ANTIETAM CREEK WATERSHED RESTORATION PLAN

Photo by: Jen Goellnetz http://www.flickr.com/photos/goellnitz/4609441907

September 17, 2012

Creation of this watershed plan was a cooperative effort by:

The Washington County Soil Conservation District
The Board of County Commissioners of Washington County
The Antietam Creek Watershed Alliance
The Canaan Valley Institute
and
Maryland Department of the Environment
Science Services Administration
TMDL Implementation Division

Canaan Valley Institute

Table of Contents

LIST OF FIGURES:

LIST OF TABLES:

LIST OF APPENDICIES:

LIST OF ABBREVIATIONS:

ACWA	Antietam Creek Watershed Alliance
Ag	Agriculture
BEHI	Bank Erodibility Hazard Index
BIBI	Benthic Index of Biotic Integrity
BMP	Best Management Practice
BRF	Bay Restoration Fund, State of Maryland Chesapeake Bay
BST	Bacteria Source Tracking
CBOD	Carbonaceous Biological Oxygen Demand
COMAR	Code of Maryland Regulations
CVI	Canaan Valley Institute
CWA	Clean Water Act
DNRF	MD Department of Natural Resources Inland Fisheries
DOC	Dissolved Organic Carbon
DPW	Washington County Division of Public Works
EOF	Edge of Field
EOS	Edge of Stream
FIBI	Fish Index of Biotic Integrity
GIS	Geographic Information System
gpm	gallons per minute
LA	Load Allocations
MACS	Maryland Agricultural Water Quality Cost-Share Program
MAST	Maryland Assessment Scenario Tool
MBSS	Maryland Biological Stream Survey
MDA	Maryland Department of Agriculture
MDE	Maryland Department of the Environment
mg/L	milligrams per liter
MPN	Most Probably Number
MS4	Municipal Separate Storm Sewer System
NBOD	Nitrogenous Biological Oxygen Demand
NPDES	National Pollutant Discharge Elimination System
NPS	Non-Point Source
NRCS	Natural Resources Conservation Service
TMDLs	Total Maximum Daily Loads
TN	Total Nitrogen
TP	Total Phosphorus
tpy	tons per year
TSS	Total Suspended Solids
USEPA	United States Environmental Protection Agency
VADCR	Virginia Department of Conservation and Recreation
VADEQ	Virginia Department of Environmental Quality
WCSCD	Washington County Soil Conservation District
WLA	Waste Load Allocations
WIP	Chesapeake Bay Watershed Implementation Plan
WRP	Watershed Restoration Plan

Acknowledgements

The Antietam Creek Watershed Restoration Plan was developed with cooperation and input from state, local and private agencies that represent the interests of the Antietam Creek Watershed.

Organization	*Representatives*
The Washington County Soil Conservation District	Elmer Weibley, CPESC, District Manager, Mike Stoner, Conservation Technician
Washington County, MD Board of County Commissioners	Joseph Kroboth III, P.E., P.L.S., Director, Division of Public Works Julie Pippel, Director, Division of Environmental Management Alexander Reed, Watershed Engineer
City of Hagerstown	Rodney Tissue, P.E, City Engineer
Antietam Creek Watershed Alliance	Dave Biser
Canaan Valley Institute	Kristen Mielcarek
Maryland Department of the Environment - Water Quality Protection and Restoration Program	Ken Shanks, Gregorio Sandi
Maryland Department of the Environment – Field Evaluation Division	Quentin Forrest

This project was funded in part by the US Environmental Protection Agency (EPA), Region III – Water Quality Assistance Grant CP-973423. Although this project is funded in part by the EPA, it does not necessarily reflect the opinion or position of the EPA.

1. Introduction

In 1996, the Antietam Creek (MD Segment 02140502) was placed on Maryland's 303(d) list for sediment, then fecal coliform (2002), and impacts to biological communities (2002). A Total Maximum Daily Load (TMDL) for sediment was developed and approved for the Antietam watershed in 2008 with a subsequent TMDL for Bacteria developed in 2009.

The headwaters of the Antietam Creek originate in Pennsylvania's Michaux State Forest. The East Branch descends from South Mountain near Waynesboro flowing over a five-foot weir at the Waynesboro Country Club. The West Branch originates near Mont Alto. The branches join just north of the Mason-Dixon Line to form the main stem of the Antietam. Approximately 5% of the total watershed is covered by water (i.e. streams, ponds, lakes, etc.) and drains into the Potomac River in Maryland. (**Figure1**)

Purpose

This plan will incorporate phased mitigation strategies to eliminate sediment and bacterial impairments associated with non-point sources and to monitor the effects of mitigation efforts on biological communities. This document provides a comprehensive Watershed Restoration Plan (WRP) for Antietam Creek with respect to Non-Point Sources (NPS) of sediment and fecal coliform. The watershed receives loads from both urban and agricultural land, but the focus of this plan will be on agricultural and rural areas. The intent of this effort is to establish a comprehensive, holistic approach toward assessment and eventual pollution abatement and mitigation of the existing water quality problems. The WRP will provide a framework for future efforts by the stakeholders of the Antietam Creek watershed for prioritizing and coordinating restoration/planning activities with citizens as well as federal and local agencies.

With the recent approval of the Chesapeake Bay TMDL and the accompanying Watershed Implementation Plan (WIP) being developed by the state of Maryland, this plan intends to follow the timeline laid out by EPA and MDE for meeting 2017 and 2025 allocations for Total Suspended Solids (TSS) within the Antietam. By pairing up the goals of meeting both TMDLs, additional funding may be available to mitigate or address local TMDL requirements as well as Bay TMDL requirements. Approaching restoration and mitigation in this phased manner would eliminate some impediments to funding as well as allow more time to develop access or relationships with the associated stakeholders in order to place effective mitigation projects in impaired segments.

This WRP will serve as a working template/framework to guide future mitigation/planning and monitoring efforts and will assist in setting mitigation priorities. Phased priority identification of sources and solutions will assist stakeholders with planning and performing more efficiently when restoring and identifying NPS outfalls and related impacts providing the means for more efficient use of already limited funding.

This plan is will demonstrate that the strategy employed will restore the Antietam and its tributaries within the state of Maryland to support their designated uses and to remove the watershed from the Maryland 303(d) list of impaired waters for bacteria and sediment.

Plan Objectives

The first objective of this plan is to identify major NPS discharges associated with established TMDLs in the Antietam watershed, obtaining existing analytical/physical data associated with the discharges, and to develop a working Geographic Information System (GIS) database of the data collected. A comprehensive GIS database of known, and newly discovered, sediment and bacterial impairments will be created in this and all sub-watersheds of Antietam

Creek within Maryland.

The second objective is to implement a prioritization schema that would allow private, local and state partners to select a priority list of impaired stream segments for which general mitigation strategies would be developed. Due to the fluctuating availability of resources, this WRP will be implemented in two Phases based on goals which coincide with the recent Chesapeake Bay TMDL:

- Phase I (2012-2017) will include several goals, one being the implementation of sediment management measures in five priority stream segments identified during an initial investigation. Pre and post implementation water quality and biological community sampling will be conducted to evaluate the effectiveness of management measures used. Additional projects not included in this assessment will also be evaluated for implementation and subject to available resources.

  Bacterial reduction strategies will be given priority in subwatersheds ANT0277 (Figure 2) and MRS0000 due to their ranking as the highest contributors of all four bacteria source sectors (Human, Domestic, Agriculture and Wildlife) within the Maryland portion of the Antietam Creek watershed. Additional opportunities in other subwatersheds will be addressed as opportunities arise in this phase.

  Subwatershed BEC0001 (Figure 2) will be the focus of anti-degradation and enhancement of an important trout fishery.

  Sediment reduction strategies will be given priority in, ANT0277, MRS0000 and BEC0001 to match resource allocation and focus for bacteria reduction efforts due to the overlapping nature of many conservation planning and implementation efforts that reduce both bacteria and sediments.

  An outreach campaign will be conducted to contact private stakeholders in order to secure access to properties and participation for implementation of phase I and phase II practices. It is anticipated that phase I will require approximately five years to complete.

  - Phase II (2017-2025) will be a continuation of Phase I where known impairments will continue to be mitigated for sediment, and any additional impairments identified during Phase I will be prioritized according to severity, access and resources available.

    Bacterial reduction strategies will continue in the priority watersheds, with additional focus on the remaining sub-watersheds to meet both local and Bay focused TMDLs.

Limitations of the WRP

This plan is based on data generated as a result of a number of previous studies within the watershed. In addition, this assessment will focus on the non-point sources of fecal coliform and sediment within the streams of the watershed including both urban and agricultural areas. Additional impairments and TMDLs may be introduced during the operating phases of this plan, when a new TMDL affecting the Antietam Creek watershed is approved, the plan will be updated/revised.

Although portions of the Antietam flow through Pennsylvania, this document addresses only the portion that flows through Maryland. (**Figure 1**) WRP partners are aware that a dialogue with Pennsylvania Department of Environmental Protection, the Franklin County Conservation District and Adams County Conservation District is needed to address sediment and bacteria loads coming from Pennsylvania's portion of the watershed. This will be part of the contingency plan since WRP partners have no authority to address these loads across state borders.

After developing and implementing, to the maximum extent possible, a reduction goal based on the anthropogenic sources identified in the TMDL, Maryland anticipates that implementation to reduce the controllable non-point sources may also reduce some wildlife inputs to the waters. (**Table 1**)

The bacteria source analysis indicates that after controls are in place for all anthropogenic sources, the waterbody will not meet water quality standards. However, while neither Maryland nor EPA is proposing the elimination of wildlife to allow for the attainment of water quality standards, managing the overpopulation of wildlife remains an option for state and local stakeholders and a wildlife management plan will be part of the goals of Phase I.

Table 1 – Maximum Practicable Reduction Scenario (2009 Bacteria TMDL)

	Applied Reductions					
Subwatershed	Domestic %	Human %	Livestock %	Wildlife %	% Total Reduction	% Target Reduction
ANT0366[1]	75	95	75	0	61.1	94.9
ANT0277sub[1]	75	95	75	0	64.3	94
MRS0000[1]	75	95	75	0	56.8	94.2
ANT0223sub	75	95	75	0	57.7	93.6
ANT0132sub	75	95	75	0	54.9	91.1
BEC0001	75	95	75	0	53	90.6
LAS0004	75	95	75	0	58.2	92.3
ANT0044sub	75	95	75	0	60	90
ANT0002sub	75	95	75	0	58.4	90.1

[1]Subwatersheds partially located in Pennsylvania

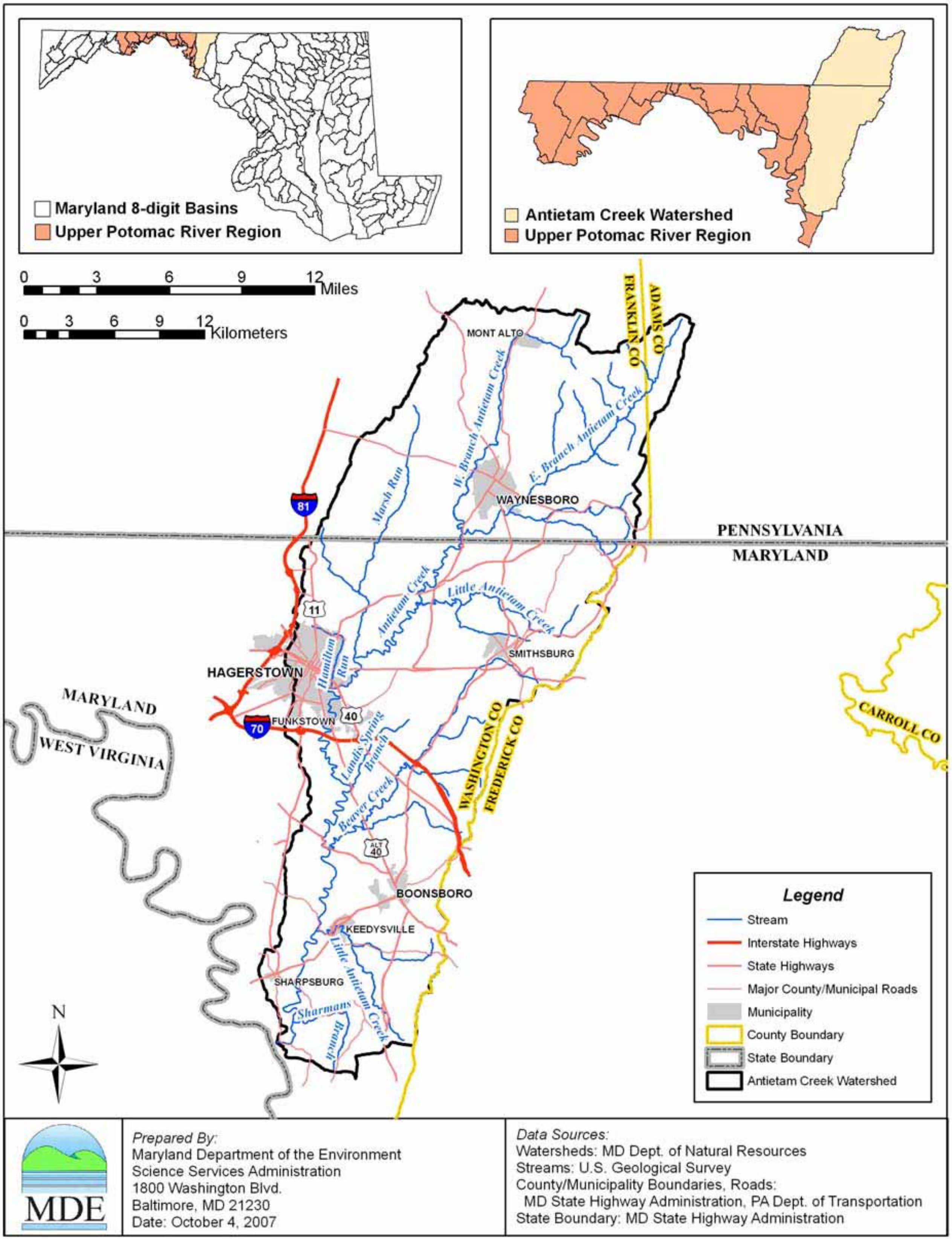


Figure 1 - Antietam Creek Watershed location

2. Watershed Characterization

The Antietam Creek is located in the Ridge and Valley Province physiographic region of Western Maryland. It is approximately 54 miles in length; 42 miles reside in Washington County, Maryland with the remainder in Franklin and Adams County, Pennsylvania. The total watershed area covers 290 square miles, with approximately 185 square miles in Maryland and 105 square miles in Pennsylvania.

The main metropolitan area, Hagerstown, is centrally located along the western edge of the watershed. Antietam Creek and its tributaries flow through several small towns including Mont Alto and Waynesboro in Pennsylvania and Smithsburg, Boonsboro and Sharpsburg in Maryland. The headwaters of Antietam Creek originate south of Waynesboro, PA with the confluence of East and West Branch Antietam Creek. It continues flowing southwest past Hagerstown, MD then through Antietam National Battlefield in Sharpsburg, and empties into the Potomac River near the town of Antietam**. (Bacteria TMDL)**

There are approximately 118,400 acres of the watershed located in Washington County Maryland. **(Figure 1)** For the purposes of this plan, the Antietam Creek watershed has been divided into nine subwatersheds to mirror those subwatersheds established in the TMDL for Fecal Coliform. Subwatersheds were referenced by their corresponding bacteria monitoring station's name and location. The nine subwatersheds (**Figure 2**) are ANT0366 (Antietam Creek in Rocky Forge), ANT0277 (Antietam Creek at Marsh Run), MRS0000 (Marsh Run), ANT0223 (Antietam Creek in Funkstown), ANT0132 (Antietam Creek in Devil's Backbone Park), BEC0001 (Beaver Creek), LAS0004 (Little Antietam Creek in Keedysville), ANT0044 (Antietam Creek at Burnside Bridge) and ANT0002 (Antietam Creek in Antietam).

The majority of the watershed is located in the Great Valley (Hagerstown Valley) The Great Valley is a wide, flat, and open valley formed on Cambrian and Ordovician limestone dolomite, and alluvial fan deposits alongside the bordering mountains. The Hagerstown Valley presents unique challenges to addressing water quality issues with its numerous limestone outcroppings and sinkholes as well as the karst geology which makes pollutant sequestration and treatment within the subsurface a challenge. **Table 2** contains a list of pollutants with approved TMDLs in the Antietam Creek watershed.

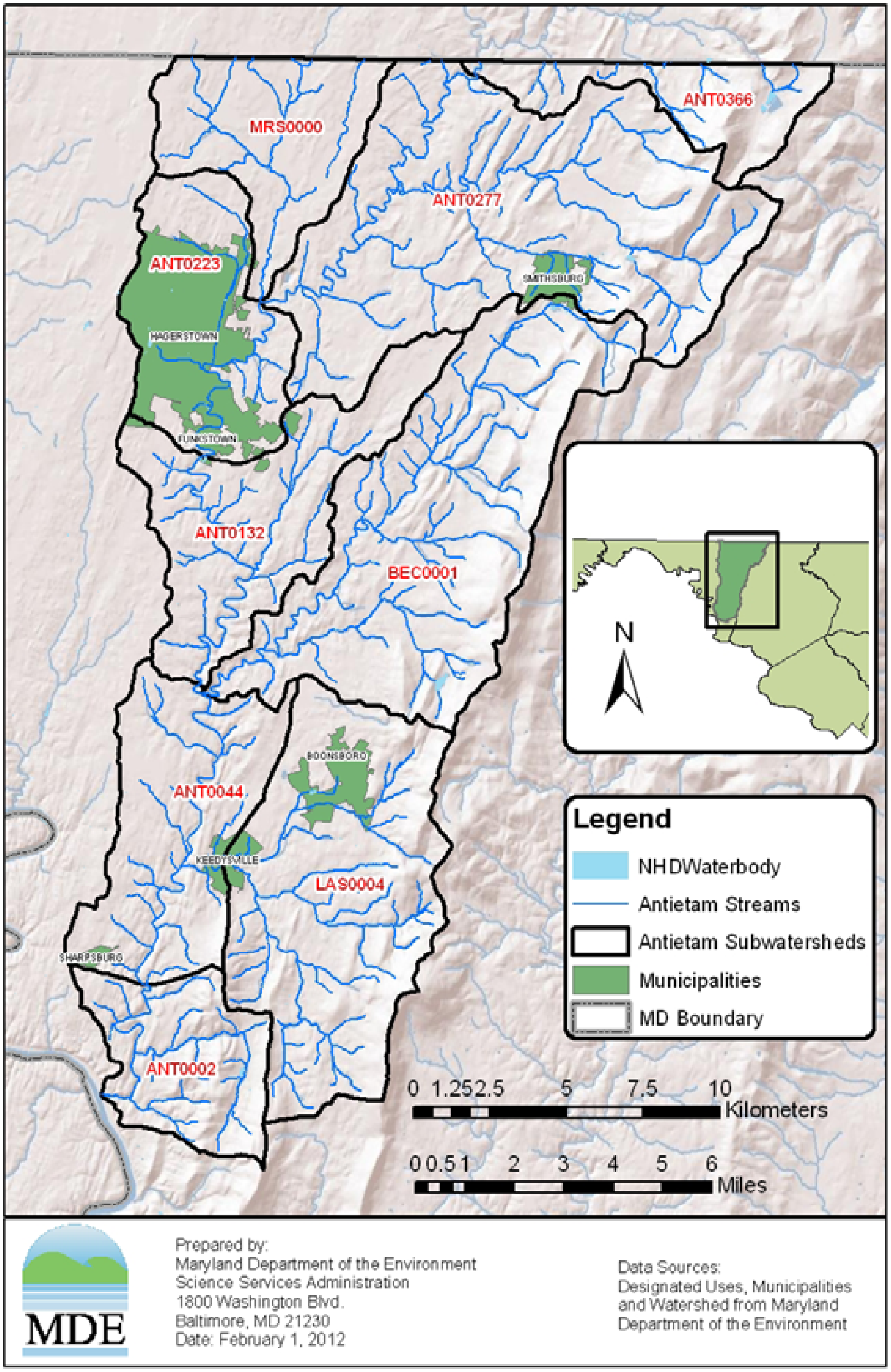


Figure 2 - Antietam Creek Sub-watersheds

Table 2 – Pollutants identified in TMDL

Pollutant or Concern	Data Source	Potential Sources of Contamination	Watershed Effects
Sediments (TSS - total suspended solids)	2009 Sediment TMDL	· Urban runoff - Agricultural runoff - In-stream erosion/ channelization - Atmospheric Deposition	- Loss of habitat for Aquatic Species - Contribution to Chesapeake Bay pollution
Bacteria	2009 Bacteria TMDL	· Urban runoff - Agricultural runoff - Failing Septic Systems - Pet waste - Wildlife	- Swimming and water contact related illnesses - Fish Consumption
Biological Impairment (addressed primarily through sediment TMDL)	MD 303d list	- Impervious surface - Hydrologic alteration - Lack of adequate stream buffers - Sedimentation	· Thermal impacts - Loss of sensitive species - Loss of trout fishery

2.1 Land Use

The total population in the MD 8-digit Antietam Creek watershed is estimated to be approximately 82,000. The TMDL documentation includes acreage of various land uses in the watershed. Approximately 31% of the watershed is forest, 42% is agriculture consisting of cropland, pasture, animal feeding operations, hay, high till and low till farming, and nurseries. Urban areas account for 27% with the majority of the urban areas being "urban pervious," which is urban or suburban areas that are not covered with rooftops, roads, or other surfaces that make the land impervious to water. (**Figure 3**)

The primary animal based agricultural enterprise is dairy with 86 active dairies currently in operation **(Figure 17)**. Urban land use is centered in the municipalities of Hagerstown, Smithsburg, Sharpsburg, Keedysville, Boonsboro, Leitersburg, and Cascade. Numerous smaller towns and villages as well as rural housing developments round out the urban landscape.

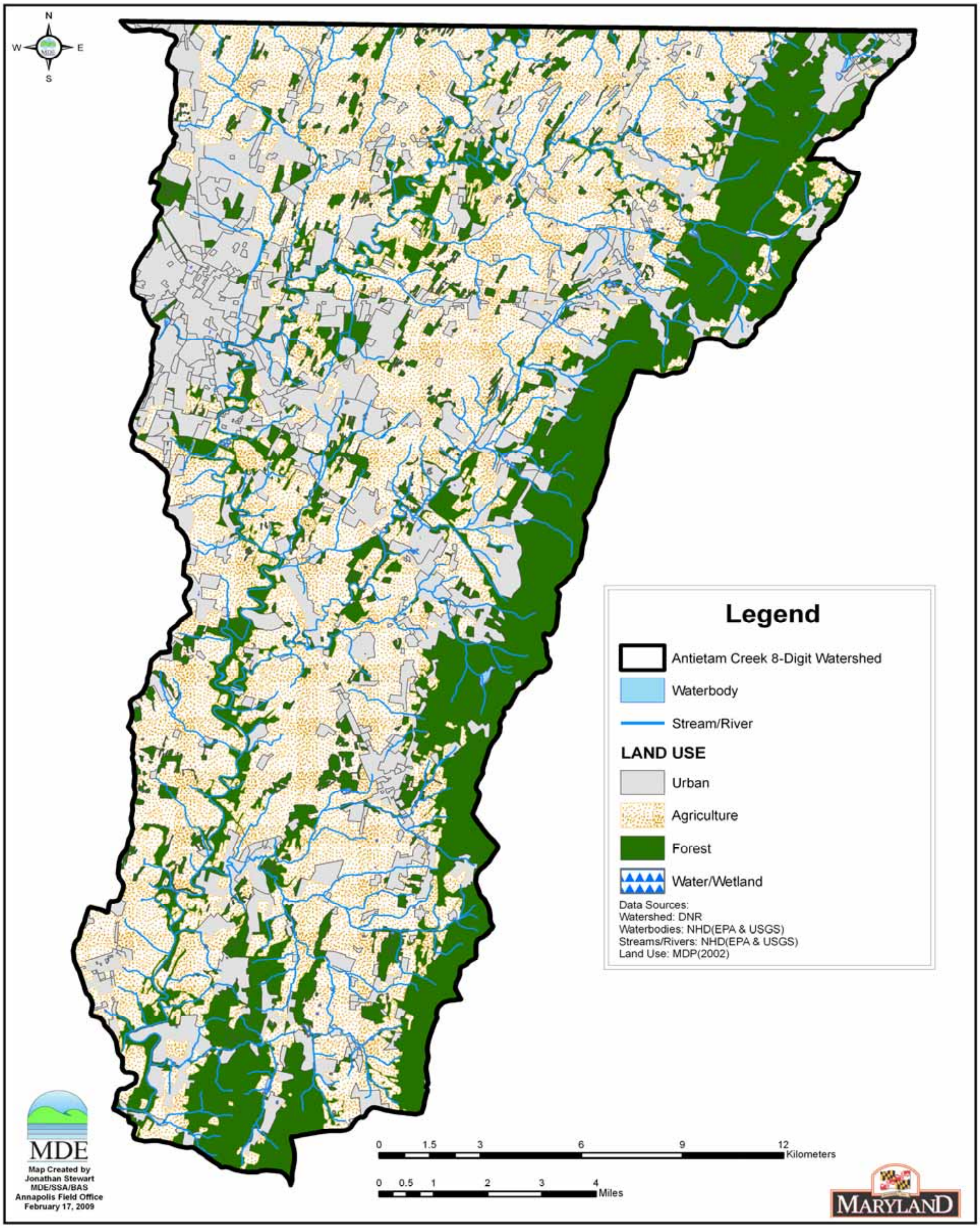


Figure 3- Land Use Map of Antietam

2.2 Geology

Characterization

The Antietam Creek Watershed lies in the Great Valley sub-province of the Valley and Ridge physiographic province and is locally known as the Hagerstown Valley of Washington County, Maryland (Duigon, 1997). The terrain of the Hagerstown Valley has developed on thick folded beds of sedimentary rocks which were deposited during the Paleozoic Era. These different types of rocks caused valleys to form when more resistant sandstone bordered carbonate formations. The more resistant sandstone (caprocks) protect the underlying softer (less resistant) bedrock from weathering and erosion while the carbonate bedrocks of the valley, which are more susceptible to weathering than the surrounding sandstone ridges, were more easily eroded, leaving valleys. Like other regions that are dominated by carbonate bedrock, the Antietam Creek Watershed exhibits karst topography which is commonly characterized by underground streams, sinkholes, caves, and caverns that are formed by the dissolution of carbonate rocks by surface and groundwater (NPS Geologic Resource Evaluation Report, 2005). The Hagerstown Valley is underlain by about 89% carbonate rocks (limestones and dolomites) that have more than 50 caves, 190 springs, many sinkholes, and about 200 wells intersecting cavernous zones that demonstrate the development of solution cavities in the bedrock of the valley (Duigon, 2001; Duigon, 2002; nps.gov, 2005).

Problems associated with Karst Terrain

Because of the unique inter-relationship between surface and subsurface hydrology on the karst landscape of the Antietam Creek Watershed, there are special challenges associated with water quality that are posed by karst features. Much of the groundwater in the area comes from streams that flow from the surrounding mountains into sinkholes in the valley. Sinkholes on a karst terrain allow water and the contaminants it carries to be directly injected to the groundwater. These contaminants can range from farm runoff containing animal waste, effluent from septic systems containing bacteria and nutrients, and petroleum based contaminants that runoff from a parking lot or industrial sites. Sinkholes are found throughout the watershed, but are mainly found in the Rockdale Run Formation, Stonehenge Limestone, Elbrook limestone, and the Conococheague Formation (NPS Geologic Resource Evaluation Report, 2005).

There are several sinking and losing streams within the watershed. In fact, the National Park Service reports that many of the local streams lose most of their flow within a mile of reaching the carbonate rocks of the valley (NPS Geologic Resource Evaluation Report, 2005). These are also places where possibly contaminated surface runoff has direct access to the aquifer. A sinking stream is where a stream disappears underground completely into a sinkhole. A losing stream leaks flow slowly through its bed into the aquifer, causing the stream to dry up at times of low flow (Field, M.F., 2006). The portion of Beaver Creek above the State Trout Hatchery would be an example of a losing stream.

