Daily Load Implementation Plans" and their descriptions.

6.4.2 Murrell's Inlet Estuary

The drainage area for the Murrell's Inlet Estuary TMDL includes sub-watersheds for Main Creek, Parsonage Creek/Allston Creek, and Garden City Canal (S. C. DHEC 2005). The drainage is located in both Horry and Georgetown counties in South Carolina and is approximately 16.02 square miles. The Murrell's Inlet Estuary TMDL did not include information on the area or population in the drainage. Because the TMDL area lies within both Horry and Georgetown counties, I looked at the population densities for those two counties. In 2000, Horry County had a population density of 173.39 people per square mile and Georgetown County had a population density of 68.46 people per square mile (Myrtle Beach Area Chamber of Commerce 2007). (Both counties population densities fall within the range of those found in the selected N. C. counties.) Forest occupies 31% of the drainage. Less than .01% of the area is agricultural land, and 24% of the area is developed. The remaining 45% of the area are barren land, wetlands, and surface waters.

There are two waste water treatment plants (WWTPs) in the watershed that discharge outside of Murrell's Inlet Estuary and do not have a direct effect on bacterial water quality there. Those WWTPs operate a total of 54 lift stations in the watershed which aid in moving sewage to the treatment plants, any of which could cause fecal coliform contamination if they malfunction. However, the S. C. Department of Health and Environmental Control (S. C. DHEC) inspected the lift stations at the time of this TMDL and found them all to be well maintained and in good working order. Therefore, they are unlikely sources of fecal coliform into the Estuary.

Two sources of fecal coliform are the two small municipal separate storm sewer systems (MS4s) in the watershed; one for Horry County and one for Georgetown County. An MS4 is a designation given to an area characterized as urbanized by the Bureau of the Census with a municipal separate storm sewer system; a small MS4 serves a population of less than 100,000 people (EPA 2000). Areas qualifying as MS4s need to obtain a National Pollution Discharge Elimination System (NPDES) permit and develop a stormwater management program (EPA 2000). The stormwater management program should reduce the discharge of pollutants to the "maximum extent practicable," protect water quality, and satisfy appropriate water quality requirements of the Clean Water Act (EPA 2000).

Additional sources of fecal coliform are humans, wildlife, and domestic animals. Wildlife in the area include deer, shorebirds, rabbits, raccoons, opossums, rodents, songbirds, and migratory waterfowl. Domestic animals include dogs, cats, horses and goats. The majority of the watershed is served by a central sewer system; there are also 119 septic systems in use in the area. A survey of these septic systems by S. C. DHEC found two malfunctioning, so septic systems are not assumed to be a source of fecal coliform. Marinas and vessel discharges are another possible source of fecal coliform contribution to waterways. While illegal vessel discharge into the water is possible, marinas are not considered a likely source of FC because water quality monitoring stations near marinas do not show elevated levels of fecal coliform. Stormwater runoff from urban and suburban areas not permitted as MS4s is identified as a significant problem in the watershed due to dense development of the area. While this TMDL does not utilize techniques to determine the likely sources of fecal bacteria, a previous study in the watershed which used multiple antibiotic resistance to determine the sources of FC found that animal sources were a far greater contributor than human sources (Kelsey et al. (2003) cited in S. C. DHEC 2005). An explicit margin of safety of 5% was used in calculating this TMDL. Once the total allowable fecal coliform load was calculated for the TMDL, it was decreased by 5%. Source reductions must meet this lower allowable loading.

The TMDL does not allocate the current loading or target reductions among nonpoint sources. Rather, all nonpoint sources in the three sub-watersheds are assigned a target reduction between 71.4% - 81.4%. The MS4s are assigned the same target reduction as the sub-watershed in which they are located; 80.4%. It is noted that the MS4s will meet their obligations toward implementing this TMDL by compliance with their NPDES stormwater permits. The fecal coliform sources and reduction allocations in each sub-watershed are in Appendix A.

This TMDL has not been implemented. S. C. DHEC has not been given any regulatory authority to implement TMDLs (Mehta 2008). Therefore, point source load reductions allocated in TMDLs are implemented through existing regulatory permit requirements and nonpoint source load allocations in TMDLs are not required to be implemented (Mehta 2008). To aid in implementation, all TMDL from the last few years have had a recommendations section, and the recommendations made have gotten more explicit as knowledge of the issues improves (Mehta 2008). However, the Murrell's Inlet

Estuary TMDL does not make any recommendations for TMDL implementation or otherwise.

The Murrell's Inlet Estuary TMDL notes that stormwater runoff from non-MS4 urban and suburban areas is a perceived threat to water quality due to dense development. Furthermore, a previous study has shown that FC loading is from animal sources. With these things in mind, reducing fecal coliform loading from these sources can likely be achieved through limiting and controlling stormwater runoff so that it is not conveying fecal coliform to the water bodies. This can be done in a variety of ways including the use of vegetated buffers along water bodies, infiltration ponds that capture stormwater runoff, and rain barrel use by homes and businesses. A list of different best management practices and their descriptions can be seen in Appendix B.

To improve water quality impaired by nonpoint sources, S. C. DHEC applies for and receives CWA Section 319 grants (Mehta 2008). Local stakeholders and organizations wishing to improve water quality impaired by nonpoint source pollutants can apply to S. C. DHEC for funds from these Section 319 grants (Mehta 2008). Organizations who are given a grant for this must sign a contract with S. C. DHEC agreeing to implement certain measures to reduce the pollutant loading (Mehta 2008). S. C. DHEC has a good monitoring program and takes responsibility for monitoring changes in water quality after improvement measures have been implemented by the organization (Mehta 2008). Because of this program, the Murrell's Inlet Estuary TMDL can be implemented in the future if an organization or group of stakeholders wishes to undertake its implementation.