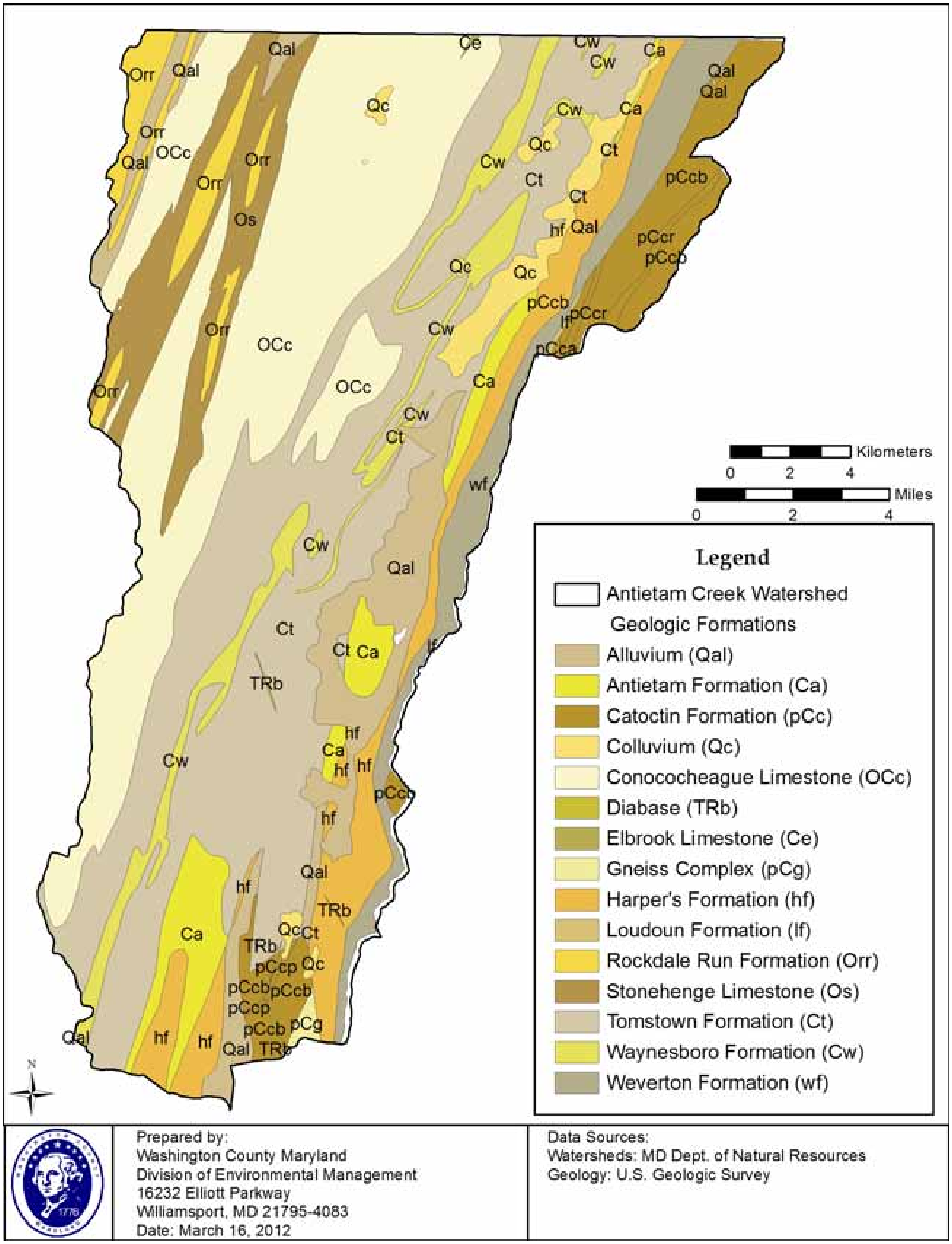


Figure 4 - Distribution of Antietam Creek Geologic Formations

Soils

The soils in the watershed are primarily in the Hagerstown-Duffield-Ryder Association and are derived from the underlying limestone, impure limestone and calcareous shale limestone respectively. They range from moderately deep to very deep; all are considered well drained with moderate permeability.

These soils are some of the most productive in Washington County. However, limestone outcrops impede some agricultural operations, and sinkholes pose a great threat to water quality. Agricultural conservation operations such as injection of animal manures and contour strip cropping to improve agricultural production and water quality are not practical on most farms in this watershed.

The soils of South Mountain are in the Thurmont-Braddock-Trego Association, on the footslopes, and in the Bagtown-Dekalb-Weverton Association on the steeper side slopes and ridge tops. They are all derived from quartzite and phyllite. The Thurmont-Braddock-Trego Association soils are well drained to moderately well drained. They all are very deep and range from moderate to slow permeability. They are well suited to crop production on their gently sloping areas. The Bagtown-Dekalb-Weverton Association soils are also well drained to moderately well drained. They range from very deep to moderately deep with permeabilities ranging from slow to rapid. This association is well suited to tree production and unsuitable for most agricultural and urban uses because of the steep slopes and surface stones (USDA 2003) (**Figure 3**). Underlying the soils in Antietam Creek is a Karst geology shaped by the dissolution of a layer or layers of soluble bedrock, which is limestone.

Hydrologic Soils (Figure 5)

<u>Group A Soils</u>
Group A soil has low runoff potential and a high infiltration rate even when wet. The group consists of soil that is deep and well-to-excessively draining. The soil ranges from sandy loam to high gravel content. The water transmission rate is greater than 0.30 inch per hour.

<u>Group B Soils</u>
Group B hydrologic soil classification indicates silt loam or loam soil. It has moderately fine-to-moderately course texture created by its mineral particle content relative to its organic matter content. It has small amounts of sand and clay in silt-size particles. Group B soils have moderate water infiltration rates 0.15 to 0.30 inch per hour. They are moderately well-to-well-draining soils.

<u>Group C Soils</u>
Group C soils have slow infiltration rates even when thoroughly wetted. They have a layer that impedes the movement of water downward. Group C hydrologic soils are moderately fine-to-fine in texture. It forms a more cohesive ball than Group B soils when squeezed in the hand. The rate of water filtration is 0.05 to 0.15 inch per hour.

<u>Group D Soils</u>
Hydrologic soil classification Group D consists of soils with high clay content and very low rate of water transmission. Clay is the finest textured soil of all classifications. It forms hard clods or clumps when dry or squeezed in the hand. It is sticky and plastic when wet. Group D soils have a permanently high water table and high swelling potential. Its rate of water filtration and transmission is 0 to 0.05 inch per hour.

The distribution of hydrologic soil types includes approximately:

- Hydrologic Group A 1,485 acres-1.2%
- Hydrologic Group B 71,600 acres-60.4%
- Hydrologic Group C 39,497 acres-33.3%
- Hydrologic Group D 2,011 acres-1.7%
- Hydrologic Group C/D 13 acres->1%

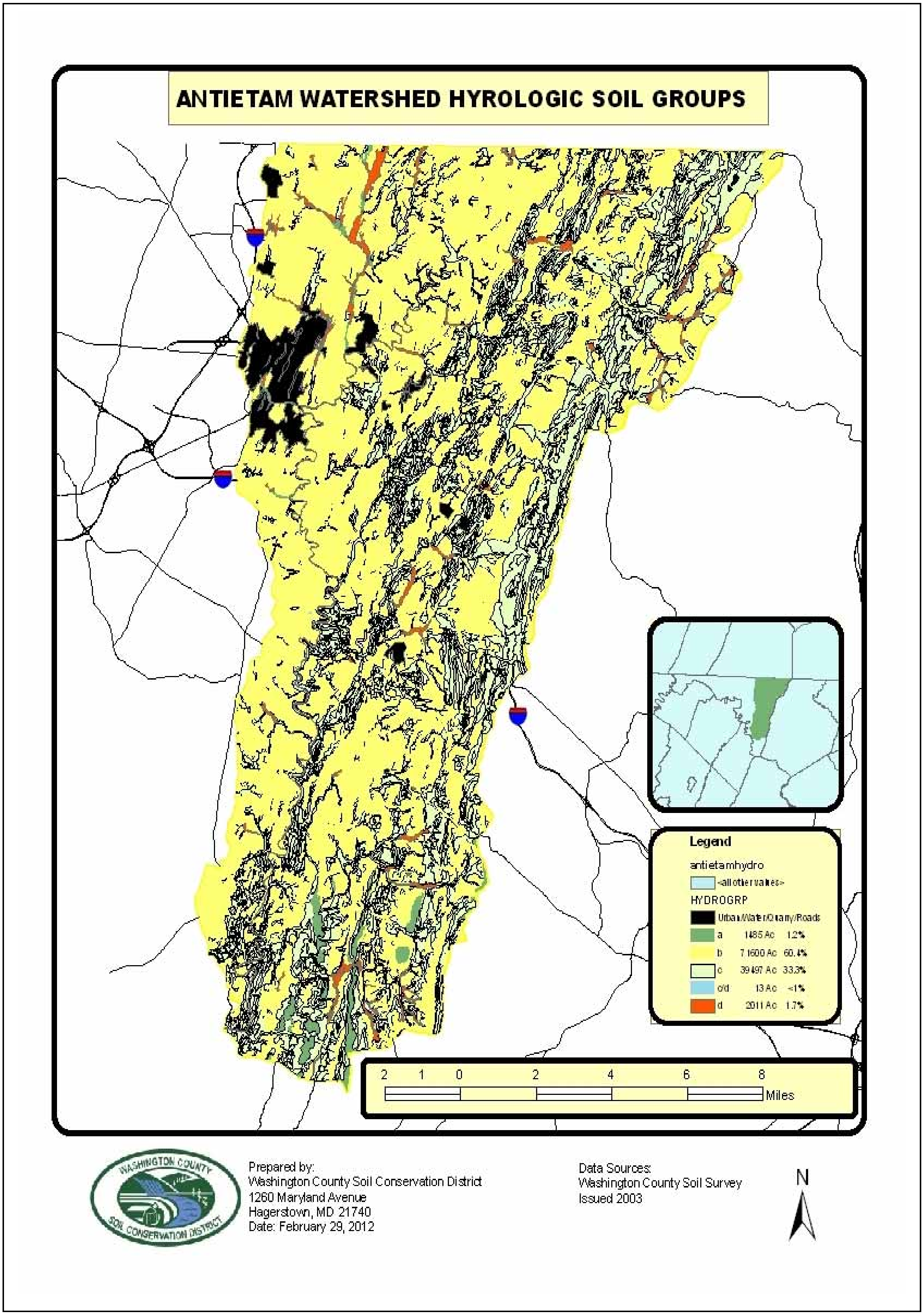


Figure 5 - Distribution of Antietam Creek Hydrologic soils

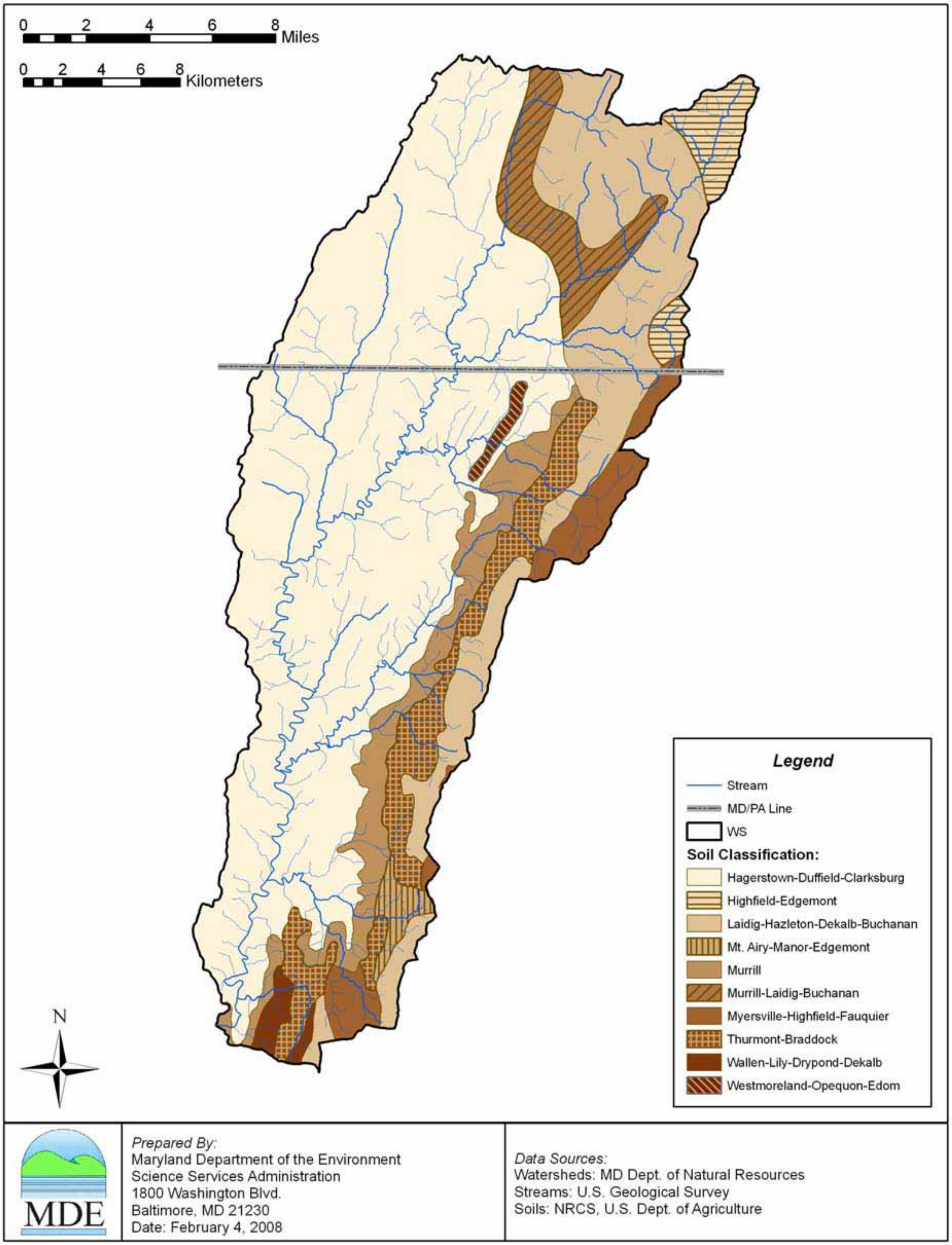


Figure 6 - Distribution of Antietam Creek soils

2.3 Historical and Recreational Significance

Early history in the Antietam watershed begins with its first known inhabitants, the native Algonquin Indians. While almost no trace of their habitation remains today, they are credited with giving us the word "Antietam," believed to be derived from a word or phrase for "swift water."

In 1910, about 150 years after European settlement, Helen Ashe Hays described the Antietam as "placid."

> "There is a stream running through Washington County, Maryland, from the Pennsylvania line to the Potomac River, whose name will be famous as long as America endures, the placid Antietam."

Milling Industry

The Antietam's waters were harnessed by many dams to power a variety of milling industries including many grist mills, many sawmills, forges, furnaces, a paper mill, a powder mill, a woolen factory, and hemp mills

- There were 19 mill dams on the main stem of the Antietam in 1818 (on average, a dam every 2-3 miles) when the Potomac Company attempted to make it navigable (ref: Dan Guzy and Harbaugh)
- There were 45 historical water-powered mills identified in the Antietam watershed in Maryland in research conducted in 1988, however (ref: by Susan Frey Winter) almost all of the dams were gone by 1988.

The Antietam and its tributaries were literally reshaped by the construction of the many mills, millraces, dams, weirs, locks, and other structures. Today some of the "swift water" has returned to the Antietam as only two of the historical mill dams remain and two modern dams still stand. To the casual observer there is little other evidence of the water-powered milling era save the place names and some of the historical structures around the mills themselves. Yet if one travels the Antietam in a small boat, they will see the tell-tale signs of human efforts along virtually every mile.

Iron Industry

The developing iron industry in the Antietam watershed, beginning about 1750, had a tremendous appetite for charcoal. The Mont Alto iron furnace in the Antietam's headwaters owned 22,000 acres of land and timber was cut at the rate of approximately one acre per day to produce charcoal. There were other iron furnaces in the Antietam watershed – principally Antietam Iron Works and Mt Aetna Furnace – that also required a steady supply of charcoal.

Although most of the dams are gone and much of the forest has returned, the legacy of those earlier days seems to be with us still. The following description of the Antietam was written over 100 years ago and yet it is surprisingly similar to what is observed today:

> "Its waters are not sparkling; they often carry a large amount of muddy matter which gives the stream a thick and turgid appearance, and after heavy rains it will carry this earthy charge for days. But it is peacefully beautiful, and flows through one of the richest farming lands in America." (Helen Ashe Hays in 1910).

Boating

Jacob Stoner wrote a newspaper column in the 1930-40s about the history and nature he observed in his wanderings along the Antietam's branches and tributaries. He lamented the lack of public access that would allow more people to explore the Creek and enjoy nature there. He also suggested local boys construct flat-bottomed skiffs to play in the Antietam as a worthwhile activity even though there were only short stretches of free-flowing water due to the many mill dams.

Today, most of the mill dams are gone and canoes and kayaks are seen traveling the length of the Antietam to the Potomac. However public access to the Creek is still very limited. To address that, several partners –Washington County Parks & Recreation, the Maryland Department of Natural Resources, and Antietam Creek Watershed Alliance - are working to develop the concept of a "water trail" that would identify new and existing public access areas and propose new ones. A water trail map is also planned that would serve as a guide to recreation on the Antietam.

The lower 14 miles of the Antietam are more accessible with three existing public areas to launch a boat and there is a take-out on the Potomac River provided by the National Park Service on C & O Canal property. There are three private companies offering canoe, kayak, and tube trips along with rentals, lessons and shuttle service; Antietam Creek Canoe is located adjacent to Devils Backbone County Park, Outdoor Excursions operates near Keedysville, and River & Trail Outfitters is based in Knoxville, MD. These outfitters bring bus-loads of adventurers from the Baltimore – Washington, DC, area and surrounding States to enjoy the cool shade and to "float through history" especially around Burnside Bridge in Antietam National Battlefield.

Fishing

For those who like to fish, the Maryland Department of Natural Resources Fisheries Service manages most of Antietam Creek as a put-and-grow fishery. This means that although stocked trout may survive and even grow to trophy size, there is insufficient suitable habitat to enable them to naturally reproduce. Approximately one mile of Antietam Creek, from Devil's Backbone County Park downstream to the mouth of Beaver Creek, is managed as a put-and-take trout-fishing area and receives more than 5,000 adult rainbow trout annually.

Several tributaries of the Antietam do have the needed water quality to support populations of naturally reproducing trout. Most notably is Beaver Creek, Maryland's only major limestone-influenced trout stream, where a 1½-mile stretch south of the Albert Powell Fish Hatchery has been designated for catch-and-release fly-fishing.

Protected Lands

Mont Alto State Park and the surrounding Michaux State Forest help to protect the headwaters of the East and West Branches of the Antietam in Franklin County Pennsylvania. These lands were once owned by several large iron companies who cut the old growth forests to make charcoal to fire their iron furnaces. Remnants of the charcoal days can still be seen in the state forest as the land where the kilns burned for so many years has yet to fully recover. http://en.wikipedia.org/wiki/Michaux_State_Forest

Devils Backbone County Park is significant because it is the only park on the Antietam in Maryland and one of the few public access areas. Throngs of people seek out the cool shade of Devils Backbone Park to picnic, launch canoes and kayaks, and to fish the pool above the dam and also downstream about for one mile to the mouth of Beaver Creek. http://www.marylandmemories.org/maps/Washington_County_Map_2006.pdf

Antietam National Battlefield was the site of the Bloodiest One Day Battle in American History after twelve hours of savage combat on September 17, 1862. The Battle of Antietam ended the Confederate Army of Northern Virginia's first invasion into the North and led to Abraham Lincoln's issuance of the preliminary Emancipation Proclamation. http://www.nps.gov/ancm/index.htm

In addition to the historic significance, the Battlefield site and the surrounding Park Service lands have protected a 3 ½ -mile section along the Antietam from development. The Park Service has also planted many trees to restore the Battlefield to the way it looked in September 1862 as well as trees along the stream. Today the Battlefield stretch of the Antietam is a favorite of fishermen who float in to fish or walk in along the Snavelys Ford Trail to bank-fish. South Mountain State Park includes 13,000-acres of forest and provides significant headwater protection for the many Antietam tributaries that originate on the western flank of South Mountain. South Mountain is a state park that encompasses nearly the entire length of South Mountain through Maryland and is contiguous with several other national, state and local parks on the mountain, including the Chesapeake and Ohio Canal National Historical Park, Gathland State Park, Washington Monument State Park, Greenbrier State Park and Pen Mar County Park (Washington County). Forty-one miles of the Maryland section of the Appalachian Trail traverses the length of the park. The park also contains part of the South Mountain Battlefield.
http://en.wikipedia.org/wiki/South_Mountain_State_Park

3. Water Quality

3.1 Water Quality Standards

Maryland's water quality standards require by law that water quality in the Antietam Creek support its designated uses. The Code of Maryland Regulations (COMAR) has two primary criteria to meet water quality standards within the state. These numeric and qualitative goals are illustrated in the form of stream designated uses **(Figure 8)** and narrative or numeric water quality criteria necessary to support those uses. Furthermore, water quality standards serve the purpose of protecting public health, enhancing the quality of water, and protecting aquatic resources.

Turbidity (COMAR 26.08.02.03-3)

A. Criteria for Use I Waters (Criteria for use IV-P is the same as Use I)—Water Contact Recreation and Protection of Nontidal Warmwater Aquatic Life.
(5) Turbidity.
(a) Turbidity may not exceed levels detrimental to aquatic life.
(b) Turbidity in the surface water resulting from any discharge may not exceed 150 units at any time or 50 units as a monthly average. Units shall be measured in Nephelometer Turbidity Units.

Fecal Coliform

The State water quality standard for bacteria (*E. coli*) is as follows:

Table 3 - Applicable Water Quality Standards for Bacteria

Indicator	Steady State Geometric Mean Indicatory Density
Freshwater	
Enterococci	33 MPN/100 ml
E. Coli	126 MPN/100 ml

*Source COMAR(26.08.02.03-3) Table 1 (Criteria for Use IV-P is the same as Use I)

3.2 TMDL Summaries

Antietam Creek's identified water quality problems are: elevated fecal bacteria indicator, elevated sediment load and turbidity. Potential ground water quality problems identified in the area are: elevated fecal bacteria indicator and elevated nutrient load. The sources of these problems are both point and nonpoint in origin and both related to rural and urban land uses. Portions of the Antietam Creek watershed have been designated as both a Priority I and Priority III waters under the Clean Water Action Plan.   (References: 208 water quality Management Plan for the Upper Potomac River Basin, September, 1976,; Maryland's 319 Nonpoint Source Assessment Report, April, 1989, Final 1998 Report on Unified Watershed Assessment, Prioritization and Plans for Restoration Action Strategies)

Total Maximum Daily Loads (TMDL's) have been approved for Carbonaceous Biochemical Oxygen Demand (CBOD) and Nitrogenous Biochemical Oxygen Demand (NBOD), August 2002, Sediment, December 2008 and Fecal Bacteria, September 2009. A Water Quality Analysis (WQA) for CBOD and NBOD indicate that Antietam Creek currently meets water quality standards for those parameters and those goals will not be included in this plan. Therefore the focus will be on sediment and fecal bacteria as measured by *E. coli*.

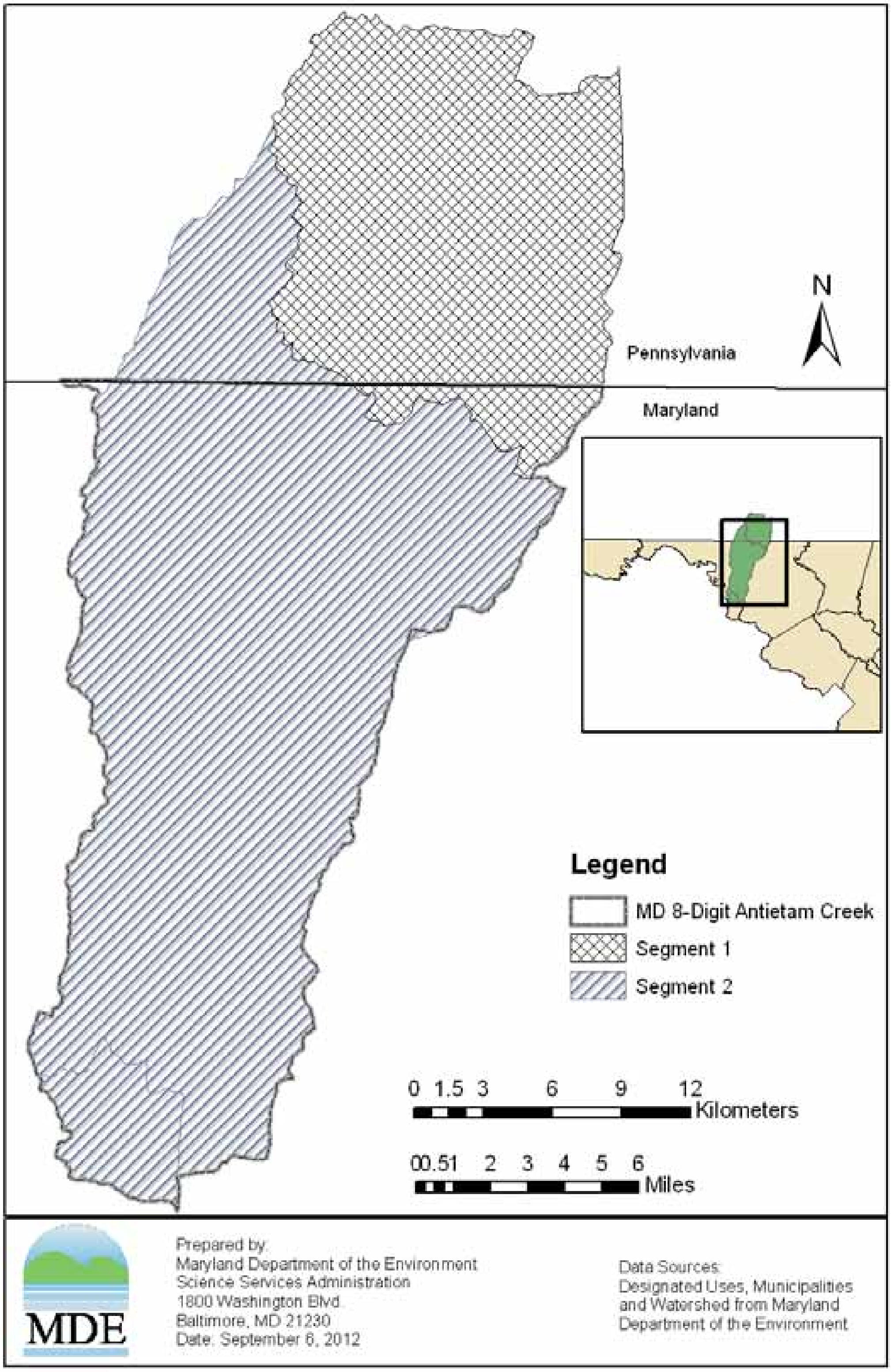


Figure 7- Sediment TMDL Segmentation

3.2.1 Sediment

The TMDL for sediment developed by the state of Maryland was for the portion of the Antietam watershed labeled as "Segment 2" (**Figure 8**) in the TMDL. This includes portions of PA and MD, however the Antietam WRP is dedicated to achieving sediment reductions in the Maryland portion of the Segement 2 watershed.

Loads and Turbidity

The computational framework chosen for the MD 8-digit Antietam Creek watershed TMDL was the Chesapeake Bay Program Phase 5 (CBP P5) watershed model target *edge-of-field* (EOF) land use sediment loading rate calculations combined with a *sediment delivery ratio*. The *edge-of stream*(EOS) sediment load is calculated per land use as a product of the land use area, land use target loading rate, and loss from the EOF to the main channel. The spatial domain of the CBP P5 watershed model segmentation aggregates to the Maryland 8-digit watersheds, which is consistent with the impairment listing. (MDE 2008)

Table 4 - Current estimated Baseline Loads and TMDLs for sediment for each load source category in the Maryland portion of Antietam Creek Watershed. (MDE 2008)

Load Source Categories	Baseline Load (ton/year)	TMDL (ton/year)	Load Reduction Needed (ton/year)	Percent reduction necessary
Crop	18,610.80	8,035.80	10,575.00	56.8
Extractive	172.4	172.4	0	0
Forest	1,629.60	1,629.60	0.00	0
Pasture	3,972.90	2,081.60	1,891.30	47.6
Urban	8,490.40	3,556.80	4,933.60	58.1
Permits	703.2	703.2	0	0
MD Totals	33,579.20	16,179.40	17,399.90	51.8

Load reduction achieved from the period of TMDL acceptance (2008) and development of the plan (2012) was calculated to create a new baseline from which to develop the Antietam Creek WRP. The analysis to create the new baseline is reflected in **Table 16**, located in section 5.1 of the plan. It was calculated that Best Management Practices (BMPs) implemented from 2008-2011 resulted in a reduction of 4,477.04 tons/yr of sediment making the goal of this plan a sediment load reduction of 12,923 tons/yr.

Biological Response to Sediment Loading (Sediment TMDL 2009)

EPA's regulations require TMDLs to take into account seasonality and critical conditions for stream flow, loading, and water quality parameters (CFR 2007b). The intent of this requirement is to ensure that the water quality of the waterbody is protected during times when it is most vulnerable. The biological monitoring data used to determine the reference watersheds integrates the stress effects over the course of time and thus inherently addresses critical conditions. Seasonality is captured in two components. First, it is implicitly included in biological sampling. Second, the Maryland Biological Stream Survey (MBSS) dataset included benthic sampling in the spring and fish sampling in the summer. (MDE 2008)

The MBSS program monitored 14 locations in the MD 8-digit Antietam Creek watershed in 2003 (**see Figure 8 and Table 5**). The MBSS parameters recommended from the stressor identification model for determining a sediment stressor were: percent embeddedness, epifaunal substrate score, instream habitat score, bank stability, and number of benthic tolerant species. These specific parameters were chosen based on their ecological and statistical significance (Southerland et. al. 2007) as well as their linkage to increased terrestrial and/or instream erosion. High percent embeddedness indicates that fine particulates are filling the spaces between cobbles, thus covering habitat and limiting food supply. Low epifaunal substrate is an indication of either stream erosion or excess deposition limiting the quality of the streambed to support a benthic community. Decreased instream habitat is an indication of potential erosion removing woody debris and is primarily linked with the Fish Index of Biotic Integrity (FIBI). The bank stability index is a composite score that indicates the lack of channel erosion, based on the presence or absence of riparian vegetation and other stabilizing bank materials. The number of benthic tolerant species is an indicator of frequent stream scouring, which prevents more sensitive species from colonizing the streambed.

Biological results from both the DNR Core/Trend and MBSS stations along the mainstem of the MD 8-digit Antietam Creek indicate that mainstem water quality can be classified as good. Statistical analysis of the long-term Core/Trend data indicates that since 1976, all stations have shown improvement and are ranked as having good water quality based on percent EPT, taxa number, biotic index, and diversity index (DNR 2007a). In addition, the MBSS mainstem station (ANTI-414-R-2003) has been assigned a BIBI score indicative of acceptable water quality.

Since all biological monitoring results on the Antietam Creek mainstem indicate good conditions, it is concluded that sediment loads from Pennsylvania and the Northeast portion of Maryland, located upstream of station ANT0336, are not impacting water quality in the MD 8-digit Antietam Creek mainstem. Furthermore, the MBSS station ANTI-107-R-2003, located upstream of station ANT0336, does not indicate a sediment impact to biological conditions. Thus, MDE had concluded that the sediment impairment is within the lower order (smaller) streams in the Maryland portion of the watershed, extending up to station ANT0336, and is subsequently dividing the watershed into two TMDL segments for sediment with only TMDL segment 2 exhibiting sediment impairments.

Table 5 - TMDL IBI and SSDI Scores (MDE 2008)

Site	Benthic IBI	Benthic SSDI	Fish IBI	Fish SSDI
ANTI-105-R-2003	2.75	3.00	3.33	3.00
ANTI-106-R-2003	2.50	1.00	2.67	1.67
ANTI-107-R-2003	1.50	3.50	2.00	4.33
ANTI-111-R-2003	1.50	1.50	2.00	1.67
ANTI-113-R-2003	3.50	4.00	4.00	3.00
ANTI-116-R-2003	2.25	3.00	3.33	3.00
ANTI-120-R-2003	2.00	4.00	1.00	2.33
ANTI-201-R-2003	2.00	3.00	3.67	3.00
ANTI-208-R-2003	4.00	2.50	3.67	1.67
ANTI-215-R-2003	3.25	4.00	2.00	3.67
ANTI-226-R-2003	2.50	2.00	2.67	3.00
ANTI-304-R-2003	1.75	1.00	NS	N/A
ANTI-310-R-2003	3.00	2.50	4.00	2.33
ANTI-414-R-2003	3.00	1.00	NS	N/A
Average	**2.54 ± 0.33**	**2.57 ± 0.49**	**2.86 ± 0.45**	**2.72 ± 0.39**

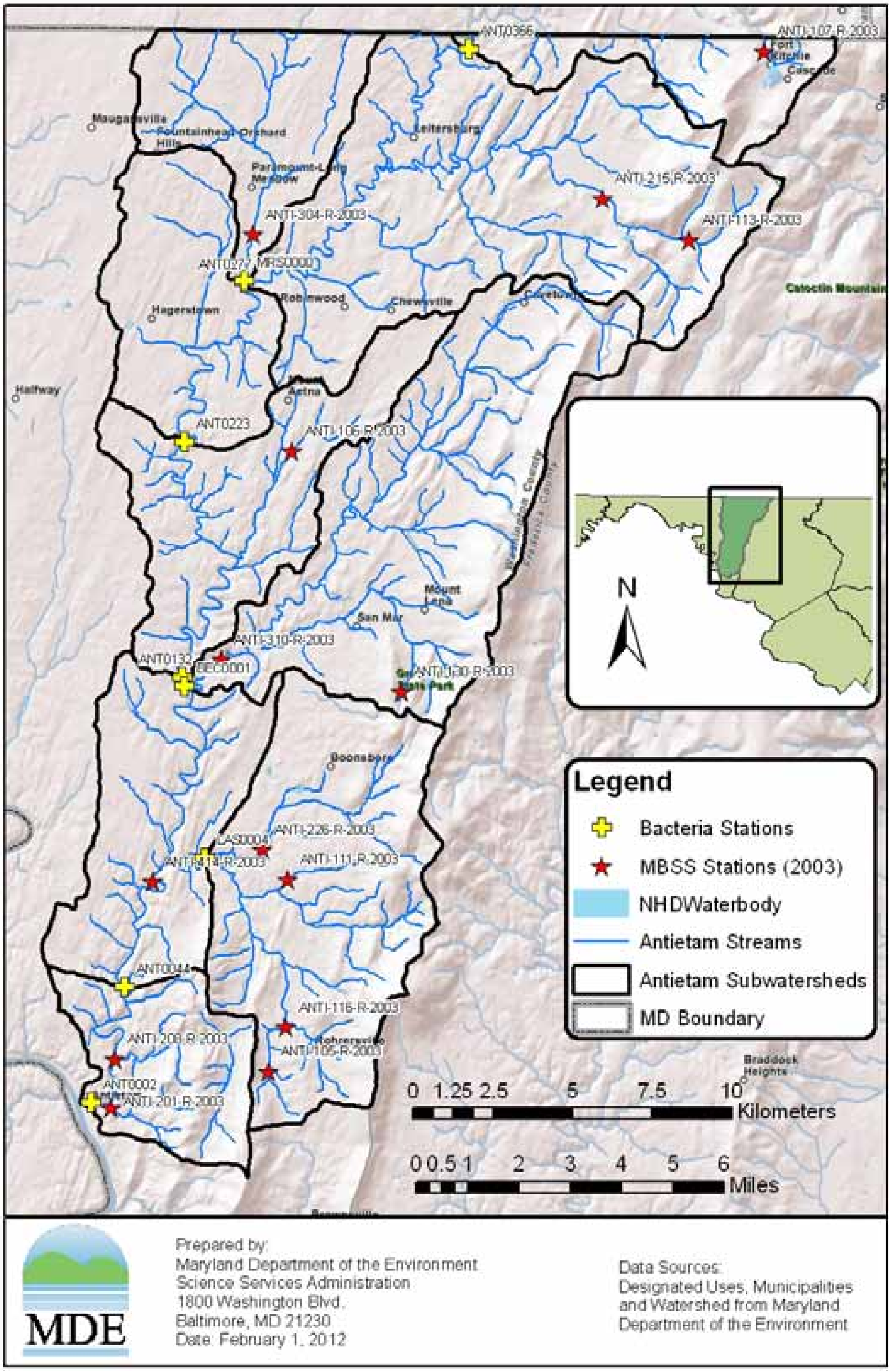


Figure 8- MBSS and Bacteria Sampling stations

3.2.2 Bacteria

Bacteria source tracking (BST) was used to identify the relative contributions of different sources of bacteria to in-stream water samples. BST monitoring was conducted at nine stations in the Antietam Creek watershed, where samples were collected once per month for one-year duration. Sources are defined as domestic (pets and human associated animals), human (human waste), livestock (agricultural animals), and wildlife (mammals and waterfowl). To identify sources, samples are collected within the watershed from known fecal sources, and the patterns of antibiotic resistance of these known sources are compared to isolates of unknown bacteria from ambient water samples.

An accurate representation of the expected contribution of each source at each station is estimated by using a stratified weighted mean of the identified sample results. The weighting factors are based on the log10 of the bacteria concentration and the percent of time that represents the high stream flow or low stream flow (see Appendix B). The procedure for calculating the stratified weighted mean of the sources per monitoring station is as follows:

1. Calculate the percentage of isolates per source per each sample date (S).
2. Calculate an initial weighted percentage (MS) of each source per flow strata (high/low). The weighting is based on the log10 bacteria concentration for the water sample.
3. Adjust the weighted percentage based on the classification of known sources.
4. The final weighted mean source percentage, for each source category, is based on the proportion of time in each flow duration zone.

This methodology produced the following baseline loads for the TMDL:

Table 6 - Current estimated Baseline Loads and TMDLs for fecal coliform in 9 subwatersheds in the Maryland Portion of Antietam Creek. (Bacteria TMDL 2009)

	Domestic Load		**Human Load**		**Livestock Load**		**Wildlife Load**		**Total Load**
Subwatershed	**%**	**(Billion *E. coli* MPN/year)**	**%**	**(Billion *E. coli* MPN/year)**	**%**	**(Billion *E. coli* MPN/year)**	**%**	**(Billion *E. coli* MPN/year)**	**(Billion *E. coli* MPN/year)**
ANT0366[1]	24.5	484,049	20.5	404,455	31.0	610,915	24.0	472,648	1,972,068
ANT0277sub[1]	21.5	194,701	27.9	252,210	28.9	261,021	21.7	196,178	904,110
MRS0000[1]	24.5	210,279	13.3	114,298	34.4	295,804	27.8	239,350	859,730
ANT0223sub	20.4	62,662	22.1	68,018	33.2	102,017	24.3	74,861	307,558
ANT0132sub	14.3	58,492	18.5	75,817	35.6	145,989	31.7	129,947	410,245
BEC0001	14.5	53,361	15.5	56,947	36.5	134,094	33.5	123,044	367,446
LAS0004	27.9	118,612	16.4	69,479	29.0	122,947	26.7	113,511	424,550
ANT0044sub	22.5	69,295	23.0	70,840	28.4	87,501	26.2	80,762	308,398
ANT0002sub	21.2	50,817	20.5	49,034	30.7	73,421	27.6	66,205	239,477

[1]Subwatersheds partially located in Pennsylvania

Table 7 - Annual Average TMDL Loading Caps

Subwatershed	*E. coli* Baseline Load (Billion MPN/year)	Long-Term Average *E. coli* TMDL Load (Billion MPN/year)	% Target Reduction
ANT0366[1]	1,972,068	100,268	94.9
ANT0277sub[1]	904,110	54,285	94.0
MRS0000[1]	859,730	49,530	94.2
ANT0223sub	307,558	19,793	93.6
ANT0132sub	410,245	36,472	91.1
BEC0001	367,446	34,572	90.6
LAS0004	424,550	32,632	92.3
ANT0044sub	308,398	30,837	90.0
ANT0002sub	239,477	23,720	90.1
Total	5,793,581	382,109	93.4

[1]Subwatersheds partially located in Pennsylvania

3.2.3 Chesapeake Bay TMDL

The waters of Antietam Creek eventually reach the Potomac River and continue on to empty into the Chesapeake Bay. With the adoption of a new Chesapeake Bay TMDL, Antietam Creek has to reduce contributions of total nitrogen (TN) total phosphorus (TP) and total suspended solids (TSS). The amount of exactly how much the Bay watershed needs to reduce these pollutants is based on the Chesapeake Bay Model version 5.3.2.

Based upon the fact that the Antietam Creek sediment TMDL is specific to this watershed and likely represents a greater amount of stressor decrease, the numbers from this TMDL will be used as a basis for measuring progress towards meeting the Chesapeake Bay TMDL goals for this watershed. Actions taken as part of this WRP are in line with Bay TMDL reduction strategies as well and will serve to meet the TMDLs of both waterbodies.

3.3 Water Quality Objectives and Goals

This watershed is on the 303(d) list as impaired by sediment and bacteria, however since biological community health is pivotal to the evaluation of successful sediment pollution mitigation, this WRP will focus on meeting water quality standards established in the Code of Maryland Regulations (COMAR) as well as the improvement of biological communities in the Antietam Creek Watershed. The end goal is to reduce sediment and bacteria loads, but also to improve stream community health to "good" standards established in the Index of Biotic Integrity (IBI) used by the Maryland Biological Stream Survey (MBSS). By fully implementing this plan it is expected that all waters of the Antietam Creek watershed comply with COMAR and meet their designated uses as identified below.

Designated Uses

All stream segments in the Antietam watershed should, at a minimum, be fishable and swimmable, and should be clean enough to contain healthy communities of indigenous aquatic species. The federal Clean Water Act (CWA) and state regulations have determined a set of interlinked water quality goals. COMAR designated uses for the streams in the Antietam watershed include: **(Figure 9)**

Use III-P Waters: Nontidal Cold Water and Public Water Supply
Use IV-P Waters: Recreational Trout Water and Public Water Supply

The mainstem of the Antietam Creek and many of its tributaries are designated as use IV-P — Recreational Trout Water and Public Water Supply (COMAR 26.08.02.08Q(6)(g)). Beaver Creek (COMAR 26.08.02.08Q(4)(b)), Little Antietam(COMAR 26.08.02.08Q(4)(d)), Marsh Run (COMAR 26.08.02.08Q(4)(c)) and their tributaries are designated as Use III-P—Water Nontidal Cold Water and Public Water Supply.

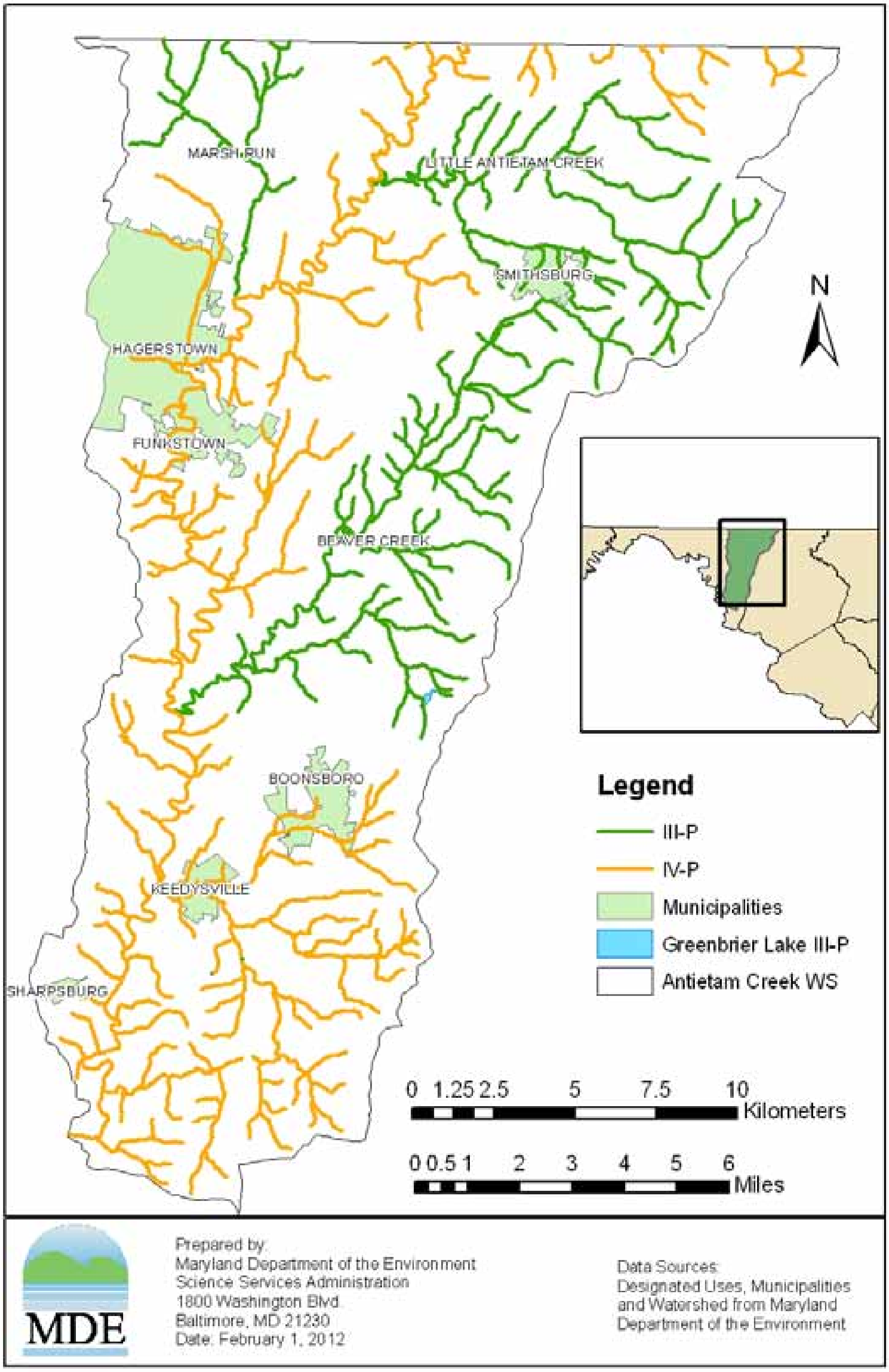


Figure 9- Antietam Creek Watershed Stream Designations

4. Non-point Source Inventory (Criterion A)

4.1 Sediment

The TMDL for sediment developed by the state of Maryland was for the portion of the Antietam watershed labeled as (http://www.mde.state.md.us/programs/Water/TMDL/ApprovedFinalTMDLs/Pages/Programs/WaterPrograms/TMDL/approvedfinaltmdl/tmdl_final_antietam_creek_sediment.aspx) "Segment 2" (**Figure 7**) in the TMDL. This includes portions of PA and MD, however the TMDL loads committed to in the section of Assurance of Implementation in the TMDL refer to the Maryland portion of Segment 2 only.

Excess sediment is a significant biological stressor of the benthic communities in Antietam Creek. The TMDL identifies sources of sediment present in Antietam Creek watershed to include permitted Process Water sources with specific TSS limits. There are 21 process water sources in the watershed which include 3 industrial sources, 15 municipal facilities and 3 mineral mines. There are two Municipal Separate Storm Sewer Systems (MS4s) permits for Hagerstown and Washington County which cover the regulated urban load

Other sources of sediment include crop, extractive, forest, and pasture lands. No load reductions were prescribed for extractive or forest sources, so this document will address primarily the sediment from crop, and pasture sources (**Table 8**).

Stream channel erosion versus surficial erosion was not differentiated in the TMDL, however are significant sources of overall TSS. Areas with significant amounts of streambank and channelization have been identified and will be addressed as separate sources. As the implementation phase of the WRP continues it is expected that further study will identify additional stream channel erosion sites in need of mitigation.

Table 8 – Estimation of MD non-point source sediment contributions from TMDL

Load Source Categories	Baseline Load (ton/year)	TMDL (ton/year)	Amount of load to be reduced as part of this plan (ton/year)
Crop	18,610.8	8035.8	10,575
Extractive	172.4	172.4	0
Forest	1,629.6	1,629.6	0
Pasture	3972.9	2,082.5	1,891.3
Urban	8,490.4	3,556.8	*4932.6
Permits	703.2	703.2	0
Baseline Reduction needed for TMDL in 2008			17399.9
Baseline Reduction needed for WRP in 2012			**12923**

*Part of the WLA, but is addressed in this plan to meet TMDL goals

Pasture and Cropland

Agricultural runoff can contribute excess sediment loads when farming practices allow soils to be washed into the stream. The erosion potential of cropland and overgrazed pasture is particularly high because of the lack of year round vegetative cover. Livestock traffic, especially along streambanks, disturbs the riparian buffer and reduces vegetative cover, causing an increase in erosion from these areas. The 2008 baseline load from crop and pasture sources is 3972.9 tons/year.

Stream Bank Erosion

Figure 10 - Little Antietam Creek Site # 1

There is very rapid stream bank erosion at various locations along the main stem of Antietam Creek and its tributaries. The erosion contributes sediment into the stream and adds to that being washed in from runoff and storm drainage. The field analyses performed in preparation of this Watershed Based Plan included two types: a general assessment of Antietam Creek mainstem by Antietam Creek Watershed Alliance (ACWA) volunteers, and site visits by Canaan Valley Institute's Circuit Rider and Aquatic Restoration specialist and WCSCD Staff in summer 2011 to estimate Bank Erodibility Hazard Index (BEHI) values. ACWA is a watershed organization that consists of Washington County residents and local, state, and federal agency personnel who are dedicated to improving the quality of water in Antietam Creek watershed. In spring 2011, ACWA volunteers, WCSCD staff and CVI staff kayaked the mainstem of Antietam Creek and noted areas of erosion and sedimentation.


Figure 11 - Main Stem Antietam Creek, Site # 2

Although there is minor erosion along much of the Antietam Creek mainstem located in Washington County, MD the assessment identified 5 erosion sites, with a total length of 3281 feet as having greater amounts of erosion than is typical for Antietam Creek. Five sites with a total length of 6186 feet were identified on Little Antietam Creek, a tributary of Antietam Creek where highly eroding banks are very typical. Three erosion sites totaling 1652 feet in length were identified as highly eroding along Beaver Creek. In addition, 2260 feet of Hamilton Run that runs through the Hagerstown Greens at Hamilton Run golf course and 680 feet of Little Grove Creek at the Smithsburg Wastewater Treatment Plant have eroding banks (**Figure12**)

Bank Erodibility Hazard Index (BEHI) estimates were made in summer 2011 for each of the 15 highly eroding sites identified from the field assessment. These provided estimates of sediment loads associated with these lengths. With this method, observations are made on bank height, depth of root zone, density of root material, bank angle, bank surface cover, bank material and soil stratification. These observations are combined to assign a rating for the erosion potential of Very Low (VL), Low, Moderate (MOD), High, Very High (VH), and Extreme for a streambank at a site. Near bank stress (NBS), a measure of the potential disproportionate energy distribution of the near bank region of the channel, is also determined. A regional curve of the measured streambank erosion in relation to near-bank stress and BEHI score was used to estimate the potential sediment contribution from eroding banks and sites were prioritized and mapped based on the amount of erosion (in tons/yr) being contributed by each site.(**Table 9 & Figure 14**) (USGS 2005). Further descriptions and example worksheets can be found in **Appendix C**.


Figure 12 - Smithsburg Wastewater Treatment Plant site, (Urban Stream Restoration)

The 15 sites evaluated are representative of a wide range of opportunities and challenges in the watershed. Settings include agricultural pasture and cropland to more urban settings such as adjacent to the Smithsburg Wastewater Treatment Plant and the golf course on Hamilton Run. Erosion from the sites also varies from 0.4 tons/year/foot to 0.008 tons/year/foot. The total amount of erosion being contributed by these 15 sites is 2385 tons/year or 15% of the total prescribed to be reduced by the TMDL in Maryland.

Sites were ranked by their BEHI scores, site accessibility, and landowner willingness for restoration to take place, public infrastructure threat and potential availability of funds for implementation. Prioritized sites are presented in **Table 9** and **Figure 14**.

The site of highest priority is located along 1910 feet of Little Antietam Creek. The site was formerly pastured but it has since been fenced with a constructed stream crossing for cows. High steep banks along this section continue to undercut and slump into the creek in large masses. This site contributes an annual sediment load of roughly 790 tons/year to Antietam Creek, whereas the site of lowest priority contributes less than 3 tons/year.

Table 9 – Estimated stream erosion contributions from 15 sites on Antietam Creek.

Map Key	Stream	BEHI*	NBS*	Bank Length (ft)	tons/yr/ft	tons/yr
1	Little Antietam	EXT	HIGH	1910	0.4	790.2
2	Antietam	VH	VH	2100	0.38	788.7
3	Little Grove Creek	VH	VH	680	0.43	290.5
4	Beaver Creek	EXT	MOD	450	0.37	166.5
5	L. Ant/Dog Creek	HIGH	HIGH	3200	0.05	148
6	Little Antietam	VH	MOD	730	0.118	87
7	Hamilton Run	MOD	HIGH	2260	0.03	58
8	Antietam	HIGH	HIGH	500	0.038	19.2
9	Antietam	MOD	HIGH	290	0.03	7.7
10	Beaver Creek	MOD	MOD	902	0.008	7.4
11	Antietam	HIGH	EXT	70	0.09	6.15
12	Little Antietam	HIGH	MOD	191	0.03	4.8
13	Beaver Creek	LOW	HIGH	300	0.02	4.6
14	Little Antietam	HIGH	LOW	155	0.02	3.6
15	Antietam	MOD	MOD	321	0.009	2.85
			Total	14059		2385.2
		Percent of prescribed reduction				19%

*Sites were evaluated using Bank Erodibility Hazard Index (BEHI) and Near Bank Stress (NBS) methods.

The 15 sites listed above were chosen as representative of the types of eroding banks found along Antietam Creek and its tributaries.

An additional ten sites (Identified as letters a through j on **Figure 13**) represent locations where eroding banks are in need of stabilization but have not yet been evaluated using the BEHI or NPS methodology. During phase I of the implementation plan these sites will be evaluated using the BEHI methodology and prioritized for implementation accordingly These sites include a section of Hamilton Run that runs through Pangborn Park, a section of Beaver Creek immediately downstream of the bridge on Crystal Falls Drive (bridge scheduled for replacement in 2015

The Washington County Department of Public Works has selected 600 foot a section of Little Antietam Creek adjacent to Greensburg Road as their first priority for stream restoration (indicated on **Figure 13** as letter e). The County has allocated significant resources as part of their annual Capital Improvement program budget for this stream restoration. The eroding stream banks threaten public infrastructure and contribute a significant amount of sediment in the watershed. A reduction of 2,140 lbs/yr is expected from completion of this project. The County has made application through the MDE for $240,000 in FFY 2012 Federal Clean Water Act Section 319 (h) to supplement county funds for project completion.

Figure 13 – Little Antietam Creek at Greensburg Road (Letter e, in Figure 17)

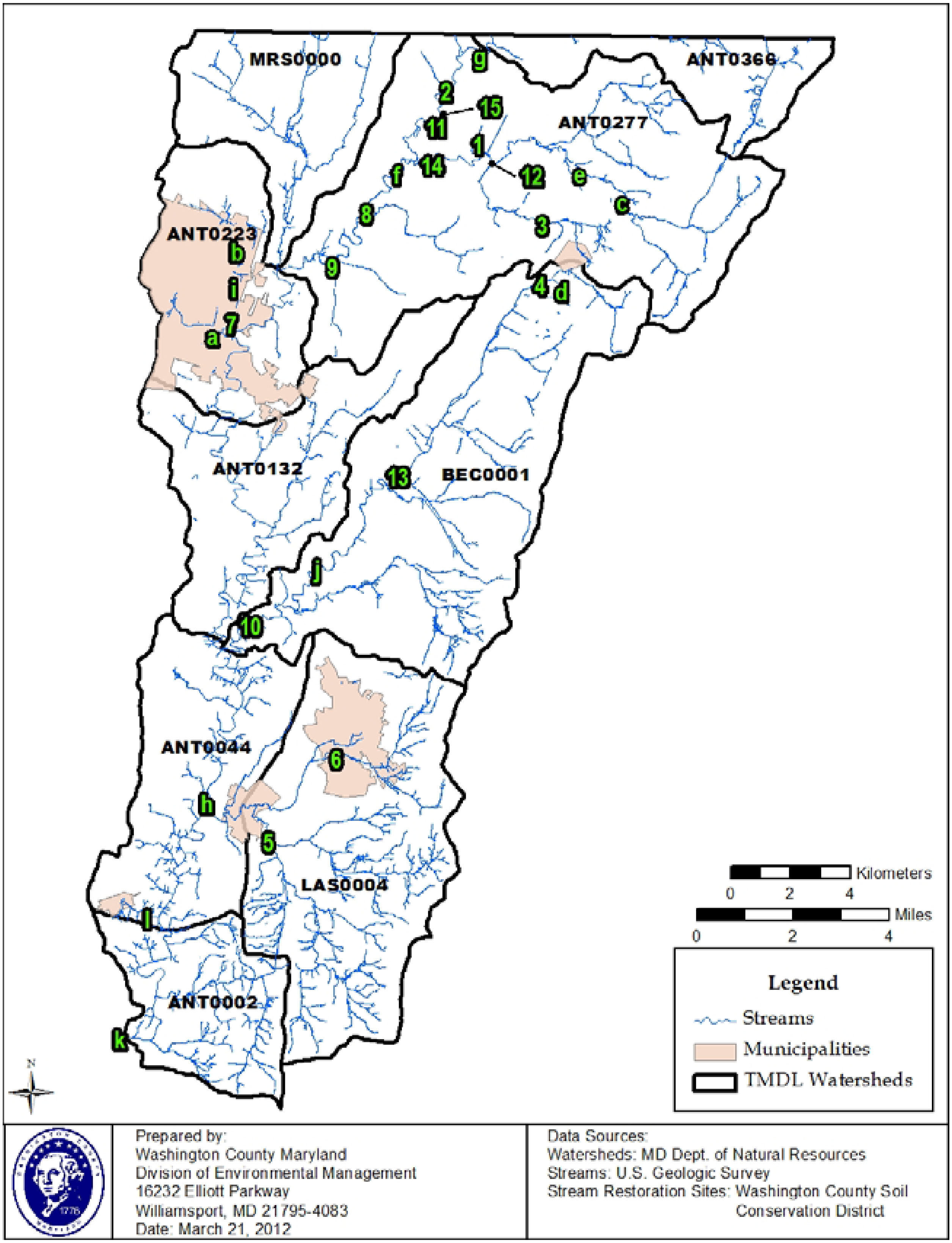


Figure 14 – Map of Priority Sites Identified for Stream Restoration*

*Numbered sites represent priority ranking for which BEHI's have been performed. Letters indicated stream erosion sites of interest to landowners, but have not evaluated fully to date.

4.2 Bacteria

(http://www.mde.state.md.us/programs/Water/TMDL/ApprovedFinalTMDLs/Pages/Programs/WaterPrograms/TMDL/approvedfinaltmdl/tmdl_final_antietam_bacteria.aspx)

The Bacteria TMDL for the Antietam Creek Watershed lists the sources of fecal coliform impairment in the watershed as those from Human, Domestic, Livestock and Wildlife. Human sources present in Antietam Creek watershed include sewage treatment facilities (12 active municipal and 2 industrial NPDES permitted point source facilities), discharges from Municipal Separate Storm Sewer Systems (MS4s), failing or nonexistent on-site sewage disposal systems (also called "septic systems" in this plan), and storm water runoff from pasture and cropland.

The sewage treatment facilities are regulated as point sources. Maryland's portion of Antietam Creek watershed is located entirely within Washington County. Parts of the Antietam Creek watershed in Maryland are covered by a general Phase II NPDES Municipal Separate Storm Sewer System (MS4) permit for the State Highway Administration, Washington County, Hagerstown, and Smithburg. Therefore, some of the fecal coliform bacteria loading associated with precipitation and runoff from residential and urbanized areas is considered regulated as a point source. **Table 10** summarizes the fecal coliform load reductions estimated to be needed from nonpoint sources. Those sources are discussed below. Since the purpose of this document is to address the non-point sources of fecal bacteria, the loads from livestock and domestic animals will be addressed primarily, as well as the portion of the human load associated with failing septic systems.

Table 10 - TMDL Baseline loads and reductions for all sectors

Source	**Baseline Load (Billion *E. coli* MPN/year)**	**Allocated Load (Billion *E. coli* MPN/year)**	**Reduction Needed (Billion *E. coli* MPN/year)**	**Percent reduction necessary**
Domestic Load[1]	1,302,268	26,045	1,276,223	98%
Human Load[1]	1,161,098	43,389	1,117,709	96%
Livestock Load	1,833,709	36,673	1,797,036	98%
Wildlife Load	1,496,506	276,002	1,220,504	82%

Numbers are taken from fecal bacteria TMDL Tables 4.6.1 and 4.7.2.
[1]Loads assigned to the Waste Load Allocation (WLA) are covered by NPDES MS4 permits

4.2a Domestic Load

Runoff from residential and urbanized areas during storm events can be significant fecal coliform sources, delivering bacteria from the waste of pets and wildlife to the water body. In the Antietam Creek watershed, approximately 94% of impervious urban acres and 80% pervious urban acres are covered under Phase II NPDES permits. The magnitude of the load reduction prescribed by the TMDL for this source is 1,276,223 billion *E. coli* MPN/year. It will be beneficial to implement residential/urban BMPs that reduce bacteria deposition or the volume of stormwater runoff into streams. These may include proper pet waste disposal, forest and grass buffers along streams, bioretention (rain gardens), wetlands, downspout disconnections, dry swales, and impervious surface reduction. Residential/urban BMPs are included in this Watershed Based Plan, and should be eligible for federal Section 319 funding.