6.4.3 Discussion

Neither of the developed case studies has been implemented. Maryland and South Carolina do not require TMDL implementation, giving no assurance that they will be implemented in the future. However, 70% of the drainage for Church Creek is forest and agricultural land, so should these land uses change, new thinking in land use planning and other existing regulations will protect water quality from these changes. The Murrell's Inlet Estuary TMDL can be implemented in the future only if a stakeholder group wishes to take on the challenge and apply for a Section 319 grant to do so from S. C. DHEC.

The case studies differ in their sources of fecal coliform. Church Creek has FC loading primarily from wildlife. The Murrells Inlet Estuary TMDL did not use bacterial source tracking to determine sources, but it notes that stormwater runoff from non-MS4 urban and suburban areas as well as FC from animals are problems. Several best management practices can be used to reduce loading from stormwater runoff, which may help reduce loading from wildlife. However, TMDLs are not intended to reduce sources of fecal coliform from wildlife.

6.5 Summary

While one might assume that forest case studies would have fecal coliform from wildlife, agriculture from livestock, and developed from humans and pets, this has been shown to be incorrect. All sources were seen present to some extent in all sub-watersheds of each case study TMDL. While the conveyance of each source might differ depending on the land uses (such as septic systems in more rural areas and stormwater runoff in more developed areas), no significant commonalities were seen between case studies of similar land uses. Therefore, appropriate implementation measures for TMDLs must be determined on a case-by-case basis rather than based on general land uses.

Furthermore, the states which case studies were obtained from each have different ways of implementing TMDLs. Virginia is the only state of the three that requires TMDL implementation, though with no timeline, implementation is not guaranteed to begin shortly after the TMDL is developed. Virginia also can not require TMDL implementation on private lands, and utilizes education and cost share programs to encourage private landowners to implement best management practices. TMDL implementation is not required in Maryland or South Carolina. Maryland is attempting to improve water quality through existing programs and regulatory framework, which will not affect existing areas and sources of fecal coliform loading (such as stormwater runoff from developed areas). This can possibly reduce impacts to water bodies from future development in the state but does not aid in improving water quality from current sources of pollutants. South Carolina makes funds available to local organizations wishing to undertake the task of improving a water body impaired by nonpoint source pollutants; however organizations apply for these funds on a voluntary basis.

7. Other Ways to Improve Water Quality

While TMDLs are required by the Clean Water Act, implementation is not. Some states require TMDL implementation while others do not, so it is important to look for other ways bacterial water quality can be improved. Several of these measures are aimed at preventing impairment, others attempt to improve water quality in an impaired water body, and some can be used in either situation. The TMDL process is lengthy, taking from three to five years to be done well (Tursi 2007), so it is important to attempt to prevent water body impairment where possible in order to avoid doing a TMDL. Furthermore, when a water body is impaired, it is best to begin working to improve water quality as soon as possible rather than waiting for several years for a TMDL to be completed and then a few more years for it to be implemented. For this reason, additional options for improving water quality have been explored and are presented in this section.

Improving bacteriological water quality can be done through any combination of reducing sources of fecal coliform, reducing stormwater runoff, or controlling stormwater runoff. Furthermore, these may be used in conjunction with one another. While this section discusses ways of approaching these methods without doing a TMDL, any of these can be used in the implementation of a completed TMDL.

7.1 Structural Best Management Practices

Structural best management practices are structures which limit and control stormwater runoff. By controlling the quantity and quality of stormwater runoff from a certain area, these BMPs limit the amount of bacteria and other pollutants that enter a water body. Many of these can be used in future development or land use changes and some can be retrofitted to existing land uses.

Structural BMPs for limiting the quantity of stormwater runoff include rainwater collection systems, the use of pervious surfaces in place of impervious surfaces, and bioretention and infiltration areas. Rainwater collection systems, such as the use of rain barrels on buildings, allow rainwater to be collected and stored for future use rather than allowing it to become surface runoff. Pervious surfaces allow water to percolate through the ground, reducing stormwater runoff and giving the soil a chance to filter out any pollutants found in the water. Pervious surfaces can be achieved in many traditionally impervious areas by reducing the paved width of residential roads, using pavers for parking lot and driveway surfaces, or using pervious pavement in place of traditional pavement (Center for Watershed Protection 1996). Bioretention and infiltration areas include traditional stormwater retention and infiltration ponds as well as vegetated swales along roadsides and rain gardens. These areas are all depressions that stormwater runoff is diverted to (or they are located downstream of the flow of runoff) and serve to capture the runoff. Retention ponds hold the runoff while the other bioretention and infiltration areas allow it to percolate into the ground at a natural rate.

BMPs meant to improve the quality of stormwater runoff are capable of filtering out pollutants, and often serve to slow down the runoff or divert it from water bodies completely. Vegetated buffers along water bodies are one good example of this. A vegetated buffer works most effectively with natural vegetation that has not been mowed (although lawn grass is technically vegetation, it does not work as well as native plants at slowing down and filtering runoff). Some municipalities, such as Winston-Salem, North Carolina, have enacted "no mow zones" along certain riparian areas for this purpose. Vegetated filter strips are similar to vegetated buffers in that they are areas of natural vegetation which are not mowed that serve to filter and slow down stormwater runoff (Va. DEQ 2003). Vegetated filter strips are best when placed downstream of a source of stormwater runoff or pollutants such as a development or livestock pasture.

Finally, structural BMPs can also be used to control the sources of fecal coliform. This is most obvious when looking at livestock having direct access to waterways. One effective BMP to reduce this FC loading is to exclude livestock from waterways with fencing and provide livestock water crossing facilities where necessary (Va. DEQ 2003). A more complete list of different structural BMPs used in Virginia to control bacterial pollution and their descriptions can be seen in Appendix B.