4.2b Human Load

Roughly 60% of Washington County consists of Karst topography, areas shaped by the dissolution of soluble limestone bedrock. Karst formations are cavernous and therefore have high rates of permeability, resulting in reduced opportunity for contaminants to be filtered out. Overloaded or malfunctioning septic tanks in Washington County may dump raw sewage directly into underground channels. Many of these channels find their opening at the banks of Antietam Creek. The TMDL considers the entire human load generated through county stormwater systems and sanitary sewer overflows as a regulated point source under Washington County's National Pollutant Discharge Elimination System (NPDES) MS4 permit.

Although the TMDL considers all of the human load from stormwater to be regulated as a point source under Washington County's NPDES MS4 permit it is likely that bacteria from failing septic systems is reaching the creek untreated. There are an estimated 31,865 households in the Antietam Creek Watershed. Of these, 8,730 are served by onsite disposal (septic) systems (**Figure 15**). According to the Washington County Health Department, it is estimated that approximately 43 of these fail or underperform each year and are in need of some type of correction (**Figure 16**). The Minnesota Pollution Control Agency found that effluent from septic systems had bacteria concentrations of up to 240,000 MPN/100ml (**Appendix E**). During the development of the West Virginia Potomac Direct Drains TMDL, Tetra Tech observed average bacteria concentrations of 527,179 counts/100ml from failing septic systems which were modeled to be contributing 50 gal (190,000ml) of untreated sewage per day (WVDWWM 2007). Therefore if the more conservative estimate of 240,000 MPN/100ml is used, it can be expected that effluent from a failing septic system passing through the karst geology contributes up to 166 Billion MPN *E. coli* per year. Each year the 43 septic systems estimated to be failing, potentially contribute 7138 Billion MPN *E. coli* to Antietam Creek.

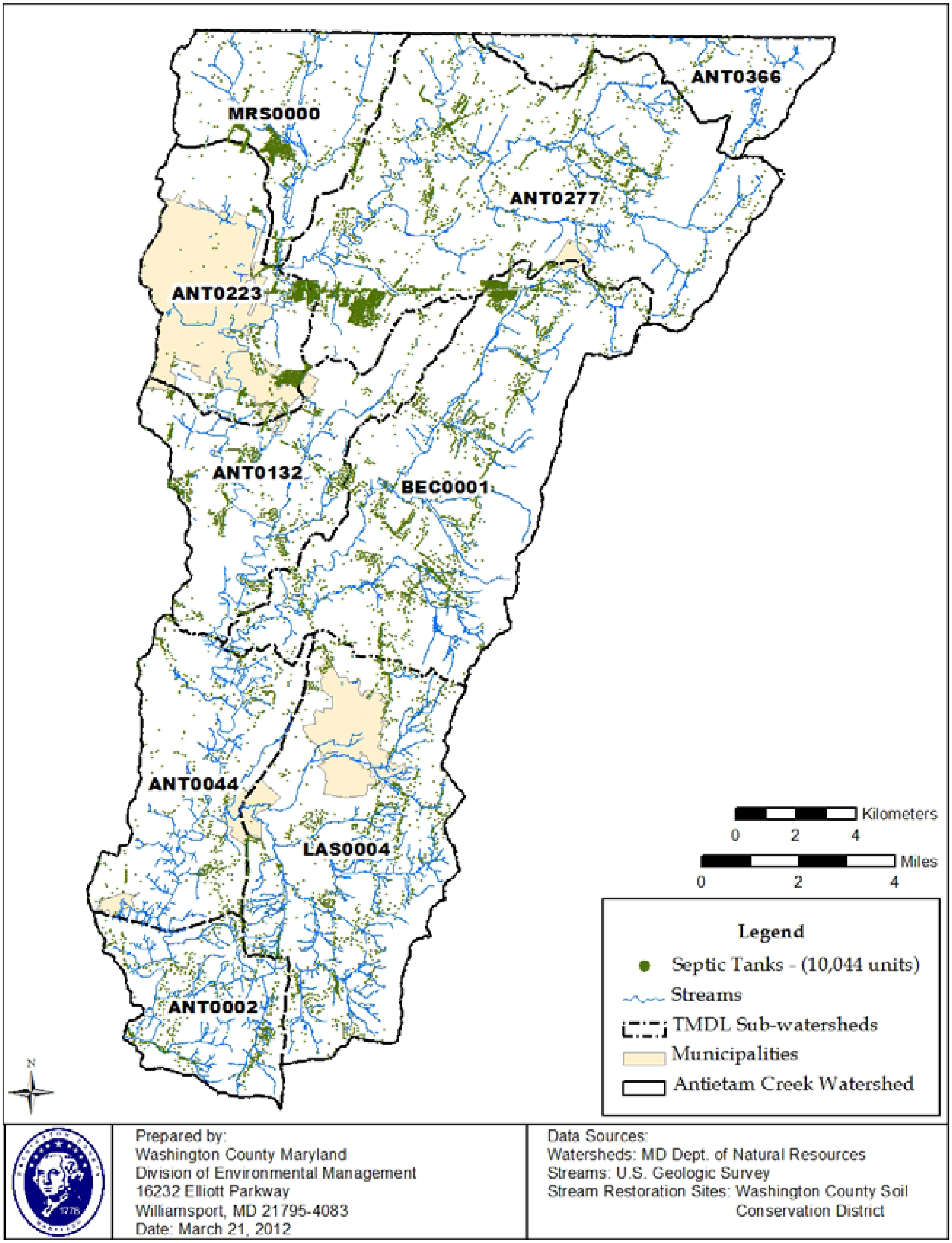


Figure 15 - Location of Septic Systems

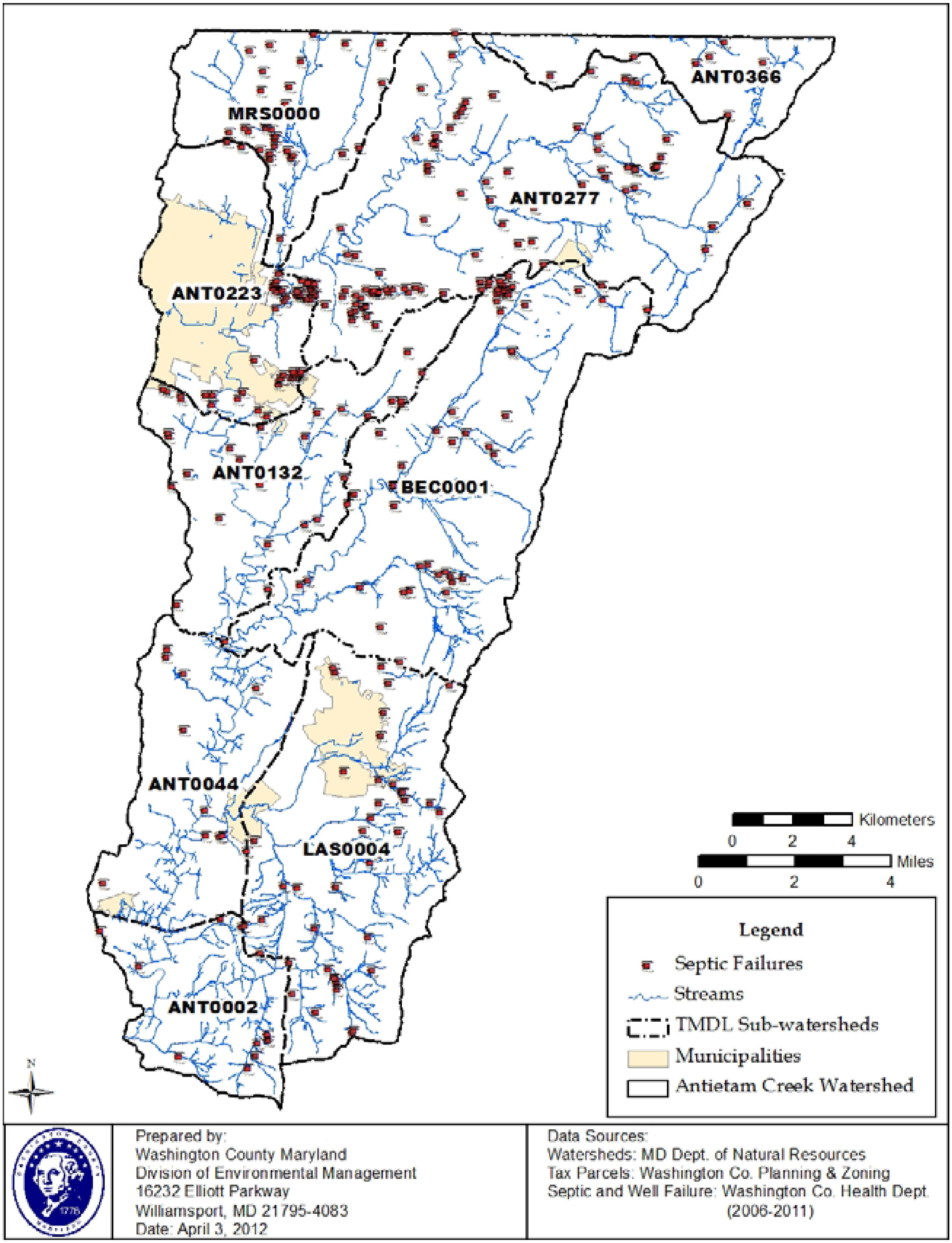


Figure 16 - Location of replaced septic systems

4.2c Livestock Load

Grazing livestock and land application of manure (cattle and poultry) result in the deposition and accumulation of bacteria on land surfaces in the Antietam Creek watershed and are the main sources of the livestock load in Antietam Creek Watershed. In addition, limestone soils in the watershed with their numerous limestone rock outcrops and sinkholes present pathways for bacteria to enter groundwater resources. Additional loadings come from barnyard areas that have uncontrolled storm water runoff flowing over areas with animal wastes present.

Unrestricted access to streams by livestock can be a significant source of bacteria due to deposition of animal waste immediately adjacent to or directly into streams. While significant strides have been made by the agricultural producers in the watershed to exclude livestock from streams this remains a significant source of bacteria.

The dairy industry is the predominant agricultural enterprise in the watershed with 86 operations licensed to ship milk. Of the operating dairies 51 (59%) have constructed animal waste storage facilities to better manage animal waste. Animal waste storage facilities allow for better timing of land application to optimize crop benefits and detrimental impacts to water resources. **Table 11** details livestock numbers by type in the watershed. **Figure 17** shows the location of dairies within MD's portion of Antietam Creek. It is estimated that agriculture contributes 1,833.708 billion *E. coli* MPN/year in the Antietam watershed.

Table 11 – Antietam Creek Livestock Census

Animal Type	Number of Animals*
DAIRY COWS	13,440
BEEF COWS	1,042
CHICKENS (Layers)	150,000
HOGS	900
SHEEP	873
DUCKS	18,800

* Animal numbers based on 2010 National Agricultural Statistics Service (NASS), 2010 Washington County Profile. Animal numbers confirmed by local knowledge of average and specific herd and flock sizes. Basic calculations based on proportionate land area in the watershed compared to NASS animal numbers for the entire County.

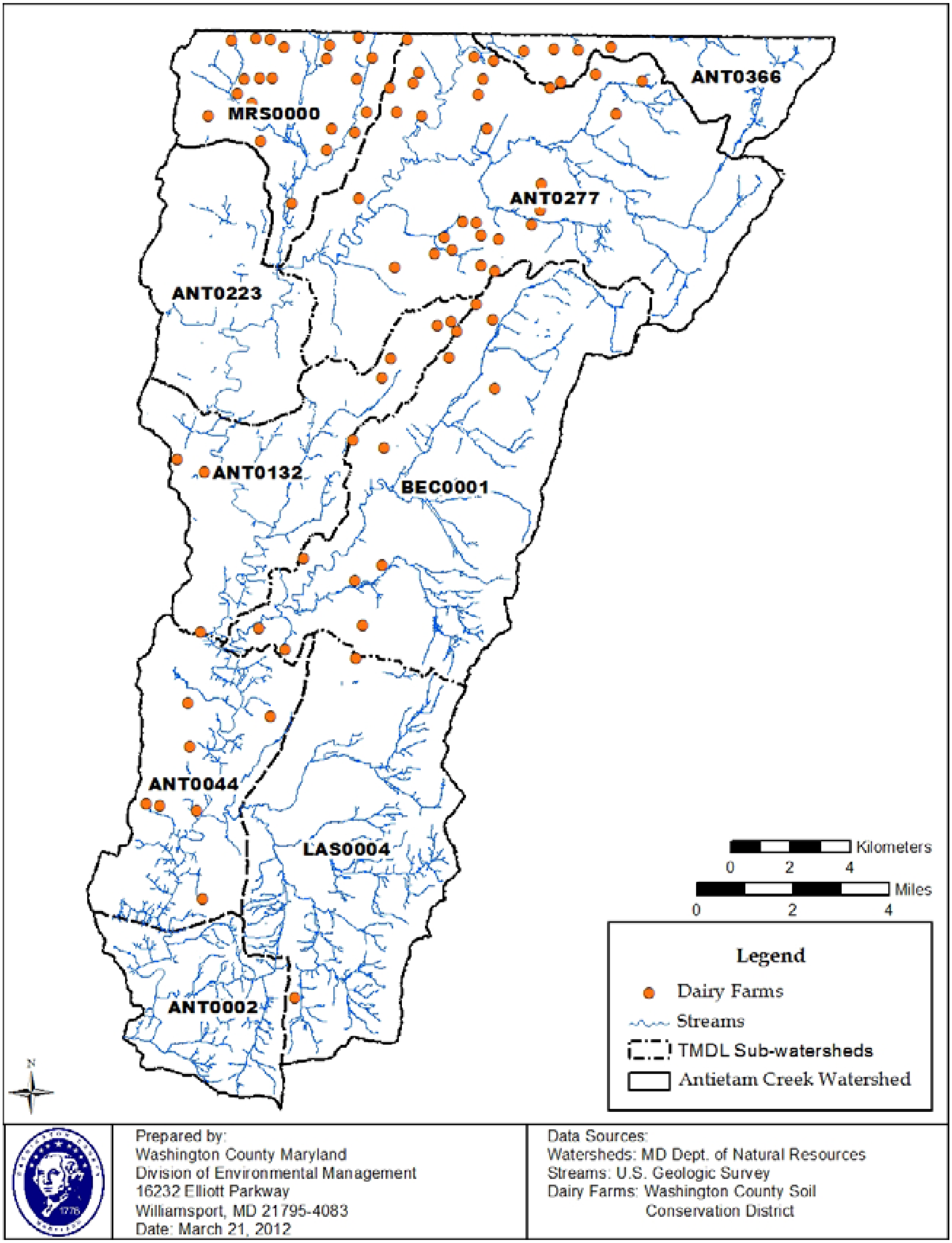


Figure 17 - Location of Dairy Operations

4.2d Wildlife Load

Wildlife are a significant source of bacteria in the watershed contributing a load of 1,496,506 billion *E. coli* MPN/year. It is anticipated that non-point source BMP's implemented for agriculture and urban lands will effect some reductions of the wildlife load, but will not achieve the required reduction of 1,220,504 billion *E. coli* MPN/year. Current methods of wildlife control center on hunting to reduce wildlife populations to achieve balance with habitats and the community. Liberal deer, small game and resident goose seasons are in place to manage wildlife populations and revision of the wildlife management plan for this area may be needed to meet TMDL goals. The wildlife load alone exceeds the TMDL for bacteria will need to be addressed once the other managed non-point source sectors have been fully implemented.

5. Non-point Source Management (Criterion B)

5.1 Sediment

Implementation for sediment load reduction is limited to "Segment 2" (**Figure 7**) as indicated in the Sediment TMDL. This includes portions of PA and MD, however the Antietam WRP is dedicated to achieving reductions in the Maryland portion of the watershed.

Load reductions for sediment were estimated using a simple accounting spreadsheet and the Maryland Assessment Scenario Tool (MAST) (www.mastonline.org). Pollution reduction efficiencies are based on those in the Chesapeake Bay Tributary Strategy (where applicable). A detailed description of the load reduction calculations can be found in Appendix B. Using this spreadsheet, the work group estimated that the sediment reductions found in the following tables would be achieved through the installations of various Best Management Practices.

Table 12 - Sediment Reductions from Non-Point Sources during period of TMDL development to 2012

2009-11					
Acres	BMP	Reduction Efficiency	Reference	Landuse	Tons (EOS)
26.25	Grass Buffer	45%	2	Hi-Till	9.35
10.9	Forest Buffer	60%	2	Hi-Till	6.66
280	Stream Protection without Fencing	40%	1	Pasture	25.21
403	Stream Protection with Fencing	75%	1	Pasture	68.03
12410	SCWQP	40%	1	Low-Till	3114.69
16	Runoff Control	75%	1	AFO	25.35
2384	Conservation Tillage	LU Change	3	Hi-Till	1047.1
4.35	Retire Highly Erodible Land	LU Change	3	Tramp. Past.	8.98
1230	Stream Rest.	MAST	4	Mix Pas, lowtill	0.27
543.6	Harvested Forest*	50%	1	Harvested Forest	171.4
	Total Reduction				4477.04

*Assumes 81% compliance with ESC practices.
1 -Chesapeake Bay Model version 4.3 BMP efficiencies
2 -Chesapeake Bay Model version 5.3 BMP efficiencies (no 4.3 values)
3 - LU Change using TMDL reduction spreadsheet from MDE
4 - Calculated using MAST w/5.3 model BMP efficiencies (no 4.3 reference)

Table 13 – Non-Point Source Strategy for 2017

2017 Milestone					
Acres	BMP	Reduction Efficiency	Reference	Landuse	Tons (EOS)
4000	Cover Crops	65%	2	low-till	1595.3
4000	Conservation Tillage	LU Change	3	Hi-Till	1562.7
6000	SCWQP	40%	1	low-till	527.1
500	Stream Protection without Fencing	40%	1	Pasture	11.25
300	Stream Protection with Fencing	75%	1	Pasture	40.5
113	Grass and Forest Buffers	53%	1	low-till	69.0
50	Retire Highly Erodible Land	MAST*	3	70 T.Past/Low-Till	173.5
0.15	Stream Rest	MAST	4	Pasture & Low-Till	1.6
543	Forest Harvesting Practices	50%	1	Forest	171
	Total Reduction				4152

1 -Chesapeake Bay Model version 4.3 BMP efficiencies
2 - Calculated by WCSCD using RUSLE2
3 - LU Change using TMDL reduction spreadsheet from MDE
4 - Calculated using MAST w/5.3 model BMP efficiencies (no 4.3 reference)

Table 14 – Non-Point Source Strategy to meet TMDL in 2025

2025 Strategy Includes building upon 2017					
Acres	BMP	Reduction Efficiency	Reference	Landuse	Tons (EOS)
4000	Cover Crops	65%	2	low-till	1380.4
6200	Conservation Tillage	LU Change	3	Hi-Till	2454.17
3050**	SCWQP	40%	1	low-till	795
1300	Stream Protection without Fencing	40%	1	Pasture	117.04
780	Stream Protection with Fencing	75%	1	Pasture	131.67
295	Grass and Forest Buffers	53%	1	low-till	98.10
130	Retire Highly Erodible Land	MAST*	3	70 T.Past/Low-Till	148.27
4800	No-Till	70%	1	low-till	2108.25
0.25	Stream Rest	MAST	4	Pasture & Low-Till	3.68
250	Forest Harvesting Practices	50%	1	Forest	78.8
	Total Reduction				7408

* Local Acreage greater than TMDL
**Additional Acres as compared with Table 13
1 -Chesapeake Bay Model version 4.3 BMP efficiencies
2 - Calculated by WCSCD using RUSLE2
3 - LU Change using TMDL reduction spreadsheet from MDE
4 - Calculated using MAST w/5.3 model BMP efficiencies (no 4.3 reference)

Table 15 – Urban Strategy to meet TMDL in 2025

BMP Type	*Sediment Reduction per Impervious Acre Treated (lbs)	% Area Of Watershed That BMP Was Applied To In MAST Scenario
Bioretention / Rain Garden	774.9	7.17
Bio-swale	774.9	7.17
Dry Detention Ponds and Hydrodynamic Structures	97.1	7.17
Dry Extended Detention Ponds	581.2	7.17
Forest Conservation (pervious only)	168.6	2
Impervious Urban Surface Reduction (impervious only)	767.7	2
MS4 Permit 20% Retrofit	629.7	7.17
Permeable Pavement (no sand or veg. with under drain AB soils)	678.3	2
Stormwater Management by era 1985 - 2002	387.5	2
Stormwater Management by era 2002 - 2010	774.9	7.17
SWM to the MEP	872.1	7.17
Urban Filtering Practices	774.9	7.17
Urban Forest Buffers	311.6	2
Urban Infiltration Practices (no sand/vegetation, no under drain)	920.6	2
Urban Nutrient Management (pervious only)	-	2
Street Sweeping 25 Times a Year	87.0	7.17
Urban Stream Restoration (per 100' of stream)	16,604.3	7.17
Vegetated Open Channel	678.3	7.17
Wet Ponds & Wetlands	581.2	7.17
	*Total tons/yr of sediment reduced from urban strategy	5930.49

*Urban Reduction calculated in MAST

Table 16 - Evaluation of reductions to meet TMDL

REDUCTION Summary	EOS Load reduced (tons/yr)
2017 Milestone NPS Reduction goal	7618
2017 Urban Sector*	3558
2017 Non-Point Source	4152
2017 Milestone NPS Reduction	**7710**
WRP TMDL Reduction goal	12923
2025 Urban Reduction*	5931
2025 Non-Point Source	7408
NPS Post-Implementation Reduction	**13339**

*Urban Reduction calculated in new model

5.2 Bacteria

Non-point source bacteria loads for the Antietam Creek were derived by measuring in-stream concentrations at various subwatershed outfalls within the Antietam Creek watershed. The NPS pollutant concentrations coming off Agricultural land and via failing Septic systems are the focus of this plan. In particular, dairy and beef operations will be the primary target of developing animal waste management systems, livestock exclusion from streams and loafing lot management to control livestock loads from animal operations. Filter Strips and new nutrient management laws will be incorporated to remove bacteria from manure applications to cropland. The reduction efficiencies associated with the individual practices and combinations of those practices should yield the necessary bacteria load reduction to meet the water quality criteria for the TMDL.

The calculation of Bacteria reductions in a strict quantitative manner was more difficult to display based on the way the TMDL was set up. The TMDL was based on in-stream concentrations that were not necessarily attributable to individual land use values and therefore an Edge of Stream or delivered load for specific land uses was not able to be calculated as was the sediment reductions. However, the bacterial reduction efficiencies (**Table 17**) will show that the implementation of the practices identified will likely meet the reductions required by the Bacteria TMDL due to their treatment of animal production facilities and manure spreading on croplands.

Table 17 – Bacteria BMPs Reduction Efficiencies

BMP Type	Description	Reduction Efficiency	Reference
Res*	Septic tank pumpout	50%	2
Res	Septic system repair	100%	1
Res	Septic system replacement	100%	1
Res*	Alternative waste treatment	100%	1
Res*	Pet waste digester	100%	4
Res*	Rain garden	40%	2,6
Res*	Pet waste education program	50%	3
Ag	Improved pasture management	50%	5,8
Ag	Riparian buffer	50%	2
Ag	Woodland buffer filter strip	60%	2
Ag	Grassed buffer filter strip	50%	2
Ag	Livestock exclusion	100%	1
Ag	Poultry litter storage	99%	7
Ag	Manure storage	80%	7
Ag	Loafing lot management system	75%	6,7
Ag	Sod waterway	50%	9
Ag	2012 MD Nutrient Management Laws	100%	10

1. Removal is defined by the practice
2. VADCR and VADEQ TMDL Implementation Plan Development Guidance Manual
3. Modified from Swann, C. 1999. A survey of residential nutrient behaviors in theChesapeake Bay. Widener Burrows, Inc. Chesapeake Bay Research Consortium.Center for Watershed Protection. Ellicott City, MD. 112pp.
4. Virginia Mill and Hawksbill TMDL IP, MapTech, September 13, 2007
5. Commonwealth of Virginia. 2005. Chesapeake Bay Nutrient and Sediment Reduction Tributary Strategy. www.naturalresources.virginia.gov/Initiatives/TributaryStrategies/
6. Chesapeake Bay Model version 4.3 BMP efficiencies
7. Virginia North River TMDL IP, MapTech, July 5, 2001
8. Bacteria efficiency estimated based on sediment and nutrient efficiency
9. Fiener, P., Auerswald, K. Effectiveness of grassed waterways in reducing runoff and sediment delivery from agricultural watersheds. J. Environ. Qual. 32:927-936 (2003).
10. Code of Maryland Regulations 15.20 (2012).

Though the Bacteria TMDL presents many challenges, the goal of Phase I is to reduce fecal coliform loads by approximately 60% in the non-point Ag sector and 25% reduction in wildlife load. This would be a reduction 1,078,221.6 billion *E. coli* MPN/year for Agriculture and a 305,126 billion *E. coli* MPN/year for wildlife in 2017. The BMPs outlined in **Table 18**, along with the new MD nutrient management laws which regulate the application of manure on croplands, will be sufficient to achieve the phase I target.

Table 18 – BMP Schedule for Bacterial Mitigation

Practice	Units	Goal 2017	Goal 2025
Pet Waste Runoff Campaign	N/A	Ongoing sustained campaign	Ongoing sustained campaign
Septic System Upgrades	Systems	248	645
Grass Buffers	Acres	13	35
Riparian Forest Buffers	Acres	100	260
Stream Protection with Fencing (livestock exclusion)	Acres	300	780
Stream Protection without Fencing (livestock exclusion)	Acres	500	1300
Livestock Stream Crossing	Each	7	17
Soil Conservation and Water Quality Planning	Acres	6,000	15,460
Runoff Control Systems (loafing lot management)	Acres	4	12
Animal Waste Management Systems (Manure Storage)	Each	10	26
Education and Outreach	Employee and outreach costs	Secure funding and hire by 2013	Maintain funding through 2025

Table 19 – Failing Septics Strategy to meet TMDL in 2025

	2012-25					
Units	Annual Amount	BMP	Estimated reduction per unit	# years Phase1&2	Landuse	Total Reduction
Systems	43	Replace Failing Septics	166 B. MPN/yr	13	Residential	92794 B. MPN/yr
Total Reduction for septic strategy and work achieved						92794 B.MPN/yr

The bacteria load from wildlife will be addressed by many of the cropland and pasture BMPs implemented. However, in order to truly reduce all wildlife loads, it will require treatment through point source (MS4) areas as well. Part of the adaptive management strategy being employed is to take care of the sources which can be affected by direct mitigation and then work with Maryland Department of Natural Resources to come up with a wildlife management plan if bacteria levels from that source are still significant.

If by the end of 2017, reductions have not been met in Ag and wildlife sectors, then new technologies such as manure digesters will be explored in order to treat bacteria at the source for livestock, and a wildlife management plan will be put into effect to limit the amount of bacteria from that sector.

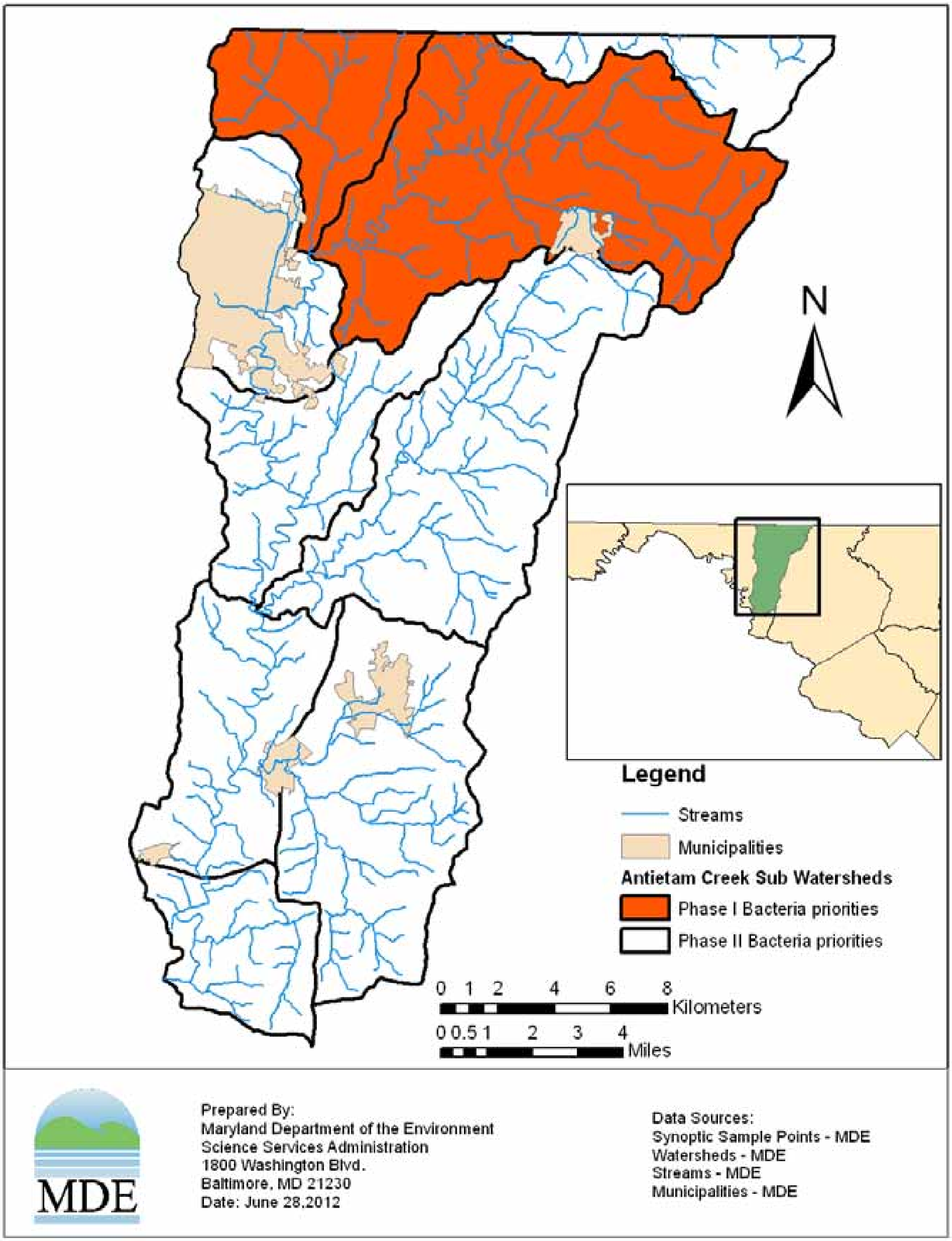


Figure 18 – Map of priority subwatersheds for bacteria BMP implementation

5.3 Potential Treatment Technologies (Criterion C)

The following list describes in depth the various best management practices that may be used to reduce sediment and fecal coliform impairments within the Antietam Creek watershed. The addition of the following indicators identifies whether or not the BMPs address sediment, fecal coliform or both: B = Both, F = Fecal Coliform specific and S = Sediment specific.

Filtering practices (B)

Filtering BMPs are designed for reduction of urban runoff impacts, water quality control, stream channel protection, and peak discharge control for both small and large storms. They capture and temporarily store the water quality volume and pass it through a filter of sand, organic matter and vegetation, promoting pollutant treatment and recharge. Examples of practices include vegetated open channels and raingardens.

Infiltration practices (B)

Infiltration BMPs are designed for reduction of urban runoff impacts, groundwater recharge, water quality control, stream channel protection, and peak discharge control for both small and large storms. Performance information for all of these practices was derived from their use in urbanized/high impervious land use areas. Effectiveness estimates vary by soil type and other factors, and are described in Simpson and Weammert 2009, pp. 342-362. The following are examples of infiltration BMPs:

- *Bioretention:* An excavated pit backfilled with engineered media, topsoil, mulch, and vegetation. These are planting areas installed in shallow basins in which the storm water runoff is temporarily ponded and then treated by filtering through the bed components, and through biological and biochemical reactions within the soil matrix and around the root zones of the plants.
- *Permeable Pavement and Pavers:* Pavement or pavers that reduce runoff volume and treat water quality through both infiltration and filtration mechanisms. Water filters through open voids in the pavement surface to a washed gravel subsurface storage reservoir, where it is then slowly infiltrated into the underlying soils or exits via an under drain.
- *Infiltration Trenches and Basins:* A depression to form an infiltration basin where sediment is trapped and water infiltrates the soil. No under drains are associated with infiltration basins and trenches, because by definition these systems provide complete infiltration.

Urban Wet Ponds (S)

Depressions or basins created by excavation or berm construction that receive sufficient water via runoff, precipitation, and groundwater to contain standing water year-round at depths too deep to support rooted emergent or floating-leaved vegetation (in contrast with dry ponds, which dry out between precipitation events). Nutrients and suspended particles are removed via settling. Nitrogen is further removed primarily via plant and microbial uptake and nitrification-denitrification reactions, while phosphorus is further removed by soil sorption.

Urban Wetlands (S)

Wetlands have soils that are saturated with water or flooded with shallow water that support rooted floating or emergent aquatic vegetation (e.g. cattails). Nutrients and suspended particles are removed via settling. Nitrogen is further removed primarily via plant and microbial uptake and nitrification-denitrification reactions, while phosphorus is further removed by soil sorption. Effectiveness estimates: (Simpson and Weammert 2009, p. 541).

Impervious Surface Reduction (B)

Practices that reduce the total area of impervious cover and practices that capture storm water and divert it to pervious areas, subsequently encouraging storm water infiltration; e.g. natural area conservation, disconnection of rooftop runoff, and rain barrels.

Pet Waste Runoff Campaign (F)

Practices to increase awareness regarding the importance of proper disposal of pet waste will include: maintaining vegetative buffer areas between streams and areas where pets or wildlife defecate, distributing and promoting pet waste digesters, installing pet waste bag stations in common areas of subdivisions, and conducting outreach about pet waste disposal, especially showcasing the above practices

Septic Upgrade (F)

Washington County is currently participating in MDE's Bay Restoration Fund (BRF) septic system upgrade program. As of July 2011 55 failing septic systems in the Antietam Creek watershed were replaced with MDE approved Best Available Technology for nitrogen removal. These systems are also efficient at addressing bacterial loads in effluent.

Grass Buffers (B)

A linear strip of grass or other non-woody vegetation maintained along stream banks helps filter bacteria, nutrients, sediment and other pollution from runoff. During highwater and flooding events, vegetation holds soil in place and can trap some excess nutrients from upstream waters flowing over it. .

Riparian Forest Buffer (B)

A tree and shrub buffer of at least 35 feet will be established and maintained along the stream corridor and/or water body to reduce excess amounts of sediment, organic material, nutrients and pesticides in surface runoff and reduce excess nutrients and other chemicals in shallow ground water flow. The location, layout, width, and density of the riparian forest buffer will be selected to accomplish the intended purpose and function

Stream Protection with Fencing (B)

A fence will be constructed adjacent to the stream bank to eliminate livestock access to streams. Pasture fencing keeps farm animals out of streams and prevents streambank erosion.

Stream Protection without Fencing (B)

Watering troughs provide a safe, reliable source of water for livestock that is away from streams. The troughs help protects stream banks from erosion that may be caused by farm animals. Water for the trough will be supplied from a well or other collection system linked to sub-surface water or a spring.

Livestock Stream Crossing (S)

A stream crossing will be constructed to improve water quality by reducing sediment, nutrient, organic, and inorganic loading of the stream and reduce stream bank and streambed erosion. The stream crossing will be constructed according to an engineering design based on NRCS standards. This practice is not given its own pollutant reduction efficiencies, but is used in conjunction with Livestock Fencing and Alternative Watering.

Runoff Control Systems (B)

Runoff control systems use a variety of techniques to direct rainwater to places where it won't cause nutrient runoff or soil erosion. Gutters and downspouts on barns and grading of the land are examples of ways to direct runoff from rainfall.

Nutrient Management Planning (F)

Farm operators develop a comprehensive plan that describes the optimum use of nutrients (sometimes consisting of animal manures) to minimize nutrient loss while maintaining yield.

Soil Conservation and Water Quality Planning (S)

Farm operators develop a plan to address soil erosion and water quality issues on their owned and rented lands.

Conservation Tillage (S)

Conservation Tillage involves planting and growing crops with minimal disturbance of the surface soil. No-till farming, a form of conservation tillage, is used to seed the crop directly into vegetative cover or crop residue with no disturbance of the soil surface. Minimum tillage farming involves some disturbance of the soil, but uses tillage equipment that leaves much of the vegetative cover or crop residue on the surface

Cover Crops (S)

Plant commodity and traditional cover crops (small grains such as wheat or rye that are planted in the fall after the harvest of corn, soybeans and other summer crops to absorb unused fertilizers that may remain in the soil and provide a ground cover to prevent soil erosion in the winter.

Continuous No-till (S)

Continuous no-till farming, a form of conservation tillage in which seed is applied into the vegetative cover or crop residue with no disturbance of the surface soil.

Retire Highly Erodible Land (S)
Retire highly erodible land on Private Lands. Land that is especially vulnerable to erosion is removed from crop or hay production and is planted in either grass or forest. This land usually is not disturbed for at least 10 years.

Natural Stream Design (NSD) (S)
Natural Stream Design will take place on properties with significant stream bank loss and which score moderate to extreme in the BEHI assessment.

Armored Stream Bank Stabilization (S)
In some cases where streambank erosion is a problem but NSD is not possible due to site constraints (e.g. a road or building very close to streambank, making a bankfull bench out of the question), rip-rap or other methods of streambank armoring may be necessary. Innovative options which allow for greater vegetative growth may also be used, such as articulated concrete block.

Manure Digesters (F)
This technology is a component of a waste management system that provides biological treatment in the absence of oxygen. These systems offer multiple benefits for the treatment of manure and other byproducts of animal agricultural operations including, pathogen reduction, odor management, capture of biogas for energy, and reduction the net effect of greenhouse gas emissions. This technology is feasible and efficient at reducing bacteria in manure. However it is also prohibitively expensive in many areas and will be used as contingency BMP if reductions are not met through other management measures.

6. Technical and Financial Assistance/Benefits (Criterion D)

To meet TMDL standards, it will take a combination of federal, state, private and public partnerships to work jointly to provide the desired outcome; restoration of the watershed.

6.1 Technical Assistance Needs and Partners

Domestic and human BMPs costs

Canaan Valley Institute's "Watershed Wastewater Protection Plan" addresses the cost of the septic system implementation. There are estimated to be 43 systems in need of repair or upgrade annually in the Antietam Creek watershed. Estimating $5,000 of project money to fix each failure would yield a project budget of roughly $215,000/year. This estimate assumes the homeowner makes up the rest of the cost not provided through Section 319 project funds. In a similar report for the Sleepy Creek watershed in Morgan County, WV (Winant, 2007), the estimated average total cost of upgrading each septic system is $7500, for a total cost of about $322,500 annually. This is likely an overestimate of what will actually be incorporated into Section 319 project proposals, because Washington County receives funds to upgrade roughly 20 failing septic systems thru MDE's Bay Restoration Fund. However the BRF program does not include the cost to upgrade or replace the disposal system (i.e.drainfield, sand mound, etc.) This cost, averaging roughly $5000 comes at the homeowners' expense making participation into the program difficult for many. Since a septic upgrade program already exists in Washington County, 319 funds will be used to assist homeowners already participating in the BRF program with the cost of the disposal unit.

Partners anticipated to contribute to meeting technical assistance needs include:

- Washington County Soil Conservation District (WCSCD)
- Canaan Valley Institute (CVI)
- Washington County Health Department (WCHD)
- Washington County Department of Environmental Management (WCDEM)
- Washington County Division of Public Works (WCDPW)
- Washington County Department of Planning (WCDP)
- Antietam Creek Watershed Association
- Maryland Department of the Environment

6.2 Financial Assistance Needs

The following table summarizes the costs associated with practices identified in the two phases of the Watershed Restoration Plan.

Table 20- Agriculture Best Management Practices and Costs

Practice	Units	Goal 2017	Goal 2025	Cost/unit	Total Cost
Pet Waste Runoff Campaign	N/A	Ongoing sustained campaign	Ongoing sustained campaign	$5,000 annually	$65,000
Septic System Upgrades	Systems	248	645	$5000	$3,225,000
Grass Buffers	Acres	13	35	$350	$12,250
Riparian Forest Buffers	Acres	100	260	$3,300	$858,000
Stream Protection with Fencing	Acres	300	780	$283	$220,740
Stream Protection without Fencing	Acres	500	1300	$150	$195,000
Livestock Stream Crossing	Each	7	17	$15,000	$255,000
Nutrient Management Planning	Acres	49,728	49,728	$7.00	$348,096
Soil Conservation and Water Quality Planning	Acres	6,000	15,460	$45.00	$695,700
Runoff Control Systems	Acres	4	12	$5,700	68,400
Cover Crops* (Annual Practice)	Acres	4,000	4,000	$50	$200,000* Annual Cost
Animal Waste Management Systems	Each	10	26	$90,000	$2,340,000
Conservation Tillage	Acres	4,000	10,000	$17	$170,000
Retire Highly Erodible Land	Acres	50	130	$1,304	$169,520
Natural Stream Design Implementation	Linear Feet	5,000	7,800	$150	$1,170,000
Armored Stream Bank Stabilization	Linear Feet	1300	3,250	$450	$1,462,500
Education and Outreach	Employee and outreach costs	Secure funding and hire by 2013	Maintain funding through 2025	$75,000 employee $10,000 activities	$85,000 annual cost
Stream Restoration Design Services	Survey, stream assessment and project design and permitting	Secure funding by 2013	Maintain funding through 2025	N/A	$50,000 annual cost

Table 21: Urban BMPs that can be implemented to achieve the urban sediment reductions.

BMP Type	Estimated Cost Per Acre With Cost Index Adjustment (King, 2011)	Sediment Reduction per Impervious Acre Treated (lbs)	% Area Of Watershed That BMP Was Applied To In MAST Scenario
Bioretention / Rain Garden	$44,967.30	774.9	7.17
Bio-swale	$39,670.40	774.9	7.17
Dry Detention Ponds and Hydrodynamic Structures	$39,670.40	97.1	7.17
Dry Extended Detention Ponds	$39,670.40	581.2	7.17
Forest Conservation (pervious only)	$39,273.70	168.6	2.00
Impervious Urban Surface Reduction (impervious only)	$131,859.00	767.7	2.00
MS4 Permit 20% Retrofit	$45,080.00	629.7	7.17
Permeable Pavement (no sand or veg. with under drain AB soils)	$216,005.33	678.3	2.00
Stormwater Management by era 1985 - 2002	$67,620.00	387.5	2.00
Stormwater Management by era 2002 - 2010	$45,080.00	774.9	7.17
SWM to the MEP	$36,064.00	872.1	7.17
Urban Filtering Practices	$50,489.60	774.9	7.17
Urban Forest Buffers	$29,752.80	311.6	2.00
Urban Infiltration Practices (no sand/vegetation, no under drain)	$57,206.52	920.6	2.00
Urban Nutrient Management (pervious only)	$54,997.60	-	2.00
Street Sweeping 25 Times a Year	$5,453.78	87.0	7.17
Urban Stream Restoration (per 100' of stream)	$58,153.20	16,604.3	7.17
Vegetated Open Channel	$23,441.60	678.3	7.17
Wet Ponds & Wetlands	$23,545.28	581.2	7.17

The Antietam Creek Sediment TMDL calls for a 58.1% reduction of the Baseline Load (8,490.4 ton/year) for the urban sector which equates to 4,932.9 ton/year. Utilizing the Maryland Assessment Scenario Tool (MAST) website, the amount of BMP implementation necessary to meet the sediment TMDL was calculated using BMP implementation parameters that were established by the County in development of the County's Urban WIP Report. The Washington County Division of Public Works developed a MAST scenario to demonstrate how many acres would have to be treated with the MDE approved suite of BMPs in the MAST in order for the County to reach its nitrogen and phosphorus WIP targets. As part of their analysis for the WIP Urban Sector Report, DPW determined which BMPs provided in the MAST could likely be implemented throughout the county to treat stormwater.

In their report, DPW presented the total area to be treated by a BMP as a "percentage" of the county since that was the only unit that the allowed at the time. The percentages that were used for each BMP application in the WIP report were used in the MAST again to determine the sediment reductions within the Antietam Creek Watershed (HUC 02140502). It should be noted that in the development of the MAST scenarios, the BMPs were applied to percentages of "County Phase I/II MS4 Impervious," "County Phase I/II MS4 pervious," "nonregulated impervious developed," "nonregulated pervious developed," "Municipal Phase II MS4 Impervious," and "Municipal Phase II MS4 pervious" land uses.

Some BMPs could be implemented more often than others and there were a few BMPs that DPW considered unlikely or infeasible to implement in the county due to the karst geology, dominant soil class, or implementation and maintenance costs. Engineers from the City of Hagerstown also developed a similar MAST scenario using the same methods, but for the "Municipal Phase II MS4 Impervious" land use. The "percent area" for BMP treatment that was applied to the municipal areas within the County was applied to the "Municipal Phase II MS4 Impervious" land use in the Antietam Creek Watershed.

A scenario was built in the MAST for just the urban land uses in the Antietam Creek Watershed. The Antietam Creek TMDL calls for a sediment reduction of 4,933.6 tons/year (9,867,200.0 lbs) from the urban sector and once the MAST scenario was completed, a reduction of 5,930.49 ton/year (11,860,983.0 lbs) was achieved. This is an excess reduction of 996.89 tons/year (1,993,783.0 lbs) of sediment that is most likely due to the fact that the "percent area" numbers were developed for nitrogen and phosphorus reduction scenarios. If the County meets the TN and TP WIP targets, then the urban sector of the ACWS will have met its 2025 sediment TMDL goals and vice versa.

The MAST was used to calculate the pound-per-acre reduction for each BMP. There are different loading reductions associated with a BMP in the MAST depending on whether or not the surface area being treated is a pervious or impervious. Since the majority of urban surface that may be treated with one of the BMPs are impervious, the "County Phase I/II MS4 Impervious" land use was used to calculate the BMP reductions, except where the BMP could only be applied to a pervious surface (i.e. Forest Conservation, Nutrient Management, etc.

The "percent area" of BMP treatment area was used in the development of the County's WIP Urban Sector Report and the same numbers were used here for consistency and for planning purposes only. These numbers in no way constitute a commitment by the Washington County BOCC or municipalities of Washington County to the reduction scenario discussed here.

6.2.1 Funding

<u>Pasture, cropland and livestock BMPs costs</u>

Unit cost estimates for pasture BMPs were provided by Washington County Soil Conservation District. Pasture, cropland and livestock BMPs will be pursued through Conservation Reserve Enhancement Program (CREP), Maryland Agricultural Water Quality Cost Share Program (MACS),Environmental Quality Incentives Program (EQIP), and Wildlife Habitat Incentives Program (WHIP) enrollments. However, there may be a need in Antietam Creek for cost share funding for fencing close to, or at the top of, streambanks. The MACS implements the cover crop program with funding from the Chesapeake Bay Restoration Fund, 2010 Trust Fund and targeted Federal grants.

The various cost-share programs pay only a portion of the BMP implementation costs the range of cost share percentage varies from 50% to 87.5% depending on landowner program eligibility. The remaining costs are born by the individual landowners.

Many of the landowners in the watershed are of the Mennonite faith and do not accept cost share funds from any source. These individuals would bear the entire cost of BMP implementation. Innovative methods of accomplishing BMP implementation will need to be developed to accelerate BMP adoption in this community.

<u>Natural Stream Design costs</u>

Costs are divided into two categories, implementation and design services. Often funding is only available from grant funders for implementation costs. This presents a challenge to local partners who do not have the staff capacity to provide the level of sophistication needed to survey, design and obtain construction permits for the projects. Federal, State and Local requirements require that professional surveyors and professional engineers provide be involved in the design process and ultimately approve the designs for implementation. Funding will be sought to hire such professionals to work collaboratively with the WRP partners to accomplish this design phase of stream restoration. Funding will be pursued from Federal, State, Local and private organizations

Education/outreach costs

In order to accelerate implementation of BMPs in the watershed it will be necessary to employ an outreach and education specialist. This position will focus on adult education in the agricultural community and coordinate urban landowner/landuser education and outreach efforts. This position will partner with existing organizations such as the University of Maryland Cooperative Extension Service, Canaan Valley Institute, the Chesapeake Bay Foundation and other federal and state agencies to accomplish the needed education and outreach.

Monitoring costs

Monitoring of pre and post implementation will need to occur in a strategic manner according to the amount of implementation being conducted throughout the watershed. TMDL monitoring stations have been established and will need to be monitored on a bi-annual basis for bacteria, and sediment monitoring will need to be modified to follow implementation of BMPs. Long-term monitoring within the watershed may be addressed through a network of auto-loggers that will record data at continuous set intervals.

6.2.2 Funding Sources

This section contains a list of know possible funding sources that contribute to implementation of the management practices identified in section

Table 22- Funding Sources (Existing/Potential)

Type	Source Name	Strategic Use
Federal	319(h) Grant, Federal Clean Water Act	BMP implementation consistent with an EPA-accepted watershed plan. Also before/after monitoring of BMP implementation. Education and Outreach and Stream Restoration design funding.
Federal	USDA, NRCS, Farm Bill Conservation Programs (EQIP,WHIP, CREP and Cooperative agreements with SCD.	BMP implementation funding and Conservation Technical Assistance funding for preparation of Soil Conservation and Water Quality Plans and Stream Restoration design funding.
Federal	Chesapeake Bay Implementation Grant (CBIG) Federal Clean Water Act	Currently funds 1 Conservation Planner, 1 Conservation Technician and a Nutrient Management Specialist focused in the Antietam Creek watershed. For preparation of SCWQP's NMP's and BMP Implementation.
Federal	Innovative Nutrient and Sediment Reduction Grant, administered by National Fish & Wildlife Federation	The creation of innovative and cost-effective projects that reduce N, P and sediment to the Bay. Funding can be used to support construction, analysis, monitoring, and policy implementation, preferably in concert. http://www.nfwf.org/chesapeake
Federal	Small Watershed Grants Program, administered by National Fish & Wildlife Federation	The development of projects that improve water quality, restore habitat, and/or build citizen-based resource stewardship. Funding can be used to support design and/or construction with project analysis and monitoring if required. http://www.nfwf.org/chesapeake
State	Maryland Department of Agriculture Office of Resource Conservation annual support to WCSCD	Preparation of Soil Conservation and Water Quality Plans. Survey, Design, Construction oversight and certification of BMPs

State	Maryland Agricultural Water Quality Cost Share Program	BMP implementation funding
State	Chesapeake and Atlantic Coastal Bays Trust Fund, administered by Maryland Dept of Natural Resources	Supports implementation of projects the reduce N, P and sediment transported to the Bay. Funding preference is given to construction, some design is supported. http://www.dnr.state.md.us/ccp/funding/trust_fund.asp
State	Chesapeake Bay Trust	Watershed planning, implementation of water quality projects, new/innovative techniques for treating nutrient and sediment, green streets/infrastructure concepts & designs, community greening (urban tree canopy). www.cbtrust.org
Local	Annual Budget for SCD	Soil Conservation District management and oversight of Watershed Plan Implementation
Local	Annual CIP Budget for Washington County	Funding for stream restoration design and implementation and tree planting projects
Private	Chesapeake Bay Foundation	Funding for pasture consultant to facilitate Management Intensive Grazing and conversion of croplands to pasture acres

7. Information, Education and Public Participation (Criteria E)

This section of the plan includes the stakeholder outreach strategy including planning for public meetings, listing of stakeholders identified to date, and education and outreach materials.

Table 23- Stakeholder Outreach Strategy for the Antietam Creek Watershed Plan

Preliminary Outreach and Education 2013-2017	Initiate outreach with key stakeholders focusing on: 1) Landowners potentially affected by watershed plan, 2) Groups and individuals potentially interested in plan goals, 3) Partner agencies concerned with NPS pollution management.
Public Participation 2013-2017	Upon release of the approved watershed plan, input from stakeholders and the public will be gathered and, as appropriate, incorporated as a watershed plan update. A public meeting will be held early 2013 in cooperation with interested groups such as the Canaan Valley Institute, Antietam Creek Watershed Alliance and the Beaver Creek Watershed Association.
Implementation Outreach 2013-2025	For stream segments where BMP implementation is anticipated, "pre-implementation outreach" with landowners and other stakeholders who have a direct stake in BMP implementation will be conducted. Input gathered during pre-implementation outreach will be used to help assess the feasibility of BMP implementation. Individual contacts with farm owners and operators will be conducted as part of the farm conservation planning process. For key landowners and stakeholders identified during pre-implementation outreach, communication will be continued during BMP implementation as needed to maintain stakeholder support. Post-implementation outreach will be addressed through Annual Progress Reporting and End Phase Assessment.
Annual Progress Reporting	Each year progress will be reported in MDE's NPS Program Annual Report, which is made available to the public via the Internet. Other special reports the may be generated will also be made publicly available. Because the majority of agricultural BMPs that will be installed also support the Watershed Implementation Plan for Washington County and the entire Chesapeake Bay annual reporting will be provided to the County and Maryland Department of Agriculture to ensure any progress is recognized as part of the larger scale efforts.
End Phase Assessments 2015, 2020, 2025	Progress toward meeting milestones will be assessed and findings in the form of watershed plan updates will be made available to the public. Input from stakeholders and the public will be gathered and, as appropriate, may be incorporated into the watershed plan as a plan update. If the assessment findings indicate that the plan should be modified, a plan addendum will be released to the public. Changes in water quality impairment (delisting) will be made public (MDE Internet). Interest in a public meeting will be solicited and, if the solicitation generates interest, a public meeting will be held in cooperation with the Washington County SCD.

Table 24- Stakeholders Identified in the Antietam Creek Watershed, February 2012

Citizen Groups	Antietam Creek Watershed Association (ACWA) The ACWA has a vested interest in projects proposed for the Antietam Creek Watershed. ACWA has been a key partner in development of the watershed plan. They are active in the watershed hosting an annual trash clean up, promoting recreational activities and act as advocates for the Creeks health. Beaver Creek Watershed Association (BCWA) has a vested interest in the sub watershed of Beaver Creek. BCWA has completed three important stream restoration projects in cooperation with the SCD and other partners such as Trout Unlimited to reduce stream bamk erosion and improve trout habitat. Antietam Fly Anglers (AFA) The AFA have participated in various restoration activities by providing funding and volunteers for tree plantings.
Land Owners	Private land owners, Washington County State of Maryland, Department of Natural Resources (DNR): - Forest Service - Park Service -Wildlife and Heritage National Park Service (Antietam National Battlefield) National Park Service (Chesapeake and Ohio Canal National Historical Park)
Government	Washington County Soil Conservation District Washington County (various agencies, elected officials) Md Dept. of Natural Resources: Fisheries Service, Wildlife and Heritage, and Forestry Service Md Dept of the Environment: NPS management, permitting Pennsylvania (state/local): coordination for upstream watershed US EPA: NPS management US Dept of Agriculture, Natural Resource Conservation Service (NRCS)
Private Business	Washington County Chamber of Commerce Others

Education and Outreach Materials

WCSCD will seek funding to hire an outreach and education specialist to implement the education and outreach portion of the plan. This individual will develop the materials listed below, coordinate the activities of all partners in outreach and education to both the farm and urban communities of landowners and land users.

Ongoing programs of outreach will continue through community events such as the Washington County Home Builders show, Washington County Ag Expo, Boonsboro Green Fest and Sharpsburg Heritage Days.

Informational Kiosks will be placed at ten locations in the watershed on public lands to provide educational materials to watershed residents and encourage voluntary implementation of individual actions to reduce sediments and bacteria.

A pet waste campaign will be initiated to educate pet owners on the need to collect and properly dispose of pet waste. This effort will build on the current efforts of the City of Hagerstown to provide pet waste disposal bags in public places frequented by pet owners.

Develop a watershed specific publication that will identify each sub-watershed and specific actions citizens can take to reduce bacteria and sediment loads from land they own or operate.

WCSCD maintains a web site at www.conservationplace.com with a variety of information and education materials related to no-point source pollution.

MDA maintains farming and homeowner related education and outreach materials on the Internet at:

http://www.mda.state.md.us/resource_conservation/technical_assistance/index.php

Citizen Participation in Education and Outreach

The Antietam Creek Watershed Alliance (ACWA), the local nonprofit watershed group, is committed to participating in implementing this plan. ACWA is actively engaged in projects that will lead to a reduction in pollutants such as nutrients, sediment, fecal coliform bacteria, and trash entering Antietam Creek and its tributaries. Through these projects they have gained visibility in the community for the issue of water quality in its streams and creeks. They communicate both through conversation and direct mailings with residential and agricultural landowners to learn about their concerns regarding the Antietam Creek watershed and in turn to share information about the need for BMPs such as proper septic system maintenance, stormwater runoff, riparian forest buffers and livestock fencing. ACWA through its activities and community network is well positioned to assist in the education and information component of this plan which will be the coordinated responsibility of all WRP partners.

Wastewater outreach

Canaan Valley Institute focuses on improvements to wastewater treatment systems to reduce pollution to the region's rivers and streams caused by inadequate wastewater treatment and have considerable experience in the development of regional comprehensive wastewater plans. These plans typically focus on four components: community engagement; assessment; identifying options; and assisting and coordinating design and implementation.

Other forums will also be used to reach out to homeowners. CVI has extensive experience in hosting public workshops on wastewater issues. Such workshops are developed to inform local citizens on: the effects of wastewater pollution on a watershed, proper maintenance and care of an onsite wastewater (septic) system, alternative options to traditional wastewater systems, and available financial assistance programs. The project team will also meet with reporters to develop articles for local newspapers about onsite maintenance.

CVI will also continue the well established relationship between CVI and ACWA for disseminating project goals to the public by developing displays and information booths at local fairs and festivals across the project area.
CVI has already developed courses on alternative onsite and subsurface disposal systems. These training courses will be made available to installers and sanitarians in the project area. Another critical component of improving wastewater treatment in the project areas will be working to educate developers about alternative treatment systems. Information

packets will be designed specifically for this group and we will work with sanitarians and other local leaders to identify key stakeholders.

Another avenue for education will be through a more technical approach. Working with consultants and technical providers, Canaan Valley Institute will provide education and technical assistance for the public and the administrators in Washington County. CVI focuses on improvements to wastewater treatment systems and natural stream design (NSD) to reduce pollution to the region's rivers and streams. CVI has considerable experience in the development of regional comprehensive wastewater plans and in designing and overseeing construction of NSD projects. Planning efforts typically focus on four components: community engagement; assessment; identifying options; and assisting and coordinating design and implementation. CVI also has extensive experience in hosting public workshops on water quality issues. Such workshops are developed to inform local citizens on:

- The effects of wastewater pollution on a watershed
- Proper maintenance and care of an onsite wastewater (septic) systems
- Alternative options to traditional wastewater systems
- Available financial assistance programs
- The benefits of stream stabilization and Natural Stream Design

8. Implementation Schedule and Milestones (Criteria F/G)

Due to the broad scope of bacteria and sediment impairment mitigation distributed through the Antietam watershed, a phased implementation schedule with milestones and measurable goals is detailed in this section. Because of the recent addition of the Chesapeake Bay TMDL being introduced by EPA, this plan will follow the implementation schedule outlined in its strategy.