7.2 Non-Structural Best Management Practices

Non-structural best management practices are not physically constructed, as structural BMPs are, however they serve the same purpose of improving water quality. Non-structural BMPs include education and public outreach, legislation, local ordinances, and management decisions. Public education and outreach are important tools to use when working to improve water quality in order to gain the support of local residents and other stakeholders.

The use of legislation, local ordinances, and management decisions can help improve or protect water quality in a variety of ways. For example, a local ordinance requiring pet owners to pick up after their pets will limit the FC coming from pets. Similarly, requiring homeowners with septic systems to have those systems regularly maintained and pumped out can reduce human sources of fecal coliform (Center for Watershed Protection 1996). Management decisions can include tax credits for developers using low impact development, the establishment of no-discharge zones in water bodies, or changing zoning laws to conserve natural areas (which can serve to reduce and filter stormwater runoff).

7.3 Watershed Management Plans

A watershed management plan can be created before or after a water body is impaired. This can be considered a holistic approach to retaining or improving water quality as it accounts for multiple pollutants and current and future threats to the water body (EPA 2008). The planning process should be implemented in an adaptive manner to incorporate new information and ensure its efficiency. Furthermore, active stakeholder involvement is important throughout the process, especially when determining which management strategies are most appropriate (EPA 2008).

The components of a watershed plan depend on the issues present in a specific watershed, and each plan will have unique goals and management strategies (EPA 2008). The U. S. Environmental Protection Agency has described the general elements of watershed plans in their “Handbook for Developing Watershed Plans to Restore and Protect Out Waters” (EPA 2008). This EPA document notes that it is important to coordinate a watershed plan with other planning efforts, which can be achieves through stakeholder participation and sharing data. Furthermore, the watershed planning process should be collaborative and participatory, actively involving stakeholders from the beginning of the process through implementation (EPA 2008).

If a TMDL has been developed for an impaired water body, the results can be incorporated into a watershed plan (EPA 2008). This ensures that the TMDL will be implemented, and provides a structural framework for addressing larger issues. If a TMDL has not been developed for an impaired water body, a watershed plan can be designed to achieve water quality standards (EPA 2008). If the watershed plan is successful at obtaining these water quality standards, a TMDL may not be necessary (EPA 2008).

7.4 Stakeholder Action

In North Carolina, the responsibility to develop TMDLs falls with the Modeling and TMDL Unit of the N. C. Division of Water Quality (DWQ 2007). The 6 people in this department are responsible for developing all TMDLs necessary throughout the state, and they often contract independent consulting firms to assist in TMDL development (Stecker 2008). Because of the limited number of people available to work on creating TMDLs, a water body can be listed as impaired for several years before a TMDL is completed for it. For this reason, action by local stakeholders to improve water quality without a TMDL is encouraged (Stecker 2008).

If a local group of stakeholders organizes with the goal of improving the water quality in an impaired water body, they can request that the Modeling and TMDL Unit of the N. C. Division of Water Quality delay developing a TMDL. The stakeholder group will be given a certain amount of time to try their own methods of improving water quality assuming that they have a realistic plan, time frame, resources, and organization (Stecker 2008). A stakeholder group could be led by an organization such as the North Carolina Coastal Federation, or could be a group of self-organized citizens.

7.5 When Water Quality Improvement is Impractical

In some cases, once a TMDL is completed and measures to reduce fecal coliform have been implemented, monitoring will show that the water body is still not meeting the water quality standards to allow for shellfish harvesting. For fecal coliform, this can be due to wildlife sources, which TMDLs are not intended to limit. In these cases, the options presented in this section may be possibilities.

7.5.1 Impaired Waters Assessment Category

Impaired water bodies listed on a state's 303(d) list are categorized based on the status of their impairment (Section 2.2). TMDLs must be developed only for those waters listed as being in Category 5, "Impaired for one or more designated uses by a pollutant(s), and requires a TMDL." Where a TMDL is not the appropriate step to take to improve water quality of an impaired water body, its category on the 303(d) list can be changed to one not requiring the development of a TMDL (Simon 2008).

For closed shellfish waters in North Carolina, the most applicable category would be Category 4, "Impaired or threatened for one or more designated uses but does not require the development of a TMDL." Category 4 has three sub-categories to give more information as to why a water body does not require a TMDL although it is impaired (DWQ 2006). The most basic of these is Category 4a, where a TMDL has been developed but the water body remains impaired. This would likely apply between TMDL development and implementation, and is not applicable to this project.

Category 4b, "Other pollution control requirements are reasonably expected to result in the attainment of the water quality standard in the near future," is assigned to an impaired water body when water quality is expected to be improved due to measures already in place (DWQ 2006). When impairment is expected to be reversed through permitting or a watershed plan, changing the water body's assessment category to 4b will avoid the TMDL process while still ensuring water quality is improved (Simon 2008). Permitting is not applicable for most cases where fecal coliform is a nonpoint source pollutant, but it is relevant where stormwater runoff from a designated MS4 is the primary source of FC. For a watershed plan to reasonably expect to improve water quality, it must specifically state how the impairment will be reversed (Simon 2008). In either case of permitting or a watershed plan, it must be shown within two years of being listed as Category 4b that the pollutant loading is being reduced (Simon 2008).

If the impairment is caused by anthropogenic activity, the EPA believes that a TMDL is not the appropriate solution and the water body should be listed as a Category 4c, "Impairment is not caused by a pollutant" (DWQ 2006). Specifically, this category is intended for water bodies impaired by water control structures, such as dams (DWQ 2006). Many parts of coastal North Carolina have been ditched to drain the land for agricultural use or for mosquito control. These ditches are water control structures, and cause stormwater runoff and the pollutants it carries to be conveyed to water bodies quickly (Reilly 1998). This rapid transport of runoff carries bacteria to larger water bodies before its natural die off rate can reduce the numbers of bacteria, resulting in an increased loading to these larger water bodies (Reilly 1998). Because these ditches are prevalent throughout coastal North Carolina, this assessment category can be appropriate in many cases.

7.5.2 Use Attainability Analysis

A Use Attainability Analysis, or UAA, is an analysis which is done to determine if the water quality standards for a water body should be changed. The UAA considers if a water body can attain its designated use in the future, not just whether it is attaining that use in its present condition (EPA 2006). In other words, a UAA is only appropriate where measures are in place to control fecal coliform loading to the maximum extent practicable and monitoring indicates that bacteriological water quality will not improve enough to allow shellfishing in the future. For areas where wildlife sources of fecal coliform are causing the water body to be impaired (after controllable sources have been limited as much as possible), this is a potential option.

A state can remove a water body's designated use that is not currently an existing use if any of several conditions apply. Those pertinent to fecal coliform in shellfish waters, especially caused by wildlife, are:

- A naturally occurring pollutant prevents attainment of the use (40 CFR 131.10(g)(1))
- Dams, diversions, or other types of hydrologic modifications prohibit the attainment of the uses, and it is not feasible to restore the water body to its original condition (40 CFR 131.10(g)(4)

The presence of wildlife sources of fecal coliform leading to impairment of a water body is considered a natural pollutant, so provision (g)(1) above would apply.

Many areas in coastal North Carolina have modified hydrology due to the use of ditching to drain wetlands for agricultural use or as mosquito prevention measures. These modified hydrology systems are meant to deliver water into water bodies more quickly than the natural landscape would. Fecal coliform is likely also being conveyed by the water in these ditches. This means that it is likely that fecal coliform is being carried to larger water bodies more rapidly that the natural die off rate is acting, which leads to an increased FC loading in those larger water bodies (Reilly 1998). In this case, provision (g)(4) above would apply because the modified hydrology is causing the fecal coliform loading and the impairment, and it would not be feasible to return all coastal areas of the state back to their natural hydrological patterns.

Before removing the shellfishing designation from a water body though, it is important to see whether the water body will meet the next most stringent designation standard (for primary contact recreation). The primary contact recreation designation has water quality standards for Enterococcus which must be met, and primary contact recreation must be an actual use of the water body (Manning 2008). For these reasons, designated uses are not generally removed in North Carolina (Manning 2008).

7.6 Summary

There are several means to improve bacterial water quality without developing a TMDL. Structural and non-structural best management practices can directly reduce fecal coliform loading into a water body. Stakeholder action can work to find sources of FC and use various best management practices to reduce or eliminate those sources. Watershed plans can be done to prevent impairment or to mitigate it. These three options can also be intertwined: a watershed plan can be the result of stakeholder action, and both stakeholder action and watershed plans can rely on best management practices to reduce or eliminate FC loading.

In situations where water quality can not be improved due to FC from wildlife sources, there are two options available. The water body impairment can be reclassified to an EPA category for impaired waters not requiring TMDL development. The second option would be to undergo a Use Attainability Analysis, where the designated use of the water body is evaluated and potentially changed.

8. Recommendations

8.1 Local-level Recommendations

While this project set out to recommend the best ways to implement TMDLs done in areas with certain land uses, the case studies have illustrated that the sources of fecal colform in a watershed are not necessarily determined by the land uses found there. Therefore, the first recommendation is to evaluate the sources of fecal coliform pollution and implement measures to improve water quality based on the sources. Information from shoreline surveys and local knowledge should be used to determine the spatial locations of these sources and possible actions that can be taken to correct problems found.

There are a range of possible best management practices that can be used to reduce fecal coliform, each suited to different sources and source locations. It is important to select the BMPs that will work best for a particular situation. Best management practices can not be required for implantation on private land, so it is necessary to use public education and outreach to inform land owners of the importance of implementing these BMPs. Furthermore, the establishment of a cost share program for this would aid in securing land owner participation in BMP implantation.

While the recommendations above can be used to implement a TMDL, they can also be used in the absence of a TMDL to improve water quality. In North Carolina, organized stakeholders, such as the North Carolina Coastal Federation, can delay TMDL development and use the suggestions above to find and reduce sources of fecal coliform. Should this method result in the attainment of water quality standards, a TMDL may not be needed.

Watershed planning is a time intensive approach to protecting water quality, but due to its holistic nature, it is likely the most effective at protecting a complete watershed. Watershed plans can be a useful tool prior to or after a water body is impaired. A watershed plan would be ideal when the water body is currently threatened or may be in the future, and multiple pollutants or sources of pollutants are present.

Ideally, all impaired shellfish waters can be improved and reopened to shellfishing. However, when this is not the case because of anthropogenic factors or excessive FC loading from wildlife, changing the water body's impairment category may be appropriate. Another option when this occurs would be to undergo a Use Attainability Analysis to change the water body's designated use; however this may be a more difficult process.

8.2 State-level Recommendations

Though this project was geared towards implementing TMDLs and improving water quality on a local level, it is important to note some areas where action by the State of North Carolina could lead to improved water quality. The primary recommendation on this level would be to enact legislation requiring TMDLs to be implemented. The Clean Water Act only requires TMDLs to be developed, and without requiring implementation, the TMDL document can not improve water quality. In addition to implementation, requiring a specified timeline would guarantee implementation would occur within a set time of TMDL development rather than at ‘some point in the future.’ Furthermore, monitoring requirements will track whether implementation measures have been effective or not, allowing the state to learn what implementation actions are effective in which situations.