These sections will be revisited in future iterations of this WRP.

8.1 Phase I (2012-2017)

Phase I seeks to address the highest priority sub-watersheds (ANT0277), MRS0000, and BEC0001for bacteria, sediment and identified stream restoration opportunities. During this period, suitable stakeholders will continued to be identified as partners in phase I and phase II project implementation.

An outreach campaign will be conducted to contact private stakeholders in order to secure access to properties and participation for implementation of phase I and phase II practices.

WCSCD will continue with implementation of BMP's on agricultural lands utilizing current staff and available cost share programs from Federal and State sources. WCSCD will seek to maintain and increase funding for staff from the Maryland Department of Agriculture, Chesapeake Bay Trust Fund, Chesapeake Bay Implementation Grant, Chesapeake Bay Foundation and the Natural Resource Conservation Service while seeking additional staff and resources from the 319 program and other sources.

8.1.1 Secure Implementation Funding

• *Secure funds for implementation projects*. Each year of project implementation, WRP partners will secure funds to pay capital costs from the 319 program, and alternative sources.

Agricultural BMP's will be funded on an ongoing basis dependant on available funding from state and federal agricultural BMP cost share programs.

8.1.2 Coordinate Project Design and Materials

• *Begin Pre-Implementation Monitoring.* The WRP partners have coordinated with the MDE 319 monitoring group to begin pre-implementation monitoring of water quality and biological conditions of specific phase I restoration sites in accordance with the proposed monitoring strategy. Additional monitoring by local partners will be included as well to cover the long-term change in sites.
• *Develop specs and site design*. The WRP partners will plan and begin to implement projects in the selected phase I project sites to improve existing water quality in the watershed. Preliminary designs for each mitigation measure or agricultural BMP will be developed based upon observed water quality problems and measured , erosivity and BEHI site inspections.
• *Permits.* Identify and acquire all the necessary permits to place the proposed measures in non-tidal freshwater streams prior to implementation of each BMP or stream restoration project.
• *Select Contractor/s.* Bid out scope to make sure that the contractors necessary to build stream restoration projects are in place.

8.1.3 Conservation Planning on Agricultural Lands

- WCSCD staff will indentify farms in the priority watersheds that are in need of a SCWQP, those in need of an updated SCWQP and complete plans where needed to document opportunities for BMP installation
- WCSCD staff will visit all dairy operations in the priority sub-watersheds to offer conservation planning and technical and financial assistance for BMP implementation.
- WCSCD staff will document farmer installed and non-cost shared BMP's already existing on agricultural lands utilizing the Non-Cost shared Best Management Practice Verification Procedures Manual developed by the Maryland Department of Agriculture as part of the conservation planning process (Appendix A).

5-year goals

• *Reassess the big picture*. At the end of a five year period, the WRP partners will reassess the strategic priorities for sediment, bacteria and any additional stressors identified in the watershed. This assessment will be used to track improvements over time and to help plan additional mitigation projects in other sections of the watershed as well as determining priorities for additional Phase I and II management measures.

• *Phase II preliminary analysis.* Site selection and initial design of phase II projects will be place in order to prepare for the next phase of implementation. Identify all potential stakeholders for site selection and begin outreach with private land owners for participation in the process.

8.1.4 Install management measures

March 2013 – December 2017

• *Build new projects*. As funds are secured, new projects will be built. In the short term, the sites selected will be based on available funding, priority assigned by this plan.

5-year goals

• *Begin monitoring project effectiveness.* Once baseline standards are taken, allow time for the project to begin working and sample at regular intervals to reflect the changes in Low and High flow impairments in accordance with the proposed monitoring strategy.

• *Demonstrate Success/Change the plan.* Identify success stories of mitigation projects throughout the watershed. Analyze what works and what does not work to modify the plan as appropriate. Incorporate any new or improved strategies to meet the TMDL in an appended timeline as appropriate.

8.1.5 Measurable goals for Phase I

By the end of Phase I in December 2017, the following measurable goals will be achieved:

•WCSCD will complete Soil Conservation and Water Quality Plans on 80% of the farms located in the sub-watersheds identified as first priority during phase I. These plans will identify opportunity for BMP implementation and document current levels of BMP adoption by farmers.

• *Project implementation.* Stream restoration projects and agricultural BMP's will have been installed on Phase I project areas of this watershed plan. These projects will function well enough to demonstrate that a reduction in bacteria and/or sediment has been accomplished. An estimated 215 septics will be fixed to Best Available Technology.

• *Water Quality Monitoring.* Instream water chemistry measurements will show that these treated reaches of the Antietam or its tributaries are meeting water quality standards for TSS and are showing a 25% reduction in bacteria.

• *Biological Monitoring.* Biological communities at the end of the five year period will show improvement in diversity of species and size of communities.

• *Document Results.* Success stories will be generated for projects where applicable. Agricultural BMP's will be tracked by the WCSCD in the Conservation Tracker program in cooperation with MDA to ensure all installed BMP's meet established NRCS standards and specifications. Sediment and bacteria reductions will be assessed for all documented BMP's and stream restoration projects.

• *Outreach for Phase II.* WRP partners will have created an additional inventory of implementation projects with private land owner permissions, preliminary monitoring plan created, and and in some cases designs in place. The Antietam

Creek Watershed Restoration Plan will need to be evaluated at this time to determine if modifications are warranted in order to continue with the next implementation phase.

8.2 Phase II (2018-2025)

8.2.1 Secure additional funding

• *Secure funds for reclamation projects***.** Funding sources will depend on the successful implementation of phase I projects as well as the types of projects being funded.

• *Investigate other funding sources***.** NRCS, State Revolving Loan Fund, US Fish & Wildlife and US Army Corp of Engineers funds will also be investigated.

8.2.2 Coordinate Project Design and Materials

• *Select next sub-watersheds to concentrate BMP implementation.* Project partners will evaluate progress water quality data and implementation opportunities to re-focus implementation in additional sub-watersheds

• *Select Mitigation Technologies.* Based on the results of phase I projects assessment, WRP partners will decide whether or not to continue with the technologies evaluated in phase I or to use different technologies to address sediment and bacteria in the phase II areas.

• *Develop specs and site design***.** Secure the personnel and resources needed to accomplish this task.

• *Select Contractor/s.* Bid out scope to make sure that the contractors necessary to construct stream restoration projects and bank armaments as well as any filtering or infiltration practices are in place.

<u>Annual goals</u>

• *Reassess the big picture***.** At the end of each year, WRP partners will reassess the strategic priorities in the phase II operating area. This assessment will be used to track progress over time and to help evaluate the potential for additional mitigation, operations and maintenance priorities for Phase I and II management measures.

8.2.3 Install management measures

• *Install projects***.** Secure landowner permissions, permits and establish agreements to operate and maintain mitigation projects.

• *Operate and maintain existing sites.* Continue to maintain and assess phase I sites as well as incorporating the needs of projects in the phase II operating area.

• *Continue monitoring project effectiveness.* Continue to assess phase I and phase II implementation in accordance with the proposed monitoring strategy.

8.2.4 Measurable goals for Phase II

By the end of Phase II in December 2025, the following measurable goals will be achieved:

• All projects identified in **Table 15** of this plan should be completed.

• *Water Quality Monitoring.* Instream water chemistry measurements will show that all treated tributaries of the Antietam Creek are meeting water quality standards for sediments and bacteria. Measurements in the Antietam Creek mainstem below these projects will also show that it is meeting standards.

• *Biological Monitoring.* Biological communities at the end of the five year period will show improvement in diversity of species and size of communities. Pollution intolerant species should begin to recolonize areas that were previously too acidic for their survival.

• *Document Results.* A summation of the mitigation strategies and observed reductions will show that the Maryland portion of the Antietam Creek is meeting water quality goals for the local TMDL and the Chesapeake Bay TMDL.

9. Load Reduction Evaluation (Criterion H)

Overall, success of this watershed plan will be determined by the extent that the Maryland water quality standards for sediment and bacteria are met in previously impaired stream segments of the Antietam Creek watershed identified in the Antietam Creek TMDLs created in 2008 and 2009 (respectively). In order to effectively document success for the impaired segments, all Best Management Practices implemented during Phase I and Phase II of the WRP will be tracked according to the 9 Antietam Creek subwatersheds identified in **Figures 8 and 14-17**.

In addition, there are other important measures of success to be considered by meeting sediment standards across the watershed in supporting more healthy populations of benthic macroinvertebrates and fish. This section presents quantitative and qualitative criteria for gauging progress and success. This section also presents approaches to adaptive management based on both criteria. Results of adaptive management, such as watershed plan updates and addenda, will be made available to the public. When a watershed plan addendum is available for public consideration, an opportunity for a public meeting will be offered (see Section E).

2017 milestone adaptive management threshold criteria that will trigger update or modification to this watershed plan:

- If sediment loads in the water column where BMP implementation has occurred do not reflect the 60% reduction estimated in the plan within the first milestone in 2017, then a re-examination of the methodology for sediment reductions and practices will trigger a plan update.
- If bacteria loads, particularly from livestock, do not show 25% reduction within the first phase of the plan, then the plan will be rewritten to incorporate newer technologies such as manure digesters which have been proven to remove up to 90% of bacteria in manure.
- If the Phase I goal for Soil Conservation and Water Quality Plans on 80% of the farms located in the first priority sub-watersheds is not achieved by a large margin indicating that insufficient stakeholder buy-in is a significant local issue, then the WCSCD and its partners will hold a local agricultural community summit focused on the priority watersheds area to actively involve farm owners/operators in sharing ideas on local successes and inhibiting factors and in building a local consensus on how to promote and accelerate buy-in during Phase II. Results of the summit will be used to update/revise the watershed plan if appropriate.
- If new TMDLs are approved in the Antietam Creek watershed, then the plan will be updated to address the impairment identified.

2025 milestone adaptive management threshold criteria that will trigger update or modification to this watershed plan include the failure to meet any of the TMDLs established for the Antietam Creek watershed.

<u>TMDLs are not met</u>

A summation of the mitigation strategies and observed reductions will show that the Maryland portion of the Antietam Creek is either meeting or not meeting the local or Chesapeake Bay TMDL. If adaptive management strategies determine the remainder of the impacting load is being generated within the state of Maryland, the focus will be on continued effort on mitigating those inputs within MD's borders. A plan update will be conducted in 2026 to address the load reductions to meet whichever TMDL is not being met and to provide a timeline that will achieve that goal.

<u>TMDLs are met</u>

If the loads being generated are being received from Pennsylvania, Maryland will appeal to Pennsylvania Department of Environmental Protection to focus mitigation in upstream areas of the Antietam Creek watershed. If Maryland is meeting its obligations established under the TMDL, it will then remove Antietam Creek from Maryland's 303(d) list of impaired waters.

9.1 Stream Segment Criterion for Biology

For each stream segment that is 1) receiving BMP implementation proscribed in this watershed plan, and 2) has a biological impairment that both appears on Maryland's 303(d) list of impaired watershed and the source assessment indicates that the impairment is caused by sedimentation, the Stream Segment Criteria for Biology is to attain a "fair" or "good" Index of Biotic Integrity for benthic macroinvertebrates and fish. After the stream segment has received some mitigation measures, stream segment monitoring for biology as described in Section 10 will be conducted to measure progress and to document success in meeting this criterion.

Adaptive management threshold criteria for biology for stream segments that will trigger update or modification to this watershed plan:

If stream biological health does not improve within several years of successful sediment mitigation monitoring, additional analysis will be conducted to ascertain if other impairments appear to be limiting improvement. After the analysis is completed, a watershed plan update or an addendum will be made available that presents the findings of the analysis and any changes to the watershed plan that are appropriate as a result.

10. Monitoring (Criterion I)

Baseline historic conditions of water quality in the Antietam Creek watershed have been documented through the TMDL studies as well as synoptic surveys conducted by MDE. In order to measure project success, it will require a comprehensive stream monitoring strategy to determine if TSS and bacteria TMDLs are being met according to individual designated use of each stream and over the entire watershed. In accordance with the proposed implementation schedule, a detailed monitoring schedule will be conducted in a phased approach with emphasis on evaluation of project effectiveness. Biological Integrity will be used in a qualitative manner to determine the effect of the mitigation/restoration projects on biological communities in impaired streams.

10.1 Phase I Monitoring Plan

10.1.1 Water Quality Monitoring

Water quality samples will be collected bi-annually from the water quality stations identified in the 2009 fecal coliform TMDL **(Figure 8)** to establish long-term trends and determine the cumulative effect of BMP implementation throughout the Antietam Creek watershed. Analyses will include nitrogen, phosphorus, TSS, fecal coliform and chlorides. All laboratories selected will perform the specified analysis in accordance with standard protocols (USEPA 1987, 1999).

In-situ water quality parameters including pH, dissolved oxygen, conductivity, and water temperature will be measured using a handheld water quality meter and stream flow measurements will also be taken at each sample site so that constituent loads can be calculated in the future.

Location and frequency of additional monitoring for individual practices will be based on the number of BMPs within proximity and implemented practices. However, it is anticipated that additional Phase I sampling sites will be based within subwatersheds ANT0277, MRS0000, and BEC0001. This is consistent with the targeted approach to implementation.

10.1.2 - Benthic Assemblage Monitoring

MDE/SSA FED biologists are responsible for performing field biological sampling, as well as, the laboratory processing and taxonomic identification for all benthic organisms collected at each site. Benthic sample stations will be established in relation to mitigation sites to document biological response over time. All sample stations will coincide with the water quality sampling sites as feasible. One benthic station will be established as close to the remediation site as possible, making sure that it is outside any negative influence from the treatment operation. A second site will be established further down stream, preferably below the confluence with the next downstream tributary, in order to document sustained biological effect. Samples will be extracted during the March/April Maryland Biological Stream Survey (MBSS) Spring Index period. Staff biologists will coordinate as appropriate with the Chemical and Biological Monitoring Division and share personnel and resources as necessary. MBSS techniques and protocols will be followed. The exact site locations for each mitigation site have yet to be determined therefore biological monitoring stations location will be determined during Phase I.

10.1.2a – Biological Field Sampling

All field sampling will be performed under guidance established by the MBSS. The Maryland Biological Stream Survey Sampling Manual, February 2000, will serve as the authority. MBSS methods include qualitative sampling of best available habitats incorporating approximately 20 square feet of substrate within each 75 meter designated station. All samples will be collected from riffle areas, as practical, because this is typically the most productive habitat in stream ecosystems. A 600-micron mesh D-net will be used to trap organisms dislodged from the sample area. The composited sample is condensed in the field with a standard 0.5-micron sieve bucket, placed in a sample jar with appropriate field label, and preserved with alcohol. Each sample is then sub-sampled to approximately 100 individual macroinvertebrates in the laboratory using a random-grid picking/sorting process. Most organisms are identified to genus, if possible, using stereoscopes. Chironomidae are slide-mounted and identified using compound microscopes. Habitat conditions will be assessed using standard MBSS methodology. In-situ water quality parameters will be recorded at each station with a multi-parameter field instrument.

10.1.2b - Laboratory Methods

All benthic macroinvertebrates will be processed and identified through guidance established in the MBSS protocol. The laboratory manual "Laboratory Methods for Benthic Macroinvertebrate Processing and Taxonomy" Maryland Department of Natural Resources, November 2000, will serve as the basis for analysis of all field samples collected.

10.1.2c - Data Analysis and Report

Each station will be ranked qualitatively according to the protocols established for calculating the Benthic Index of Biological Integrity (BIBI) score (Stribling et al. 1998.), where "good" equals 4.0-5.0, "Fair" equals 3.0-3.9, "Poor" equals 2.0-2.9 and "Very Poor" equals 1.0-1.9. Each BIBI score will be compared against percentage of the best attainable in stream physical habitat in order to assess relationships between habitat and biology. The benthic IBI will be calculated using Non-Coastal Plain metrics. (Mercurio et al. 1999)

10.1.2d - Habit Assessment

Habitat conditions will be assessed using standard MBSS methodology targeting riffle/run prevalent streams. This methodology involves the field observations of eight parameters, including: instream habitat, epifaunal substrate, velocity/depth diversity, pool/glide/eddy quality, riffle/run quality, embeddedness, shading, and Trash Rating. Each category contains a maximum value of twenty and overall habitat will be rated as a percentage of the best possible score. There are four categories, Excellent 76-100, Good 51-75, Fair 26-50, and poor 0-25. (Stranko et at. 2010)

10.1.3 –Synoptic Surveys

The synoptic survey is a monitoring design which attempts to canvas an entire watershed taking grab samples within a short period of time to glimpse several snapshots of water quality that can be compared with other sampling in that area. In Maryland's case, most sampling is limited to TN and TP, but may involve some TSS. For the Antietam, it will incorporate TSS and periodic bacteria count sampling. An additional synoptic survey is scheduled for completion in 2012 (**Figure 18**), this will add to the general knowledge of baseline water quality conditions within the Antietam Creek watershed.

Continuing to include synoptic surveys during the Phase I project may serve an additional purpose to allow WRP partners to establish a methodology for using nutrient concentrations as an indicator for bacteria concentrations in agricultural areas. Another added benefit will be the overall characterization of the watershed outside of the established long-term stations. A cost benefit analysis of continued synoptic surveys should be conducted near the end of Phase I implementation period to see if continuing this monitoring is warranted in Phase II.

10.2 Phase II Monitoring Plan

The second phase of monitoring will be a modified continuation of the Phase I plan to continue to evaluate long-term effects and an adjustment to the number of monitoring sites selected during Phase I in order to compliment Phase II of implementation. The monitoring plan will need to be revised and adjusted according to any trends observed from the Phase I mitigation projects yet maintain the integrity of the data collected during Phase I and Phase II.

This phase of the monitoring plan should start to be revised in the fifth year of Phase I to create a seamless transition between the two phases and include baseline monitoring in new project areas, as well as continued monitoring of Phase I project areas. Frequency and number of sites depend upon the success of projects implemented.

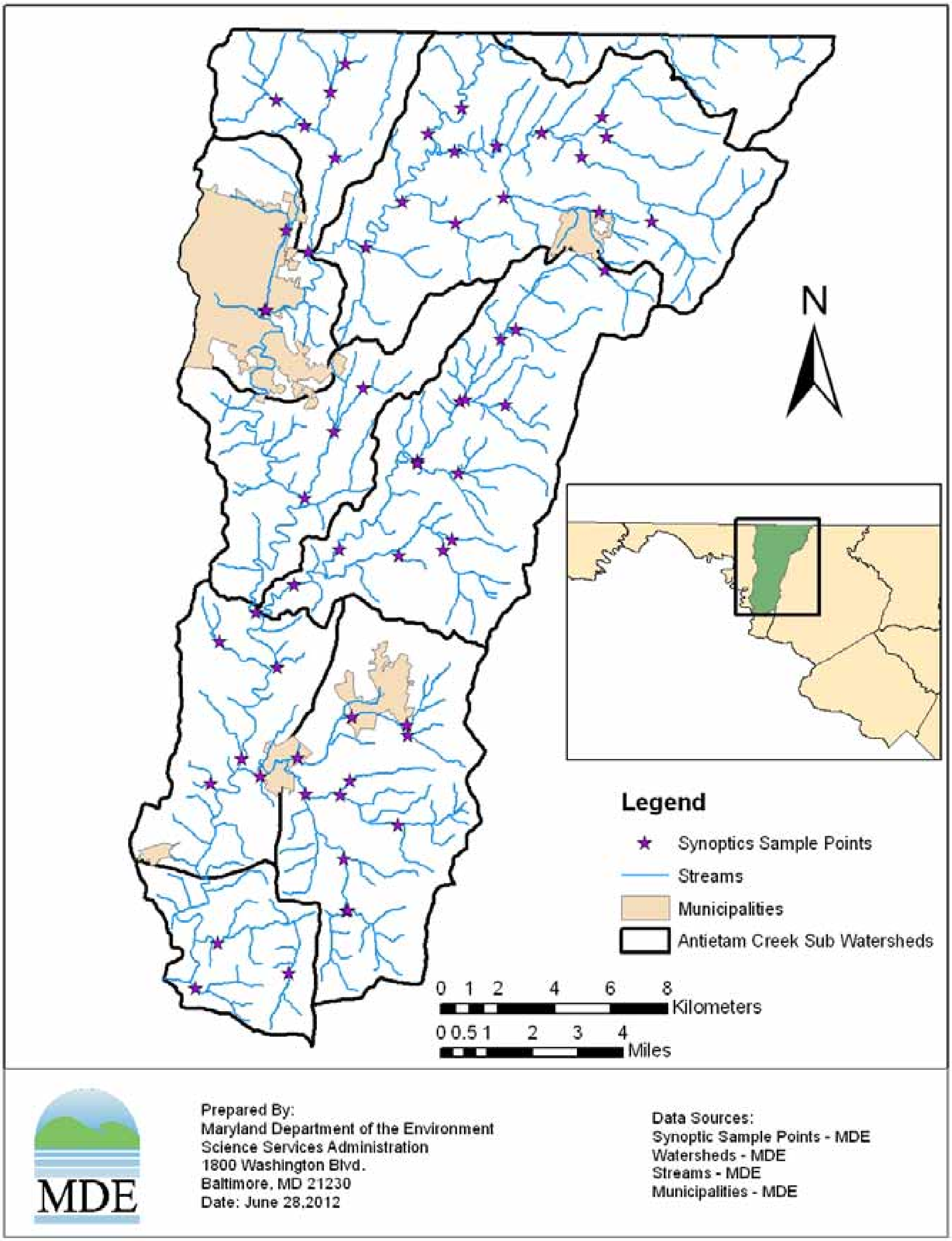


Figure 19 – Synoptic Survey Sites

References:

COMAR (Code of Maryland Regulations). 2005. *Code of Maryland Regulations* (COMAR), Title 26, Subtitle 08, Chapter 02, Section 03 (Surface Water Quality Criteria). <http://www.dsd.state.md.us/comar/getfile.aspx?file=26.08.02.03.htm>

Duigon, M.T. 1997. *A brief discussion of the Project, "Karst Hydrogeology in the Hagerstown Valley, Maryland and its Influence on Ground-Water-Quality Protection"*. Maryland Geologic Survey. Baltimore , MD. 2 pp.

Duigon, M.T. 2001. *Karst Hydrogeology of the Hagerstown Valley, Maryland*. Report of Investigation (RI 73). Maryland Geologic Society. Baltimore , MD. http://www.mgs.md.gov/esic/publications/pubcat19.html#ri73

Duigon, M.T. 2002. *Karst Hydrogeology of the Hagerstown Valley, Maryland* (abstract). Maryland Geologic Survey. Baltimore , MD. 1 p.

Field, M.F. 2006. Tracer-Test Design for Losing Stream-Aquifer Systems. International Journal of Speleology, 35 (1), pp. 25-36. Bologna (Italy).

King, D., Hagan, P. 2011. *Costs of Stormwater Management Practices In Maryland Counties*. Technical Report Series No. TS-626-11 of the University of Maryland Center for Environmental Science.

Maryland Department of the Environment (MDE). 2008. *Total Maximum Daily Loads ofSediment for the Antietam Creek Basin in Washington County, Maryland*.

Maryland Department of the Environment (MDE). 2009. *Total Maximum Daily Loads of Fecal Bacteria for the Antietam Creek Basin in Washington County, Maryland*. <http://www.mde.state.md.us/programs/Water/TMDL/ApprovedFinalTMDLs/Documents/www.mde.state.md.us/assets/document/Antietam_Bacteria_TMDL_09-15-09_final.pdf>

Mercurio, Ginny. Chaillou, Janis C. Roth, Nancy E. 1999. *Guide to using 1995-1997 Maryland Biological Stream Survey Data*. < http://www.dnr.state.md.us/streams/pdfs/R1dataguide.pdf > Accessed September 2010.

National Park Service, 2005. Antietam National Battlefield, Chesapeake and Ohio National Historical Park, & Harpers Ferry National Historical Park, Geologic Resource Evaluation Report. Geologic Resource Division. Denver, Colorado.

Nps.gov, 2005. *Antietam National Battlefield, Geology Fieldnotes*. Park Geology. URL: http://www.nature.nps.gov/geology/parks/anti/index.cfm URL:http://www.nature.nps.gov/geology/parks/anti/anti_choh_hafe_gre_rpt_view.pdf

Stranko, Scott. Boward, Dan. Kilian, Jay. Becker, Andy. Ashton, Matthew. Schenk, Ann. Gauza, Rachel. Roseberry-Lincoln, Ann. Kazyak, Paul. 2010. *Maryland Biological Stream Survey, Round Three Field Sampling Manual*. < http://www.dnr.state.md.us/streams/pdfs/ea-07-01b_fieldRev2010.pdf > Accessed September 2010.

Stribling, James B. Jessup, Benjamin K. White, Jeffrey S. Boward, Daniel. Hurd, Marty. 1998. *Development of a Benthic Index of Biotic Integrity for Maryland Streams.* < http://www.dnr.state.md.us/streams/pdfs/ea-98-3_benthic_ibi.pdf >

West Virginia Division of Water and Waste Management (WVDWWM), 2007, *Total Maximum Daily Loads for Selected Streams in the Potomac Direct Drains Watershed, West Virginia*, Prepared by Water Resources and TMDL Center, TetraTech, Inc. 59 pp. & Appendices

APPENDIX A

MD 2008 Antietam Creek Sediment TMDL
Included as hyperlink for document review
http://www.mde.state.md.us/programs/Water/TMDL/ApprovedFinalTMDLs/Pages/Programs/WaterPrograms/TMDL/approvedfinaltmdl/tmdl_final_antietam_creek_sediment.aspx

APPENDIX B

MD 2009 Antietam Creek Fecal Bacteria TMDL
Included as hyperlink for document review
http://www.mde.state.md.us/programs/Water/TMDL/ApprovedFinalTMDLs/Pages/Programs/WaterPrograms/TMDL/approvedfinaltmdl/tmdl_final_antietam_bacteria.aspx

APPENDIX C

Sediment Calculation Worksheet Example

		Acres	EOS Load (Ton)	EOS rate (ton/ac)	EOF (ton/ac)	Del/BMP Factor
	Animal Feeding Operations	65.1	137.5	2.1121	12.16	0.17363
	Hay	11,256.40	2,967.80	0.2637	1.6	0.164784
	High Till	80.00	6,394.60	79.9325	6.24	0.163159
	Low Till	20,428.40	8,927.70	0.4370	3.74	0.167769
Crop	Nursery	88.5	183.2	2.0701	12.16	0.170176
Extractive	Extractive	101.4	172.4	1.7002	10	0.170004
	Forest	34,169.40	1,484.50	0.0434	0.31	0.140146
Forest	Harvested Forest	345.1	145.1	0.4205	3	0.140134
	Natural Grass	1,878.90	574.2	0.3056	1.5	0.203736
	Pasture	14,335.70	3,226.60	0.2251	1.28	0.175839
Pasture	Trampled Pasture	75	172.1	2.2947	12.16	0.188604
	Urban: Barren	1,631.30	841.6	0.5159	12.5	0.041273
	Urban: Imp	5,860.40	4,899.20	0.8360	5.18	0.161387
Urban	Urban: perv	22,618.30	2,749.60	0.1216	0.74	0.164278
	Total	112,934.90	32,876.00	0.2911	----------	----------
		TMDL	**15,476.50**			

		Acres	EOS rate (ton/ac)	BMP Factor (%)	EOS Load (Ton)
	Animal Feeding Operations	65.1	2.1121	0	137.50
		32.00	2.1121	0.6	27.04
	Hay	11,256.40	0.2637	0	2,967.80
	High Till (untreated)	80.00	1.0181	0	81.45
	High Till (treated)	0.00	1.0181	0.6	0.00
	Low Till	4,968.40	0.6275	0	3,117.45
	Low Till (treated)	15,460.00	0.6275	0.6	3,880.19
Crop	Nursery	88.5	2.0701	0	183.20
Extractive	Extractive	101.4	1.7002	0	172.40
	Forest	34,169.40	0.0434	0	1,484.50
	Harvested Forest	345.1	0.4205	0	145.10
Forest	Harvested Forest (treated)	780.00	0.4205	0.25	245.97
	Natural Grass	1,878.90	0.3056	0	574.20
	Pasture	13,555.70	0.2251	0	3,051.04
	Pasture(treated)	780.00	0.2251	0.25	131.67
	Trampled Pasture	75	2.2947	0	172.10
Pasture	Pasture(treated)	70.00	2.2947	0.1	144.56
	Urban: Barren	1,631.30	0.5159	0	841.60
	Urban: Imp	5,860.40	0.8360	0	4,899.20
	Urban: Imp (treated)	0.00	0.8360	0.75	0.00
	Urban: perv	22,618.30	0.1216		2,749.60
Urban	Urban: perv (treated)	0.00	0.1216	0.75	0.00
	Total	48,142.90			**25,006.57**

APPENDIX D

Bank Erosion Hazard Index/Near Bank Stress Methodology

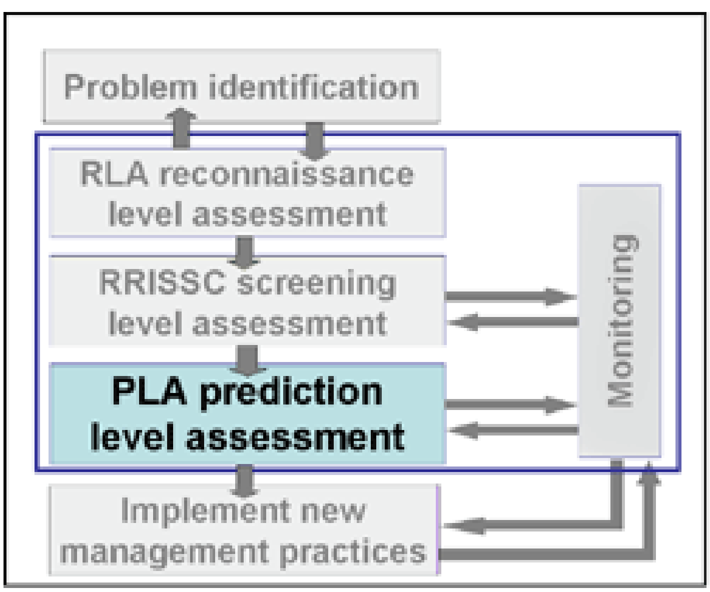
Estimating Sediment Loads using the
Bank Assessment of Non-point source Consequences of Sediment (BANCS)