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Appendix A: Fecal Coliform Loading and Reduction Allocations for Sub-Watersheds in Case Studies

Ware River: Wilson Creek Sub-watershed		
Source	**BST Allocation (% of total load)**	**% Reduction Needed**
Human	35	100
Pets	26	100
Livestock	18	100
Wildlife	23	30
Total	**100**	**84**

Ware River: Ware River Sub-watershed		
Source	**BST Allocation (% of total load)**	**% Reduction Needed**
Human	39	100
Pets	23	10
Livestock	16	100
Wildlife	22	0
Total	**100**	**57**

Ware River: Mill Run Creek Sub-watershed		
Source	**BST Allocation (% of total load)**	**% Reduction Needed**
Human	33	100
Pets	30	19
Livestock	12	100
Wildlife	25	0
Total	**100**	**51**

Corrotoman River: Ewells Point Sub-watershed		
Source	**BST Allocation (% of total load)**	**% Reduction Needed**
Human	24	100
Pets	23	100
Livestock	28	100
Wildlife	25	10
Total	**100**	**77**

Corrotoman River: Taylor Creek Sub-watershed		
Source	**BST Allocation (% of total load)**	**% Reduction Needed**
Human	3	100
Pets	40	57
Livestock	53	100
Wildlife	3	0
Total	**100**	**80**

Corrotoman River: Millenbeck Creek Sub-watershed		
Source	**BST Allocation (% of total load)**	**% Reduction Needed**
Human	27	100
Pets	19	93
Livestock	47	100
Wildlife	8	0
Total	**100**	**91**

Corrotoman River: Myer Creek Sub-watershed		
Source	**BST Allocation (% of total load)**	**% Reduction Needed**
Human	16	100
Pets	14	0
Livestock	55	97
Wildlife	15	0
Total	**100**	**69**

Corrotoman River: Bell Creek Sub-watershed		
Source	**BST Allocation (% of total load)**	**% Reduction Needed**
Human	25	100
Pets	33	0
Livestock	23	67
Wildlife	19	0
Total	**100**	**41**

Corrotoman River: E. Branch Corrotoman River Sub-watershed		
Source	**BST Allocation (% of total load)**	**% Reduction Needed**
Human	32	100
Pets	29	10
Livestock	33	100
Wildlife	5	0
Total	**100**	**69**

Corrotoman River: Hill Creek Sub-watershed		
Source	**BST Allocation (% of total load)**	**% Reduction Needed**
Human	26	100
Pets	31	89
Livestock	34	100
Wildlife	9	0
Total	**100**	**88**

Corrotoman River: W. Branch Corrotoman River Sub-watershed		
Source	**BST Allocation (% of total load)**	**% Reduction Needed**
Human	35	100
Pets	23	65
Livestock	41	100
Wildlife	9	0
Total	**100**	**83**

Corrotoman River: Senior Creek Sub-watershed		
Source	**BST Allocation (% of total load)**	**% Reduction Needed**
Human	29	100
Pets	31	42
Livestock	31	100
Wildlife	9	0
Total	**100**	**73**

Messongo and Guilford Creeks: Messongo Creek Sub-watershed		
Source	**BST Allocation (% of total load)**	**% Reduction Needed**
Human	54	100
Pets	0	100
Livestock	25	100
Wildlife	21	88.4
Total	**100**	**97.6**

Messongo and Guilford Creeks: Youngs Creek Sub-watershed		
Source	**BST Allocation (% of total load)**	**% Reduction Needed**
Human	29	100
Pets	17	100
Livestock	35	100
Wildlife	19	54.1
Total	**100**	**91.3**

Messongo and Guilford Creeks: Guilford Creek Sub-watershed		
Source	**BST Allocation (% of total load)**	**% Reduction Needed**
Human	30	100
Pets	18	100
Livestock	21	100
Wildlife	31	89.95
Total	**100**	**96.9**

St. Clements Bay: St. Clements Bay Sub-watershed		
Source	**BST Allocation (% of total load)**	**% Reduction Needed**
Human	0.1	24
Pets	2.6	24
Livestock	85	24
Wildlife	12.3	0
Total	**100**	**21**

St. Clements Bay: Canoe Neck Creek Sub-watershed		
Source	**BST Allocation (% of total load)**	**% Reduction Needed**
Human	0.1	34.4
Pets	2.4	34.4
Livestock	86.2	34.4
Wildlife	11.3	0
Total	**100**	**30.6**

St. Clements Bay: St. Patrick Creek Sub-watershed		
Source	**BST Allocation (% of total load)**	**% Reduction Needed**
Human	0.1	82.9
Pets	1.3	82.9
Livestock	95.1	82.9
Wildlife	3.5	0
Total	**100**	**80**

Church Creek: Church Creek Sub-watershed		
Source	**BST Allocation (% of total load)**	**% Reduction Needed**
Human	0.3	95
Pets	14.2	95
Livestock	2.8	95
Wildlife	82.7	63.7
Total	**100**	**69.1**

Murrells Inlet Estuary: Main Creek Sub-watershed	
% Reduction Needed for MS4	**% Reduction Needed for Nonpoint Sources**
80.4	80.4

Murrells Inlet Estuary: Garden City Canal Sub-watershed	
% Reduction Needed for MS4	**% Reduction Needed for Nonpoint Sources**
N/A	71.4

Murrells Inlet Estuary: Parsonage Creek/Allston Creek Sub-watershed	
% Reduction Needed for MS4	**% Reduction Needed for Nonpoint Sources**
N/A	81.4

Appendix B: Best Management Practices for Bacteria Used in Virginia*

* From Virginia Department of Environmental Quality. Guidance Manual for Total Maximum Daily Load Implementation Plans. July 2003. 23 July 2007 <http://deq.state.va.us/export/sites/default/tmdl/implans/ipguide.pdf>.

BACTERIA

Best Management Practice	Impairment Source			Efficiency	Avg Cost	Unit	Notes
	Agriculture	Mining	Urban				
Animal waste management				75 %			
Artificial wetland/rock reed microbial filter							
Compost facility					$5.00	cu. ft. storage	
Conservation landscaping							
Detention ponds/basins				25 %			
Diversions/earthen embankments					$2.21	lin. ft.	
Drip irrigation							
Fencing				75 %	$1.78	lin. ft.	does not include cost of charger & gates
Filtration (*e.g.*, sand filters)				30 %			
Infiltration basin				50 %			
Infiltration trench				50 %			
Irrigation water management							
Lagoon pump out							
Land-use conversion							
Limit livestock access							
Litter control							
Livestock water crossing facility				100 %	$27.40	lin. ft.	reduction in direct deposition

BACTERIA

Best Management Practice	Impairment Source			Efficiency	Avg Cost	Unit	Notes
	Agriculture	Mining	Urban				
Manufactured BMP systems							
Onsite treatment system installation							
Porous pavement				50 %			
Proper site selection for animal feeding facility							
Rain garden /bioretention basin				40 %			
Range and pasture management				50 %			
Retention ponds/basins				32 %			
Riparian buffer zones				43 – 57 %	$547.00	acre	forested buffer w/o incentive payment
Septic system pump-out				5 %			
Sewer line maintenance (*e.g.*, sewer line flushing)							
Stream bank protection and stabilization (*e.g.*, riprap, gabions)				40 - 75 %	$47.00	lin. ft.	40 % w/o fencing; 75 % w. fencing
Terraces					$1.70	lin. ft.	
Vegetated filter strip					$99.00	acre	
Waste system/storage (*e.g.*, lagoons, litter shed)				80 – 100 %	$27,272	system	
Water treatment (*e.g.*, disinfection, flocculation, carbon filter system)							
Wetland development/enhancement				30 %	$859.00	acre	includes creation and restoration

Sources: BMP Efficiencies Chesapeake Bay Watershed Model (Phase IV) August 1999; Draft FC and Nitrate TMDL IP for Dry River (2001); EPA (1998); EPA (1999b); Novotny (1994); Storm Water Best Management Practice Categories and Pollutant Removal Efficiencies (2003); USDA (2003); DCR (1999); DEQ/DCR (2001).

Animal waste management: A planned system designed to manage liquid and solid waste from livestock and poultry. It improves water quality by storing and spreading waste at the proper time, rate and location.

Artificial wetland/rock reed microbial filter: A long shallow hydroponic plant/rock filter system that treats polluted waste and wastewater. It combines horizontal and vertical flow of water through the filter, which is filled with aquatic and semi-aquatic plants and microorganisms and provides a high surface area of support media, such as rocks or crushed stone.

Avoid adding materials containing trace metals: Limiting or eliminating application of fertilizers and pesticides containing trace metals.

Compost facility: Treating organic agricultural wastes in order to reduce the pollution potential to surface and ground water. The composting facility must be constructed, operated and maintained without polluting air and/or water resources.

Conservation landscaping: The placement of vegetation in and around stormwater management BMPs. Its purpose is to help stabilize disturbed areas, enhance the pollutant removal capabilities of a stormwater BMP, and improve the overall aesthetics of a stormwater BMP.

Conservation tillage: Any tillage and planting system that maintains at least 30% of the soil surface covered by residue after planting for the purpose of reducing soil erosion by water.

Contour farming: Tillage, planting, and other farming operations performed on or near the contour of the field slope. This results in reducing sheet and rill erosion and reducing transport of sediment and other water-borne contaminants. This practice applies on sloping land where crops are grown and is most effective on slopes between 2 and 10 percent.

Cover crops and rotations: Establishing grass and/or legume vegetation to reduce soil erosion and enhance water quality.

Critical area planting: Establishing permanent vegetation on sites that have or are expected to have high erosion rates, and on sites that have physical, chemical or biological conditions that prevent the establishment of vegetation with normal practices. This practice is used in areas with existing or expected high rates of erosion or degraded sites that usually cannot be stabilized by ordinary conservation treatment.

Crop rotations: Growing crops in a recurring sequence on the same field in order to: reduce sheet and rill erosion, reduce soil erosion from wind, maintain or improve soil organic matter content, manage the balance of plant nutrients, improve water use efficiency, manage saline seeps, manage plant pests, provide food for domestic livestock, and provide food and cover for wildlife.

Crop/plant variety selection: management strategy (part of Integrated Pest Management) used to control pests (i.e. weeds, insects, diseases) while minimizing pollution. Crop rotation is used to break pest life cycles. Volunteer plants serving as hosts for certain diseases and insects can be controlled by destroying the crop two to three weeks prior to planting new crops.

Detention pond/basin: Detention ponds maintain a permanent pool of water in addition to temporarily detaining stormwater. The permanent pool of water enhances the removal of many pollutants. These ponds fill with stormwater and release most of it over a period of a few days, slowly returning to its normal depth of water.

Diversions: Establishing a channel with a supporting ridge on the lower side constructed along the general land slope which improves water quality by directing nutrient and sediment laden water to sites where it can be used or disposed of safely.

Drip irrigation: An irrigation method that supplies a slow, even application of low-pressure water through polyethylene tubing running from supply line directly to a plant's base. Water soaks into the soil gradually, reducing runoff and evaporation (*i.e.,* salinity). Transmission of nutrients and pathogens spread by splashing water and wet foliage created by overhead sprinkler irrigation is greatly reduced. Weed growth is minimized, thereby reducing herbicide applications. Vegetable farming and virtually every type of landscape situation can benefit from the use of drip irrigation.