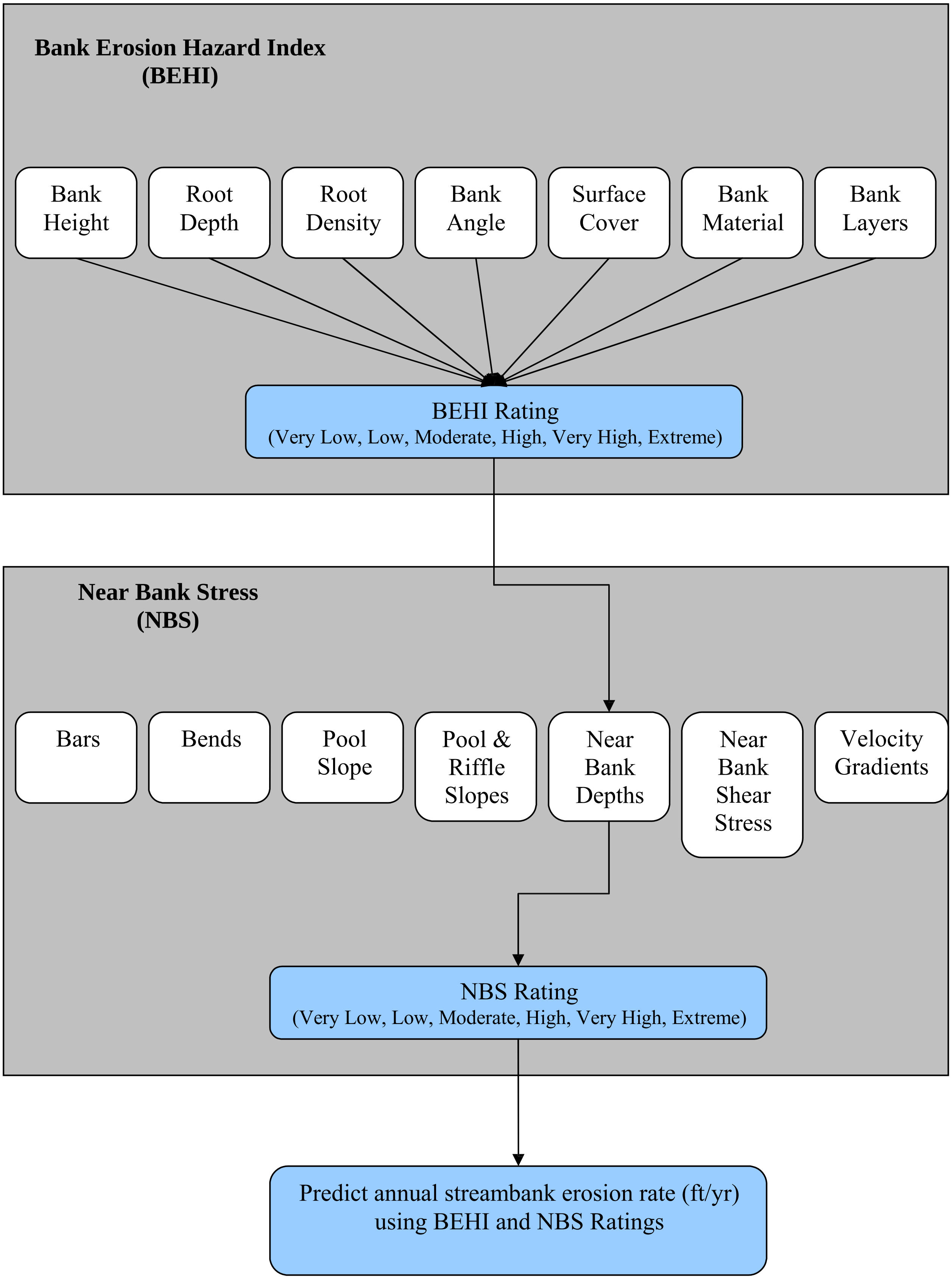
Watershed Assessment of River Stability and Sediment Supply (WARSSS): a technical procedure developed by David L. Rosgen for water quality scientists to use in evaluating streams and river impaired by excess sediment

(images and forms available from EPA WARSSS technical tools website: http://water.epa.gov/scitech/datait/tools/warsss/pla_box08.cfm)

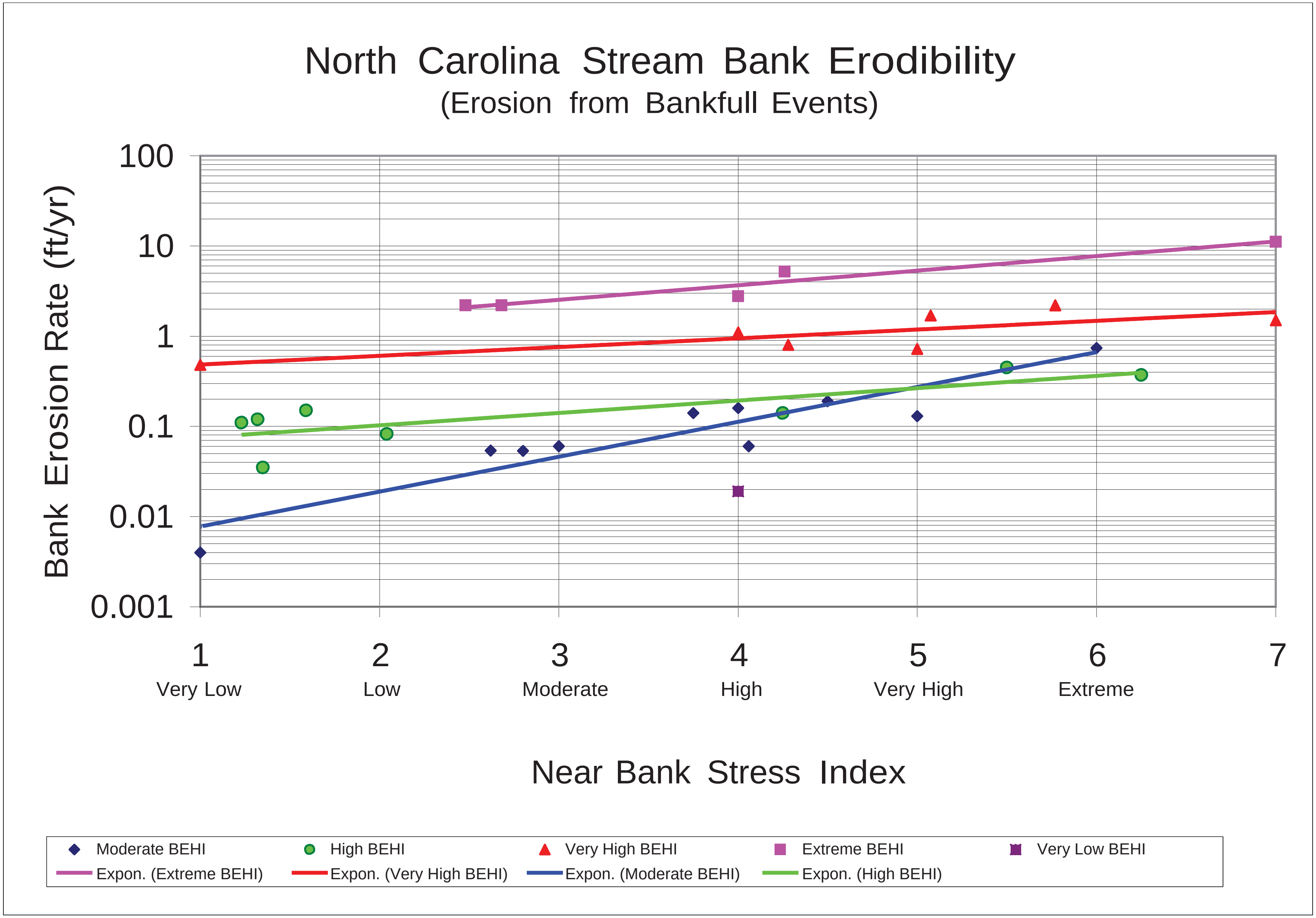
May 10, 2011
Hagerstown, Maryland

Abby McQueen (abby.mcqueen@canaanvi.org)
Canaan Valley Institute





Modified from River Stability Field Guide (Rosgen, 2008)



From "Stream Restoration A Natural Channel Design Handbook" prepared by the North Carolina Stream Restoration Institute and North Carolina Sea Grant (http://www.bae.ncsu.edu/programs/extension/wqg/sri/stream_rest_guidebook/sr_guidebook.pdf)

Worksheet 20. BEHI variable worksheet

Stream:	Cross Section:	Date:	Observers:

Bank Height/Max Depth Bankfull (C)

Study Bank Height (ft) A	Bankfull Height (ft) B	A/B = C

Root Depth/Bank Height (E)

Root Depth (ft) D	Study Bank Height (ft) A	D/A = E

Weighted Root Density (G)

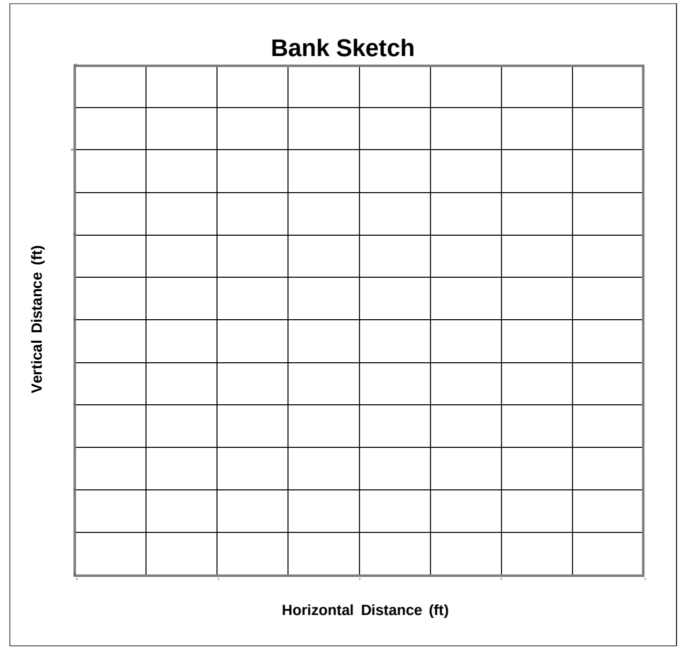
Root Density (%) F	F*E = G

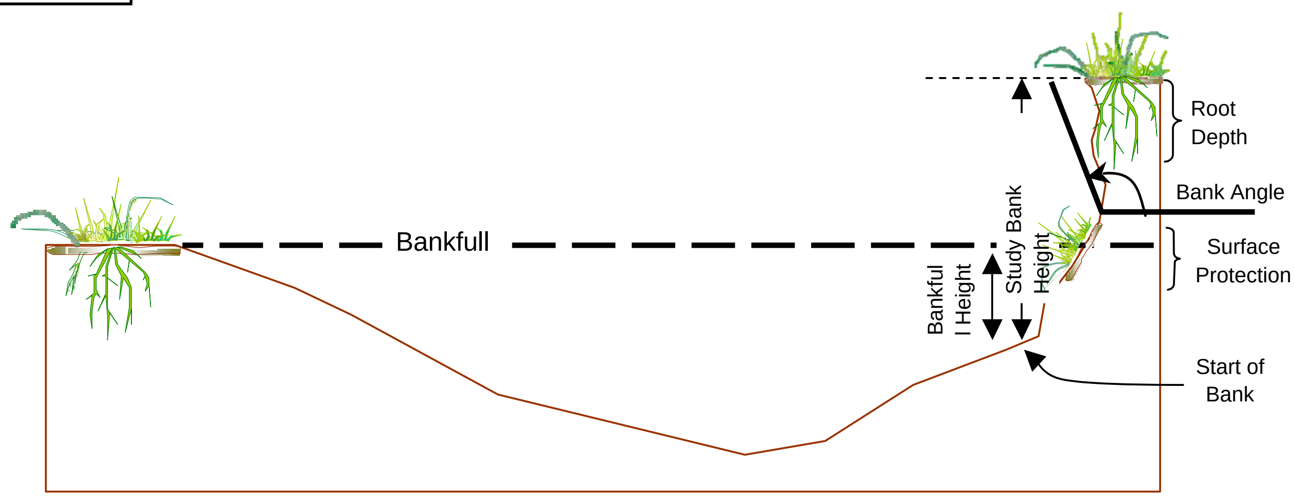
Bank Angle (H)

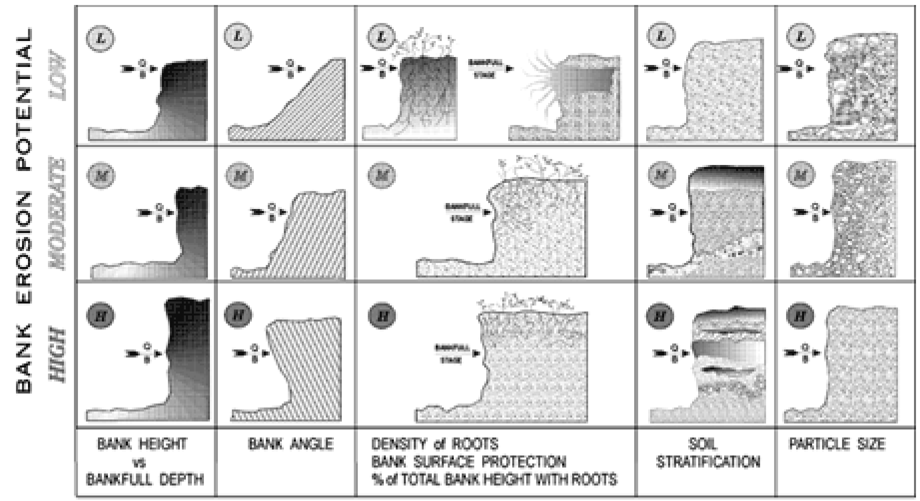
Bank Angle (Degrees) H

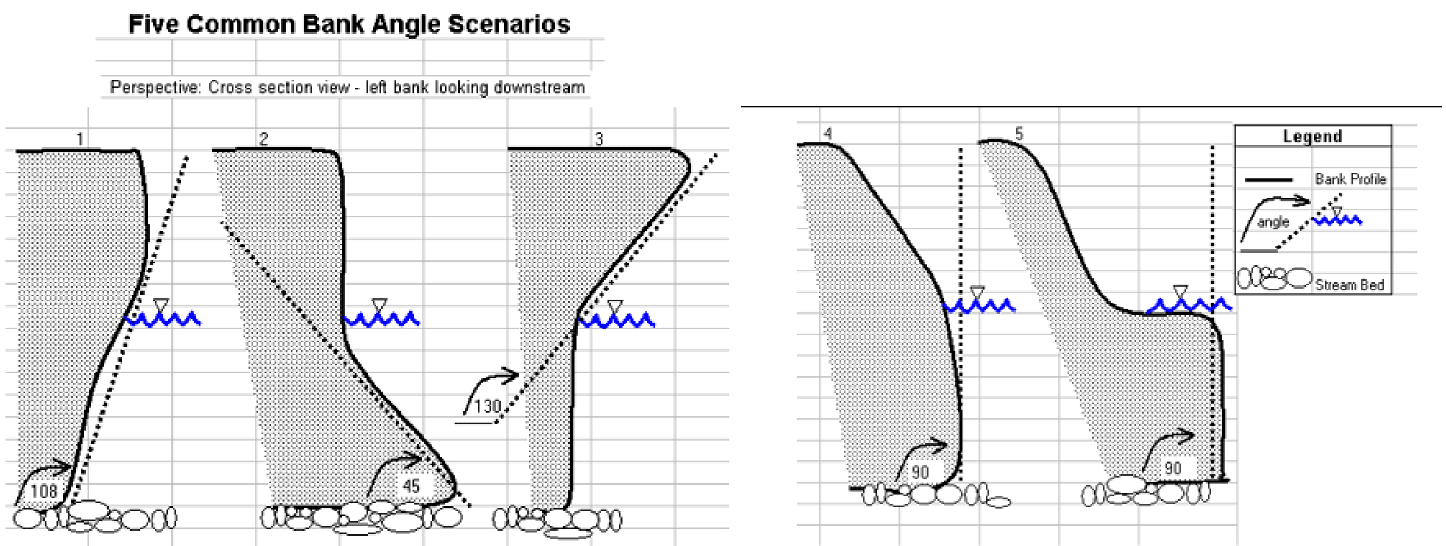
Surface Protection (I)

Surface Protection % I






BANK EROSION POTENTIAL
LOW
MODERATE
HIGH
L
M
H
BANK HEIGHT vs BANKFULL DEPTH
BANK ANGLE
DENSITY of ROOTS
BANK SURFACE PROTECTION
% of TOTAL BANK HEIGHT WITH ROOTS
SOIL STRATIFICATION
PARTICLE SIZE


Five Common Bank Angle Scenarios
Perspective: Cross section view - left bank looking downstream
1
2
3
4
5
108
45
130
90
90
Legend
Bank Profile
angle
Stream Bed

Worksheet 21. Summary of bank erosion hazard index (BEHI)

Bank Erosion Hazard Rating Guide

Stream Reach Date Crew

Bank Erosion Potential	Bank Height (ft): / Bankfull Height (ft):		Bank Height/ Bankfull Ht	Root Depth/ Bank Height	Root Density %	Bank Angle (Degrees)	Surface Protection%
	VERY LOW	Value	1.0-1.1	1.0-0.9	100-80	0-20	100-80
		Index	1.0-1.9	1.0-1.9	1.0-1.9	1.0-1.9	1.0-1.9
		Choice	V: I:	V: I:	V: I:	V: I:	V: I:
	LOW	Value	1.11-1.19	0.89-0.5	79-55	21-60	79-55
		Index	2.0-3.9	2.0-3.9	2.0-3.9	2.0-3.9	2.0-3.9
		Choice	V: I:	V: I:	V: I:	V: I:	V: I:
	MODERATE	Value	1.2-1.5	0.49-0.3	54-30	61-80	54-30
		Index	4.0-5.9	4.0-5.9	4.0-5.9	4.0-5.9	4.0-5.9
		Choice	V: I:	V: I:	V: I:	V: I:	V: I:
	HIGH	Value	1.6-2.0	0.29-0.15	29-15	81-90	29-15
		Index	6.0-7.9	6.0-7.9	6.0-7.9	6.0-7.9	6.0-7.9
		Choice	V: I:	V: I:	V: I:	V: I:	V: I:
	VERY HIGH	Value	2.1-2.8	0.14-0.05	14-5.0	91-119	14-10
		Index	8.0-9.0	8.0-9.0	8.0-9.0	8.0-9.0	8.0-9.0
		Choice	V: I:	V: I:	V: I:	V: I:	V: I:
	EXTREME	Value	>2.8	<0.05	<5	>119	<10
		Index	10	10	10	10	10
		Choice	V: I:	V: I:	V: I:	V: I:	V: I:
	V = value, I = index			**SUB-TOTAL** (Sum one index from each column)			

Bank Material Description:

Bank Materials

- **Bedrock** (Bedrock banks have very low bank erosion potential)
- **Boulders** (Banks composed of boulders have low bank erosion potential)
- **Cobble** (Subtract 10 points. If sand/gravel matrix greater than 50% of bank material, then do not adjust)
- **Gravel** (Add 5-10 points depending percentage of bank material that is composed of sand)
- **Sand** (Add 10 points)
- **Silt Clay** (+ 0: no adjustment)

BANK MATERIAL ADJUSTMENT

Stratification Comments:

Stratification

Add 5-10 points depending on position of unstable layers in relation to bankfull stage

STRATIFICATION ADJUSTMENT

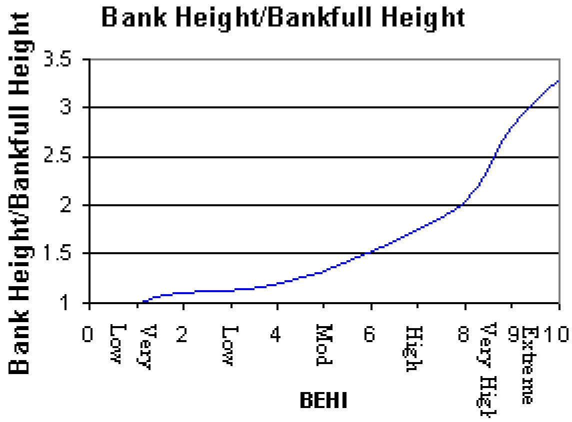
VERY LOW	LOW	MODERATE	HIGH	VERY HIGH	EXTREME
5-9.5	10-19.5	20-29.5	30-39.5	40-45	46-50

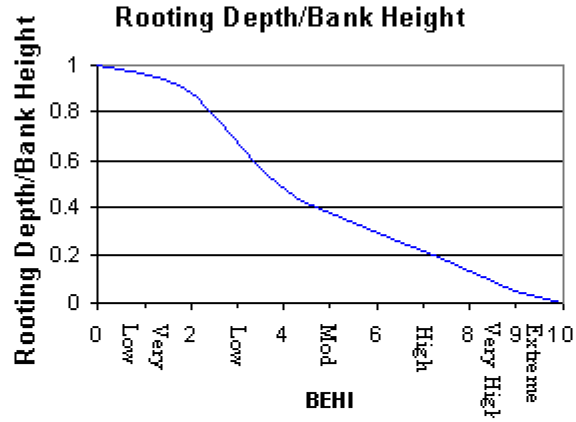
Bank location description (circle one)

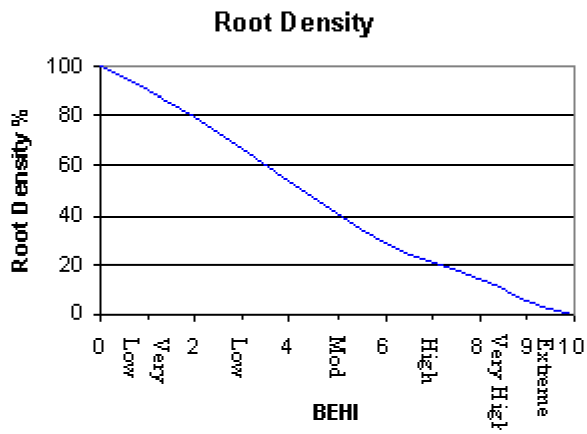
Straight Reach Outside of Bend

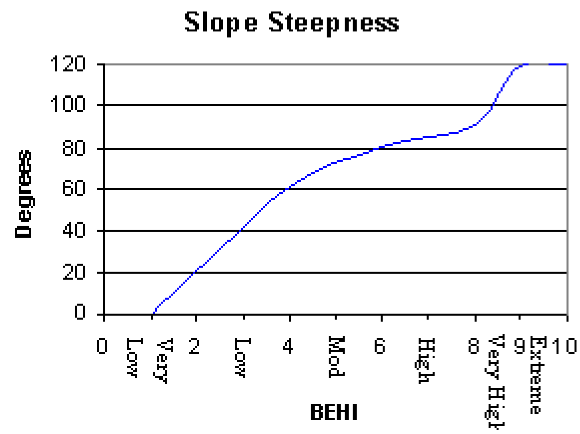
GRAND TOTAL

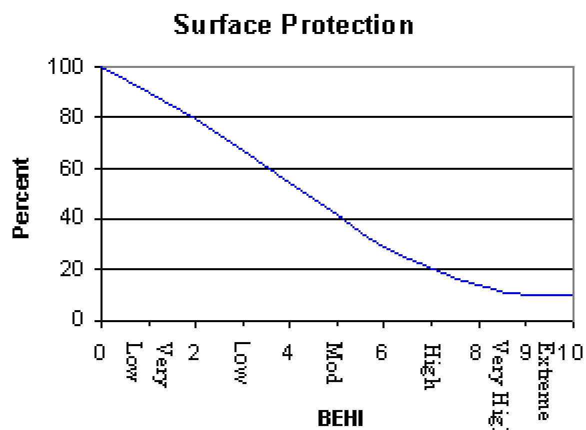
BEHI RATING


Bank Height/Bankfull Height
Bank Height/Bankfull Height
3.5
3
2.5
2
1.5
1
0
Low
Very
2
Low
4
Mod
6
High
8
Very High
9
Extreme
10
BEHI


Rooting Depth/Bank Height
Rooting Depth/Bank Height
1
0.8
0.6
0.4
0.2
0
0
Low
Very
2
Low
4
Mod
6
High
8
Very High
9
Extreme
10
BEHI


Root Density
Root Density %
100
80
60
40
20
0
0
Low
Very
2
Low
4
Mod
6
High
8
Very High
9
Extreme
10
BEHI


Slope Steepness
Degrees
120
100
80
60
40
20
0
0
Low
Very
2
Low
4
Mod
6
High
8
Very High
9
Extreme
10
BEHI


Surface Protection
Percent
100
80
60
40
20
0
0
Low
Very
2
Low
4
Mod
6
High
8
Very High
9
Extreme
10
BEHI

Worksheet 22A. Various field methods of estimating Near-Bank Stress risk ratings for the calculation of erosion rate.

Estimating Near-Bank Stress (NBS)

Stream:		Location:		Date:		Crew:	

Methods for Estimating Near-Bank Stress

(1) Transverse bar or split channel/central bar creating NBS/high velocity gradient: **Level I - Reconnaissance.**

(2) Channel pattern (Rc/W): **Level II - General Prediction.**

(3) Ratio of pool slope to average water surface slope (S_p/S): **Level II - General Prediction.**

(4) Ratio of pool slope to riffle slope (S_p/S_{rif}): **Level II - General Prediction.**

(5) Ratio of near-bank maximum depth to bankfull mean depth (d_{nb}/d_{bkf}): **Level III - Detailed Prediction.**

(6) Ratio of near-bank shear stress to bankfull shear stress (τ_{nb}/τ_{bkf}): **Level III - Detailed Prediction.**

(7) Velocity profiles/Isovels/Velocity gradient: **Level IV - Validation.**

Level I – (1)

- Transverse and/or central bars - short and/or discontinuous. NBS = High/Very High
- Extensive deposition (continuous, cross channel). NBS = Extreme
- Chute cutoffs, down-valley meander migration, converging flow (Figure X). NBS = Extreme

Level II – (2)

Radius of Curvature Rc (feet)	Bankfull Width W_{bkf} (feet)	Ratio Rc/W	Near-Bank Stress

Level II – (3)

Pool Slope S_p	Average Slope S	Ratio S_p/S	Near-Bank Stress

Level II – (4)

Pool Slope S_p	Riffle Slope S_{rif}	Ratio S_p/S_{rif}	Near-Bank Stress

Dominant Near-Bank Stress

Level III – (5)

Near-Bank Max Depth d_{nb} (feet)	Mean Depth d (feet)	Ratio d_{nb}/d	Near-Bank Stress

Level III – (6)

Near-Bank Max Depth d_{nb} (feet)	Near-Bank Slope S_{nb}	Near-Bank Shear Stress τ_{nb} (lb/ft^2)	Mean Depth d (feet)	Average Slope S	Shear Stress τ (lb/ft^2)	Ratio τ_{nb}/τ	Near-Bank Stress

Level IV – (7)

Velocity Gradient (ft/s/ft)	Near-Bank Stress

Converting Values to a Near-Bank Stress Rating

Near-Bank Stress Rating	Method Number (1)	(2)	(3)	(4)	(5)	(6)	(7)
Very Low	N/A	>3.0	< 0.20	< 0.4	<1.0	<0.8	<1.0
Low		2.21 - 3.0	0.20 - 0.40	0.41 - 0.60	1.0 - 1.5	0.8 - 1.05	1.0 - 1.2
Moderate		2.01 - 2.2	0.41 - 0.60	0.61 - 0.80	1.51 - 1.8	1.06 - 1.14	1.21 - 1.6
High	See (1) Above	1.81 - 2.0	0.61 - 0.80	0.81 - 1.0	1.81 - 2.5	1.15 - 1.19	1.61 - 2.0
Very High		1.5 - 1.8	0.81 - 1.0	1.01 - 1.2	2.51 - 3.0	1.20 - 1.60	2.01 - 2.3
Extreme		< 1.5	> 1.0	> 1.2	> 3.0	> 1.6	> 2.3

Overall Near-Bank Stress Rating

Worksheet 23. Total Bank Erosion Calculation

Stream:				Total Bank Length:		Stream Type:	
Observers:				Date:		Graph Used:	
	Station (ft)	**BEHI (adjective)***	**Near Bank Stress (adjective)**	**Erosion Rate (ft/yr)***	**Length of Bank (ft)**	**Bank Height (ft)**	**Erosion Sub-Total (ft^3/yr)**
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							
12							
13							
14							
15							
I. Sum erosion sub-totals for each BEHI/NBS combination						**Total Erosion (ft^3/yr)**	
II. Divide total erosion ($feet^3$) by 27 $feet^3/yard^3$						**Total Erosion (yd^3/yr)**	
III. Multiply Total Erosion ($yard^3$) by 1.3 (conversion of yd^3 to tons for average material type)						**Total Erosion (tons/year)**	
IV. Calculate erosion per unit length: divide total erosion (ton/year) by total length of stream (ft) surveyed						**Total Erosion (tons/yr/ft)**	

*Use numerical category spread to predict rates. (i.e. 21 = Moderate but at start of category, where as 28 is on upper end of relation - use prediction values appropriate to numerical rating).