Earthen embankment: A raised impounding structure made from compacted soil. It is appropriate for use with infiltration, detention, extended-detention or retention facilities.

Fencing: A constructed barrier to livestock, wildlife or people. Standard or conventional (barbed or smooth wire), suspension, woven wire, or electric fences shall consist of acceptable fencing designs to control the animal(s) or people of concern and meet the intended life of the practice.

Field borders: The establishment of field borders adjacent to wildlife habitats that will soften field transitions to other land uses. These borders can be on any side of a field and are not restricted to lower field borders, as are filter strips.

Filtration (*e.g.,* sand filters): Intermittent sand filters capture, pretreat to remove sediments, store while awaiting treatment, and treat to remove pollutants (by percolation through sand media) the most polluted stormwater from a site. Intermittent sand filter BMPs may be constructed in underground vaults, in paved trenches within or at the perimeter of impervious surfaces, or in either earthen or concrete open basins.

Grade stabilization (*e.g.,* chemical stabilization): A temporary measure employed on bare soils until permanent vegetation is established or other long-term erosion-control measures are implemented. The use of organic chemicals and oil derivatives may not be possible due to suspected surface and ground water contamination by carcinogenic priority organic pollutants.

Grassed swale: A broad and shallow earthen channel vegetated with erosion resistant and flood-tolerant grasses. Check dams are strategically placed in the swale to encourage ponding behind them. The purpose of a grassed swale is to convey stormwater runoff at a non-erosive velocity in order to enhance its water quality through infiltration, sedimentation, and filtration.

Grassed waterway: A natural or constructed channel that is shaped or graded to required dimensions and established with suitable vegetation which conveys runoff from terraces, diversions, or other water concentrations without causing erosion or flooding and reduces gully erosion.

Green rooftops: A thin layer of vegetation that is installed on top of a conventional flat or slightly sloping roof. It can consist of a light weight vegetated system, or an elaborate rooftop landscape or garden. Internal drainage layers serve to moderate the rate of runoff while allowing for water and nutrient uptake by vegetated materials. Green rooftops can often be engineered to conform to existing load requirements of most roofs—therefore enabling the retrofit of existing buildings.

Infiltration Basin: A vegetated open impoundment where incoming stormwater runoff is stored until it gradually infiltrates into the soil strata. While flooding and channel erosion control may be achieved within an infiltration basin, they are primarily used for water quality enhancement.

Infiltration Trench: A shallow, excavated trench backfilled with a coarse stone aggregate to create an underground reservoir. Stormwater runoff diverted into the trench gradually infiltrates into the surrounding soils from the bottom and sides of the trench. The trench can be either an open surface trench or an underground facility.

Integrated pest management: A procedure to prevent excessive and/or unnecessary application of pesticides to land and/or crops for the control of pests. Improves water quality by scouting fields and/or crops and applying pesticides only when the pest reaches the threshold of economic damage.

Irrigation water management: The process of determining and controlling the volume, frequency, and application rate of irrigation water in a planned, efficient manner. An irrigation system adapted for site conditions (soil, slope, crop grown, climate, water quantity and quality, etc.) must be available and capable of applying water to meet the intended purpose(s).

Lagoon pump out: A waste treatment impoundment made by constructing an embankment and/or excavating a pit or dugout in order to biologically treat waste (such as manure and wastewater) and thereby reduce pollution potential by serving as a treatment component of a waste management system.

Land-use conversion: BMPs that involve a change in land use in order to retire land contributing detrimentally to the environment. Some examples of BMPs with associated land use changes are: Conservation Reserve Program (CRP) - cropland to pasture; Forest conservation - pervious urban to forest; Forest/grass buffers - cropland to forest/pasture; Tree planting - cropland/pasture to forest; and Conservation tillage - conventional tillage to conservation tillage.

Limit livestock access: Excluding livestock from areas where grazing or trampling will cause erosion of stream banks and lowering of water quality by livestock activity in or adjacent to the water. Limitation is generally accomplished by permanent or temporary fencing. In addition, installation of an alternative water source away from the stream has been shown to reduce livestock access.

Litter control: Litter includes larger items and particulates deposited on street surfaces, such as paper, vegetation residues, animal feces, bottles and broken glass, plastics and fallen leaves. Litter-control programs can reduce the amount of deposition of pollutants by as much as 50%, and may be an effective measure of controlling pollution by storm runoff.

Livestock water crossing facility: Providing a controlled crossing for livestock and/or farm machinery in order to prevent streambed erosion and reduce sediment.

Manufactured BMP systems: Structural measures which are specifically designed and sized by the manufacturer to intercept stormwater runoff and prevent the transfer of pollutants downstream. They are used solely for water quality enhancement in urban and ultra-urban areas where surface BMPs are not feasible.

Mulching/protective covers: Applying plant residues, by-products or other suitable materials produced off site, to the land surface. This practice conserves soil moisture, moderates soil temperature, provides erosion control, suppresses weed growth, establishes vegetative cover, improves soil condition, and increases soil fertility.

Nutrient management: Determining nutrient needs for cropland (with the exception of hay or pasture that receives mechanical applications of collected animal manure) and adjusting the application of nutrients accordingly.

Onsite treatment system installation: Conventional onsite wastewater treatment and disposal system (onsite system) consists of three major components: a septic tank, a distribution box, and a subsurface soil absorption field (consisting of individual trenches). This system relies on gravity to carry household waste to the septic tank, move effluent from the septic tank to the distribution box, and distribute effluent from the distribution box throughout the subsurface soil absorption field. All of these components are essential for a conventional onsite system to function in an acceptable manner.

Porous pavement: An alternative to conventional pavement, it is made from asphalt (in which fine filler fractions are missing) or modular or poured-in concrete pavements. Its use allows rainfall to percolate through it to the subbase, providing storage and enhancing soil infiltration that can be used to reduce runoff and combined sewer overflows. The water stored in the subbase then gradually infiltrates the subsoil.

Proper site selection for animal feeding facility: Establishing or relocating confined feeding facilities away from environmentally vulnerable areas such as sinkholes, streams, and rivers in order to reduce or eliminate the amount of pollutant runoff reaching these areas.

Rain garden: Rain gardens are landscaped gardens of trees, shrubs, and plants located in commercial or residential areas in order to treat stormwater runoff through temporary collection of the water before infiltration. They are slightly depressed areas into which stormwater runoff is channeled by pipes, curb openings, or gravity.

Range and pasture management: Systems of practices to protect the vegetative cover on improved pasture and native rangelands. It includes practices such as seeding or reseeding, brush management (mechanical, chemical, physical, or biological), proper stocking rates and proper grazing use, and deferred rotational systems.

Re-mining: Surface mining of previously mined and abandoned surface and underground mines to obtain remaining coal reserves. Re-mining operations create jobs in the coal industry, produce coal from previously disturbed areas, and improve aesthetics by backfilling and re-vegetating areas according to current reclamation standards. Re-mining operations also reduce safety and environmental hazards (by sealing existing portals and removing abandoned facilities), enhance land use quality, and decrease pre-existing pollution discharges.

Retention basin: A stormwater facility that includes a permanent pool of water and, therefore, is normally wet even during non-rainfall periods. Inflows from stormwater runoff may be temporarily stored above this permanent pool.

Riparian Buffer Zone: A protection method used along streams to reduce erosion, sedimentation, and the pollution of water from agricultural nonpoint sources.

Roof down-spout system: A structure that collects, controls, and transports precipitation from roofs. This practice may be applied as a part of a resource management system in order to improve water quality, reduce soil erosion, increase infiltration, protect structures, and increase water quantity.

Septic system pump-out: A typical septic system consists of a tank that receives waste from a residence or business, and a drain field or subsurface absorption system consisting of a series of percolation lines for the disposal of the liquid effluent. Solids (sludge) that remain after decomposition by bacteria in the tank must be pumped out periodically.

Sewer line maintenance/sewer flushing: Sewer flushing during dry weather is designed to periodically remove solids that have deposited on the bottom of the sewer and the biological slime that grows on the walls of combined sewers during periods of low-flow. Flushing is especially necessary in sewer systems that have low grades which has resulted in velocities during low-flow periods that fall below those needed for self-cleaning.

Silt Fencing: A temporary sediment barrier consisting of filter fabric buried at the bottom, stretched, and supported by posts, or straw bales staked into the ground, designed to retain sediment from small disturbed areas by reducing the velocity of sheet flows. Because silt fences and straw bales can cause temporary ponding, sufficient storage area and overflow outlets should be provided.

Spillway, emergency: A vegetated emergency spillway is an open channel, usually trapezoidal in cross-section, which is constructed beside an embankment. It consists of an inlet channel, a control section, and an exit channel, and is lined with erosion-resistant vegetation. Its purpose is to convey flows that are greater than the principal spillway's design discharge at a non-erosive velocity to an adequate channel.

Spillway, principal: The primary outlet device for a stormwater impoundment usually consisting of either a riser structure in combination with an outlet conduit (which extends through the embankment) or a weir control section cut through the embankment. The purpose of a principal spillway is to provide a primary outlet for storm flows, usually up to the 10- or 25-year frequency storm event. The principal spillway is designed and sized to regulate the allowable discharge from the impoundment facility.

Stream bank protection and stabilization: Stabilizing shoreline areas that are being eroded by landshaping, constructing bulkheads, riprap revetments, gabion systems, or establishing vegetation.

Street sweeping: The practice of passing over an impervious surface, usually a street or a parking lot, with a vacuum or a rotating brush for the purpose of collecting and disposing of accumulated debris, litter, sand, and sediments. In areas with defined wet and dry seasons, sweeping prior to the wet season is likely to be beneficial; following snowmelt and heavy leaf fall are also opportune times.

Strip cropping: Growing row crops, forages, small grains, or fallow in a systematic arrangement of equal width strips across a field that reduces soil erosion and protects growing crops from damage by wind-borne soil particles.

Terraces: An earth embankment, or a combination ridge and channel, constructed across the field slope. Terraces can be used when there is a need to conserve water, excessive runoff is a problem, and the soils and topography are such that terraces can be constructed and farmed with reasonable effort.

Vegetated filter strip: A densely vegetated strip of land engineered to accept runoff from upstream development as overland sheet flow. It may adopt any naturally vegetated form, from grassy meadow to small forest. The purpose of a vegetated filter strip is to enhance the quality of stormwater runoff through filtration, sediment deposition, infiltration and absorption.

Waste system/storage (*e.g.,* lagoons, litter shed): Waste treatment lagoons biologically treat liquid waste to reduce the nutrient and BOD content. Lagoons must be emptied and their contents disposed of properly.

Water treatment: Physical, chemical and/or biological processes used to treat concentrated discharges. Physical-chemical processes that have been demonstrated to effectively treat discharge include sedimentation, vortex separation, screening (*e.g.,* fine-mesh screening), and sand-peat filters. Chemical additives used to enhance separation of particles from liquid include chemical coagulants such as lime, alum, ferric chloride, and various polyelectrolytes. Biological processes that have been demonstrated to effectively treat discharges include contact stabilization, biodiscs, oxidation ponds, aerated lagoons, and facultative lagoons.

Wetland development/enhancement: The construction of a wetland for the treatment of animal waste runoff or stormwater runoff. Wetlands improve water quality by removing nutrients from animal waste or sediments and nutrients from stormwater runoff.