APPENDIX E

Minnesota Pollution Control Agency Paper

Effects of Septic Systems on Ground Water Quality - Baxter, Minnesota

May, 1999

Published by

Minnesota Pollution Control Agency Ground
Water and Toxics Monitoring Unit
Environmental Monitoring and Analysis Section
Environmental Outcomes Division
520 Lafayette Road North
St. Paul, Minnesota 55155-4194
(651) 296-6300 or (800) 657-3864

Prepared by

Ground Water Monitoring and Assessment Program (GWMAP)

This material may be made available in other formats,
Such as Braille, large type or audio, upon request.
TDD users call (651) 282-5332

Printed with soy-based inks in recycled paper containing at least 10 percent fibers from paper recycled by consumers.

Table of Contents

Acknowledgments

We would like to thank officials from the City of Baxter for making this project possible. Mark Wespetal assisted with input prior to conducting the study and conducted measurements at individual septic systems. Most of all, we would like to thank the numerous property owners who allowed us to sample their wells and septic systems.

List of Tables

List of Figures

Executive Summary

In 1998, the Minnesota Pollution Control Agency (MPCA) conducted a study to determine the effects of septic systems on ground water quality in residential areas of Baxter, Minnesota. The Baxter area is experiencing rapid expansion with unsewered developments. A sensitive aquifer underlies the study area. Numerous lakes are in direct connection with ground water and may be impacted by septic discharges to ground water.

The study was conducted in two phases. In Phase 1, 40 permanent domestic and 12 temporary wells were sampled at different depths in the shallow sand aquifer. Nitrate was the primary chemical of concern. Median nitrate concentrations were significantly higher in areas with Individual Sewage Treatment Systems (unsewered areas; 1980 ug/L or parts per billion) than in areas served by municipal sewers (sewered areas; 778 ug/L). All four exceedances of drinking water criteria (10000 ug/L) were in unsewered areas. Nitrate concentrations were highest in the upper 15 to 20 feet of the aquifer, then decreased rapidly with depth. Denitrification most likely accounts for the decrease in nitrate with depth. Total and dissolved organic carbon were also greater in unsewered areas.

The objective of Phase 2 was to examine concentrations of chemicals within ground water plumes originating beneath individual septic systems. Plumes were observed beneath each of the seven systems sampled. The average plume length was approximately 25 meters and ranged from 10 to over 100 meters. Chloride was used as an indicator of the septic plume. At each site, nitrate concentrations exceeded the drinking water criteria throughout most of the plume. Nitrate concentrations decreased slowly along the plume lengths, as indicated by decreasing nitrate to chloride ratios. If the plumes studied are typical of plumes throughout Baxter, one acre lots should result in about 7 percent of the shallow portion of the aquifer having nitrate concentrations above the drinking standard. Twenty-five percent of the geoprobe wells drilled during Phase 1 exceeded the HRL, however. The higher than expected rate may be due to biases in sampling, inputs from fertilizers, lot sizes smaller than one acre, or typical plumes being longer than those that were sampled.

Bacteria and Volatile Organic Compounds (VOCs) were found in septic effluent at all seven sites. Most probable number concentrations of total coliform were as high as 200000/100-mL. These concentrations are similar to those observed in the literature. Concentrations of coliform bacteria in ground water decreased by two orders of magnitude within 15 meters of the drainfield. Total VOC concentrations in septic tanks ranged from 138 to 800 ug/L. The most common VOCs were substituted benzenes, which accounted for about 67 percent of the 41 total detections. There were thirteen VOC detections in ground water, eleven of which were chloroform. There were no exceedances of drinking water criteria for VOCs.

Phosphorus is an important chemical of concern in northern Minnesota because of the recreational value of lakes. There were no significant differences in phosphorus concentrations in ground water under sewered and unsewered areas. Phosphorus concentrations in septic plumes approached background concentrations within 12 meters of the drainfield. Phosphorus from septic systems does not represent a threat to surface water based on results of this study. Further investigations may be required for more sensitive environments, such as in areas with a large number of nonconforming systems, in aquifers that have low pH and are poorly buffered, and in areas where drainfields are close to lakes that lack riparian buffers.

The results for Baxter differ from St. Cloud, where concentrations in unsewered areas approach the drinking water standard for nitrate. Residential areas in St. Cloud are older than those found in Baxter. Lot sizes are also smaller in St. Cloud. Additional Phase 1 sampling is recommended in other unsewered areas of Minnesota. Sampling should focus on residential areas with differing lot sizes and ages of development, since individual plumes may take several years to stabilize. This information can be used to assess potential risk to drinking water receptors for new communities or communities considering sewering.

The plume investigations in this study were not sufficiently rigorous to evaluate three important aspects of sewage effects on ground water. First, none of the seven sampled plumes appeared to discharge to a lake. Additional efforts to track septic plumes into lakes should focus on probing parallel to shorelines so that plumes can be identified close to the ground water-surface water interface. Second, a one-time sampling for bacteria does not address temporal variations in populations, although literature indicates this is a very important factor. Virus behavior in septic systems was also not studied, and viruses potentially have more serious health impacts than bacteria. Third, effects of hydrology on water quality within plumes could not be addressed. Measurements of recharge, response to precipitation, and measurement of physical parameters (using slug tests) are necessary to determine how a plume behaves in response to hydrologic factors.

An important consideration in ground water monitoring of septic systems is the change in water quality following sewering. This monitoring work is not recommended for Baxter at this time. The median nitrate concentration of 1980 ug/L (parts per billion) under unsewered areas, although higher than the concentration under sewered areas, is well below the drinking water standard. The area will largely be sewered within the next five years, which should prevent further degradation of ground water with nitrate. The low concentrations prevent easy evaluation of water quality changes following sewering.

Introduction

Septic systems are designed to treat human waste. Properly functioning systems attenuate organic matter, microbes, and most cations, but not anions. Systems that have are placed close to the zone of saturation are effective in attenuating nitrogen, but are ineffective at attenuating pathogens, organic matter, and phosphorus (Noss and Billa, 1988; Kaplan, 1987).

There are nearly half a million septic systems servicing over a million people in Minnesota. Septic system effluent discharged to the unsaturated zone reaches ground water, where it impacts water quality. Chemical concentrations in drainfield effluent vary with the type of use. For a typical household using the drainfield for discharge of drinking, shower, toilet, and laundry water, concentrations of nitrogen, sodium, potassium, bicarbonate, chloride, phosphorus, and carbon are greater in septic effluent than in ground water.

Septic waste discharged to coarse-textured soils proceeds vertically through the unsaturated zone and into ground water. Once in ground water, a septic plume develops and moves with ground water flow. Approximate times for septic effluent to pass through the unsaturated zone to ground water range from a few hours to fifty days, depending on the volume of effluent and the distance to ground water (Robertson et al., 1991; Robertson, 1994; Robertson and Cherry, 1995). A septic plume in ground water moves at a rate similar to the ground water velocity.

Chloride is potentially a good indicator of a septic plume, while sodium, pH, and specific conductance may occasionally be useful for delineating a plume. Vertical and lateral (transverse) dispersion of the plume are small, being about 1 and 10 percent, respectively, of the horizontal (longitudinal) dispersivity (Childs et al., 1974; Brown, 1980; Anderson et al., 1987; Harman et al., 1996; Robertson et al., 1991).

Pathogens present in septic tank effluent are usually attenuated in the soil treatment system. Attenuation occurs within a clogging mat, which occurs at the interface between native soils and drainfield media. If the seasonal high water table is less than three feet from the system bottom, or if there is preferential flow of sewage for systems without a clogging mat, microbes can reach ground water. Several cases of bacterial and viral transport for long distances in ground water have been documented (Yates and Yates, 1988; Brown, 1980; Hagedorn et al., 1978; Reneau, 1978; DeBorde et al., 1998). Virus transport can be extremely rapid in ground water. Yates and Yates (1988) observed virus transport of 400 feet within 100 days.

Wilhelm et al. (1994) and Brown (1980) report that most phosphorus goes into the septic tank in organic forms, but that orthophosphate accounts for about 80% of the total phosphorus in the tank effluent. Phosphate precipitates in the unsaturated zone or is adsorbed in the aquifer close to the drainfield. In old systems, the attenuation capacity within the unsaturated zone diminishes and phosphate can reach ground water and move down-gradient in the septic plume. Robertson et al. (1998) observed phosphate migration exceeding 10 meters in six of ten plumes investigated. In contrast, Harman et al. (1996) observed phosphate concentrations of less than 1000 ug/L within ten meters of the drainfield for a 44-year old system servicing an elementary school. Movement of phosphate rarely exceeds 5 meters, even in very old systems (Wilhelm et al., 1994). Phosphate may be a concern in poorly buffered systems if the pH within the plume drops below 6.0.

Volatile Organic Compounds (VOCs) and most semi-volatile organic compounds are not a component of human waste. Oil and optical brighteners, however, are commonly found in laundry effluent (Fay et al., 1995; Alhajjar et al., 1990; Kaplan, 1987). Some VOCs have been used for odor control (Robertson, 1994), while VOCs may also be introduced into septic systems after household use (e.g., paints, varnishes, degreasers). Some organic compounds may be present as breakdown products of human waste (Muszkat et al., 1993). Many organic compounds will be conservative in ground water, particularly halogenated VOCs.

There is little information on the fate of trace inorganics in septic plumes. Concentrations of these chemicals, including heavy metals, are typically low in human waste (Wilhelm et al., 1996; Robertson and Blowes, 1995). Concentrations of trace inorganics may reach levels of concern in poorly buffered ground water systems where the pH within the plume falls below 6.0 (Robertson and Blowes, 1995).

Nitrate is the primary chemical of concern in most septic plumes. Nearly all nitrogen passing through the drainfield converts to nitrate in the aerobic soil zone and eventually leaches to ground water (Brown, 1980; Walker et al., 1973; Wilhelm et al., 1996; Kaplan, 1987; Robertson and Cherry, 1995). Nitrates are conservative in shallow ground water because oxygen is present and total organic carbon concentrations are too low to sustain intensive microbial activity (Wilhelm et al., 1996), although Steinheimer et al. (1998) suggest autotrophic denitrification (non-organic food source) may be an important mechanism of denitrification. Nitrate plumes slowly attenuate as a result of dilution from recharge water and dispersion within the aquifer. Nitrate concentrations can exceed drinking water criteria at distances of 100 meters or more from the drainfield.

Predicting nitrate concentrations in an unsewered area consists of quantifying the contribution of each system. It is difficult, however, to predict the nitrate concentration in specific locations because plumes may mix and the fate of individual plumes is unknown. In addition, seasonal changes in ground water flow may occur because of different inputs from the septic system, effects of surface water bodies, and local pumping from wells.

Researchers have used different approaches to quantify or predict nitrate distribution in unsewered areas. Hantzsche and Finnemore (1992) drilled several wells in three different unsewered developments and reported mean nitrate concentrations of 9600 to 13900 ug/L. Concentrations in individual wells ranged from less than 3000 ug/L to 65000 ug/L. Quan et al. (1974) sampled several domestic wells in a deep sand and gravel aquifer and found concentrations between 5000 and 11000 ug/L. Harmsen et al. (1996) installed multilevel wells along two hydrologic transects in two separate unsewered subdivisions with lot sizes ranging from 0.5 to 0.7 acres. Concentrations of nitrates ranged from 5000 to 15000 ug/L, with average concentrations of 6000 to 8000 ug/L. Tinker (1991) measured nitrate concentrations in residential wells in five unsewered subdivisions with lot sizes ranging from 0.5 to 1.1 acre. Concentrations gradually increased from 1000 to 13000 ug/L from the up-gradient to the down-gradient edge of the subdivisions. Miller observed median nitrate concentrations of 2000 and 13000 ug/L in ground water under half acre lot developments that were two and 15 years old, respectively. Although water quality of individual septic systems are similar regardless of age, ground water quality within an aquifer will continue to change until plumes from individual systems stabilize.

Several researchers have attempted to predict nitrate distribution using hydrologic models (Hantzsche and Finnemore, 1992; Anderson et al., 1987; Baumann and Schafer, 1984). Lot sizes less than 1.0 acre in size in sandy soils result in nitrate concentrations exceeding the drinking water criteria of 10000 ug/L over a significant portion of the aquifer.

Despite the vast amount of information on ground water quality associated with septic wastes, there are research gaps. Researchers have provided limited information regarding the overall spatial distribution of nitrate in an unsewered subdivision. Because of this, there is little information useful for quantifying the risk that a particular well will exceed the drinking water criteria. Since most research has focused on behavior of individual systems, predictive modeling has used plume information in conjunction with hydrogeologic information to predict nitrate distributions. This approach lacks calibration of modeling results with data from an entire unsewered subdivision. There is little information describing effects of septic systems on surface water (Magner and Regan, 1994). Finally, there have been few long-term monitoring studies conducted in changing land use settings, such as when an unsewered area is sewered.

We initiated a study in 1998 to assess the environmental impact of on-site sewage disposal systems on ground water quality. The objectives of the study were to

1. determine the spatial distribution of nitrate in ground water across an unsewered development; and
2. delineate individual septic plumes and determine the distribution for chemicals of potential concern within the plumes.

Information from this study may be useful in assessing nutrient loading to lakes from septic systems, determining overall patterns of risk to human and ecological receptors resulting from septic system discharges, and developing predictive models.

Methods and Materials

The study was conducted in the City of Baxter, located in east-central Minnesota (Figure 1). The Branierd-Baxter area has a population of approximately 40000 and is undergoing rapid expansion with unsewered developments. Many of these developments consist of lakeshore or near lakeshore property. The study area is located in an area of sandy soils underlain by a sensitive sand aquifer. Many unsewered developments will be sewered within the next ten years. Figure 2 illustrates the location of unsewered areas within the study area.

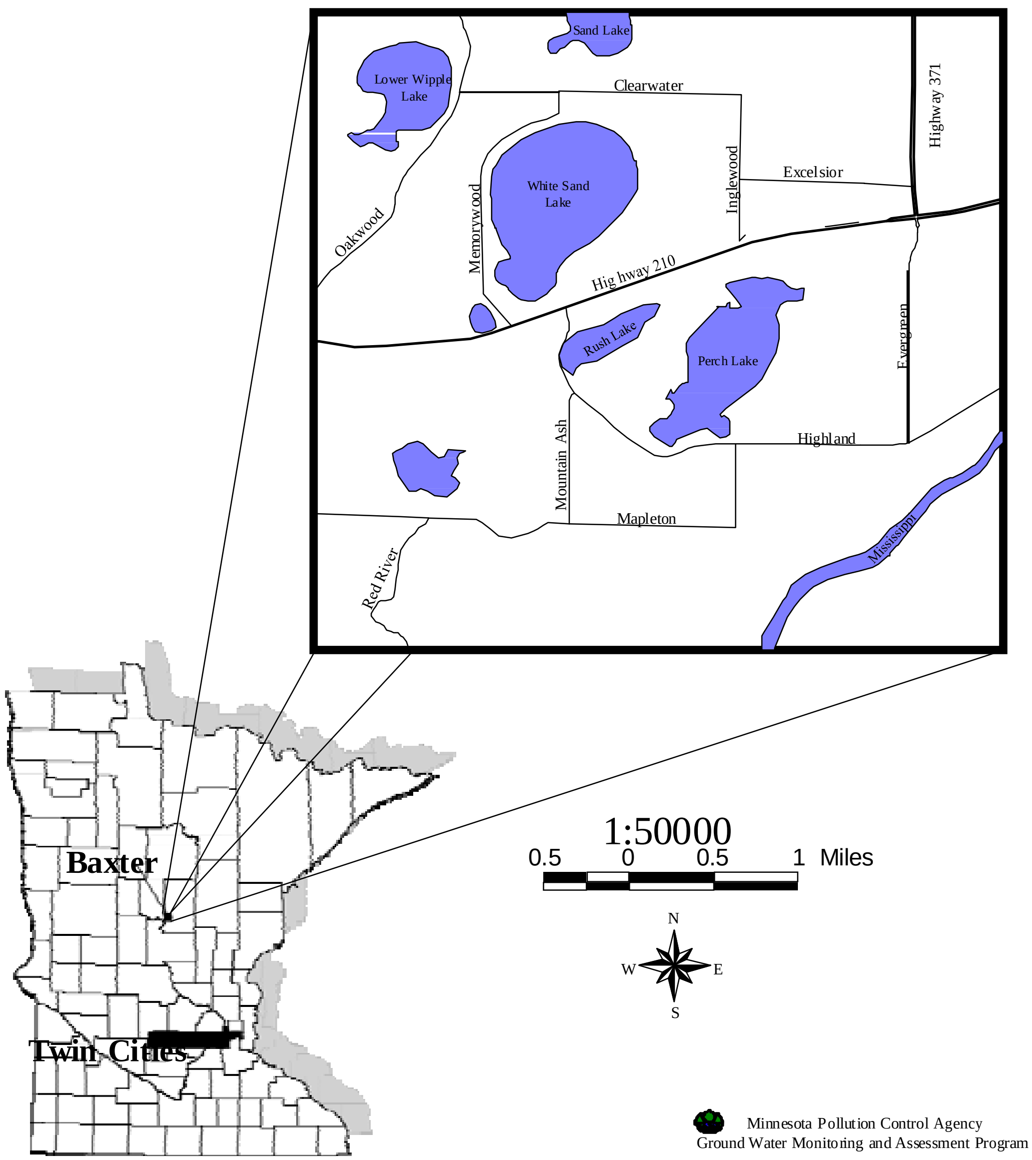


Figure 1 : Location of Baxter study area.

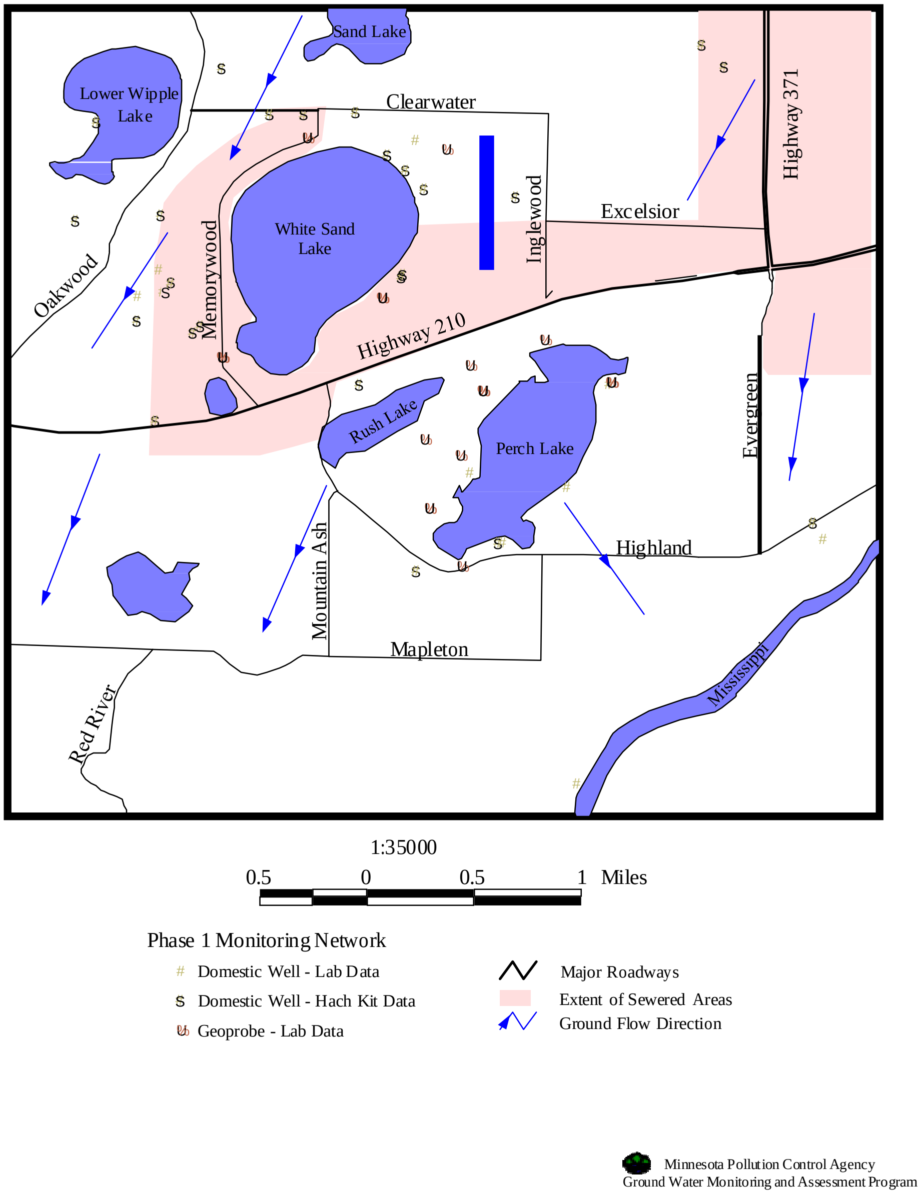


Figure 2 : Map of the study area illustrating sewered and unsewered areas, ground water flow direction, and sampling locations.

The surficial geology consists of outwash deposits of sand and gravelly sand associated with the Wadena Lobe. Localized alluvium consisting of less than six feet of silt loam and loamy sand occurs along the Crow Wing River. Isolated peat deposits and sandy till lenses are found in the study area but comprise small areas. Peat deposits, where they are mapped, are associated with organic deposits greater than three feet in thickness and are found in marshes, often adjacent to lakes and drainageways. Till deposits associated with the Wadena Lobe are sandy loam, unsorted, and become very dense with depth. Precambrian age deposits underlie the area, but these are more than 100 feet below the land surface and are unimportant hydrologically.

Soils belong to the Menahga and Zimmerman series. Menahga (Typic Udipsamment) consists of light colored, well drained, medium acid loamy soils 4 to 8 inches thick over fine sand. Sands are limy below 4 to 6 feet. Zimmerman (Alfic Udipsamment) consists of light colored, excessively drained loamy fine sands or fine sands over acid fine sand and medium sand. Peat occurs in depressions over approximately five percent of the area. Poorly drained sandy tills, such as those from the Lino series, occur as lenses within the well-drained sands. Native vegetation is predominantly jack pine.

Average annual precipitation in the study area is about 24.8 inches, 11 of which falls between June and August. Average July and January temperatures are approximately 70 and 10 ^{o}F, respectively. The frost-free period extends from mid-May to late-September. A National Weather Service station is located at the Branierd airport.

Ground water flows toward the Mississippi River and through the lakes in the area, as illustrated in Figure 2. During late summer and through winter, ground water generally flows out from the lakes. Annual recharge to the aquifer is approximately six inches a year.

Phase 1

The objective of Phase 1 was to determine the distribution of chemicals, particularly nitrate, across sewered and unsewered areas.

Design and Data Collection

We sampled 40 domestic wells, screened at depths of 0 to 60 feet below the water table. Figure 2 illustrates sampling locations. The County Well Index (Wahl and Tipping, 1991) provided drilling and geologic information for several hundred wells. The sampling locations include a range of well depths and assure an approximately even distribution of wells across the study area.

Field sampling methods are described in MPCA, 1998a. Sample collection for domestic wells consisted of connecting one end of a hose to an outside spigot and the other end to a YSI 600XL[1] multiparameter probe. Once the spigot was turned on, continuous measurements of oxidation-reduction potential (mV), temperature (^{o}C), pH, specific conductance (umhos/cm), and dissolved oxygen (mg/L) were taken. Samples were collected once temperature, specific conductance, and pH had stabilized to 0.1^{o}C, 10%, and 0.1 pH unit, respectively, for three successive readings. At 28 sites, nitrate was analyzed in the field using a Hach DR/4000 Spectrophotometer. The remaining 12 samples were analyzed at the University of Minnesota Research Analytical Laboratory using the cadmium reduction method and a reporting limit of 10 ug/L. Alkalinity, chloride, and sulfate were measured in the field using commercially available field test kits.

We selected twelve additional locations for geoprobe sampling (Figure 2). Split spoon samples were collected at four foot intervals and textural analysis was performed on the split spoon samples (Table 1). The data indicate soils consist primarily of very fine sands to depths of more than 15 feet. Soil remaining in the 0.1 mm sieve consisted of uniform, very fine sands. Five-foot screens (0.010 slot, threaded PVC) were installed across the water table. Samples were pumped using a peristaltic pump until sample turbidity became uniform and field parameters stabilized. At five sites, an additional sample was collected 5 to 10 feet below the water table. Dissolved oxygen, oxidation- reduction potential, pH, temperature, and specific conductance were measured during pumping. Alkalinity, nitrate-nitrogen, chloride, and sulfate were measured in the field using commercially available field test kits. Laboratory analysis included major cations and anions, dissolved and total organic carbon, ammonia-nitrogen, and total Kjeldahl nitrogen. Reporting limits and analytic methods are summarized in Table 2.

		% by Weight				
Sample ID	**Depth (ft)**	**> 1 mm (V. Coarse)**	**1 - 0.5 mm (Coarse)**	**0.5 - 0.25 mm (Medium)**	**0.25 - 0.1mm (Fine)**	**< 0.1 mm (V. Fine)**
1	0-4	0.0	0.7	1.9	27.0	70.4
	4-8	0.0	2.6	8.5	41.3	47.7
		% by Weight				
Sample	**Depth (ft)**	**> 1 mm**	**1 - 0.5 mm**	**0.5 - 0.25 mm**	**0.25 - 0.1mm**	**< 0.1 mm**

[1] Mention of a particular product does not represent endorsement of or preference for that product.

ID		(V. Coarse)	(Coarse)	(Medium)	(Fine)	(V. Fine)
2	0-4	0.0	1.0	8.6	59.6	30.8
	4-8	0.0	0.2	1.6	56.3	41.9
	8-12	0.0	1.0	7.6	59.6	31.8
	12-16	0.0	0.4	4.6	60.8	34.2
	16-20	0.0	0.3	2.6	46.4	50.8
	20-24	0.0	0.8	6.2	55.2	37.8
3	0-4	0.0	0.4	3.7	56.2	39.6
	4-8	0.0	0.2	2.5	70.0	27.3
	8-12	0.0	0.4	2.3	44.6	52.8
	12-16	0.0	0.1	0.3	33.2	66.3
	16-20	0.0	0.3	3.0	48.8	47.9
	20-24	0.0	0.3	1.9	65.2	32.5
4	0-4	0.0	0.7	2.5	60.0	36.8
	4-8	0.0	0.1	0.7	40.4	58.8
	8-12	0.5	1.5	5.3	49.7	43.1
	12-16	0.0	0.4	2.4	30.3	66.9
	16-20	0.0	0.6	2.1	31.3	66.0
5	0-4	0.0	0.4	3.1	47.3	49.1
	4-8	0.0	0.3	4.3	48.2	47.1
	8-12	0.0	0.8	8.8	65.0	25.3
	12-16	0.0	0.4	2.6	42.2	54.7
6	0-4	0.0	1.6	5.1	41.4	52.0
	4-8	0.0	2.8	8.4	56.5	32.2
	8-12	0.0	1.6	4.8	53.7	39.9
	12-16	0.0	1.3	2.8	44.1	51.8
7	0-4	0.0	0.7	26.3	63.3	9.6
	4-8	0.0	0.9	19.1	63.6	16.4
8	0-4	0.0	0.9	4.2	55.0	39.9
	4-8	0.0	0.3	1.6	51.5	46.7
	8-12	0.0	1.8	8.3	62.3	27.5
	12-16	0.3	1.1	15.7	62.0	21.0
9	0-4	0.2	1.8	7.8	53.9	36.4
	4-8	0.1	1.0	7.9	50.1	40.9
	8-12	0.0	1.1	6.6	68.8	23.5
10	0-4	0.5	2.3	3.8	33.4	59.9
	4-8	0.0	0.0	0.7	25.1	74.2
	8-12	0.0	0.6	3.7	31.5	64.3
11	0-4	0.2	0.4	6.0	53.6	39.8
	4-8	0.0	0.1	2.3	59.6	38.0
	8-12	0.0	0.2	0.7	36.1	63.0
12	0-4	0.0	0.1	3.5	60.5	35.8
	4-8	0.0	0.9	12.1	58.4	28.6
	8-12	0.8	1.5	6.6	53.1	38.1
	12-16	0.0	0.7	2.7	25.8	70.8

Table 1 : Results of particle size analysis for geoprobe samples.

Parameter	Method	Reporting Limits (ug/l)

NO_3-N	Cadmium reduction	500
Total phosphorus, Ca, Mg, Na, K, Fe, Mn, Zn, B	ICP	14, 5, 20, 60, 100, 3.1, 0.9, 1.7, 6.5
Cl, F, SO4, Br	Ion chromatography	100, 200, 100, 200
Dissolved Oxygen	Field meter	300
Alkalinity	Titration	1000
Oxidation-reduction potential	Field meter	1 mV
Total organic carbon	Dohrman carbon analyzer	100
Ammonia	Colorimetric	20
Kjeldahl-nitrogen	Block digestor method	200

Table 2 : Analytic method and detection limit for sampling parameters.

Data Analysis

Statistical methods (MPCA, 1998b) included the Mann-Whitney test for comparison of nitrate concentrations in sewered and unsewered areas, the Spearmann rank method for correlation analysis, and the Kruskal-Walis test for comparison of chemical concentrations between different depth classes. Depth classes included geoprobe samples screened at the water table, geoprobe samples screened below the water table, domestic wells less than 30 feet deep, and domestic wells greater than 30 feet deep.

Phase 2

The objective of Phase 2 was to determine the distribution of chemicals in individual septic plumes.

Design and Data Collection

Temporary wells, installed with a geoprobe, were used to track plumes from seven conventional septic systems with year-round usage for families of 2 to 5 people. Site locations are illustrated in Figure 3. General site information is illustrated in Table 3. Conforming systems are those with three or more feet of soil above the top of the drainfield and no evidence of soil mottling between the bottom of the drainfield and the top of the water table (Wespetal, personal communication). Mottling is used as an indicator of the seasonal high water table, since mottling is considered to occur rapidly under anaerobic conditions. It is unclear, however, how long the water table must be close to the bottom of the drainfield to affect the hydraulic performance of the system.

We drilled 20 to 30 temporary wells at each site, but only retained samples considered to be from the septic plume. These were samples in which field-measured chloride concentrations were more than twice the measured background concentration.

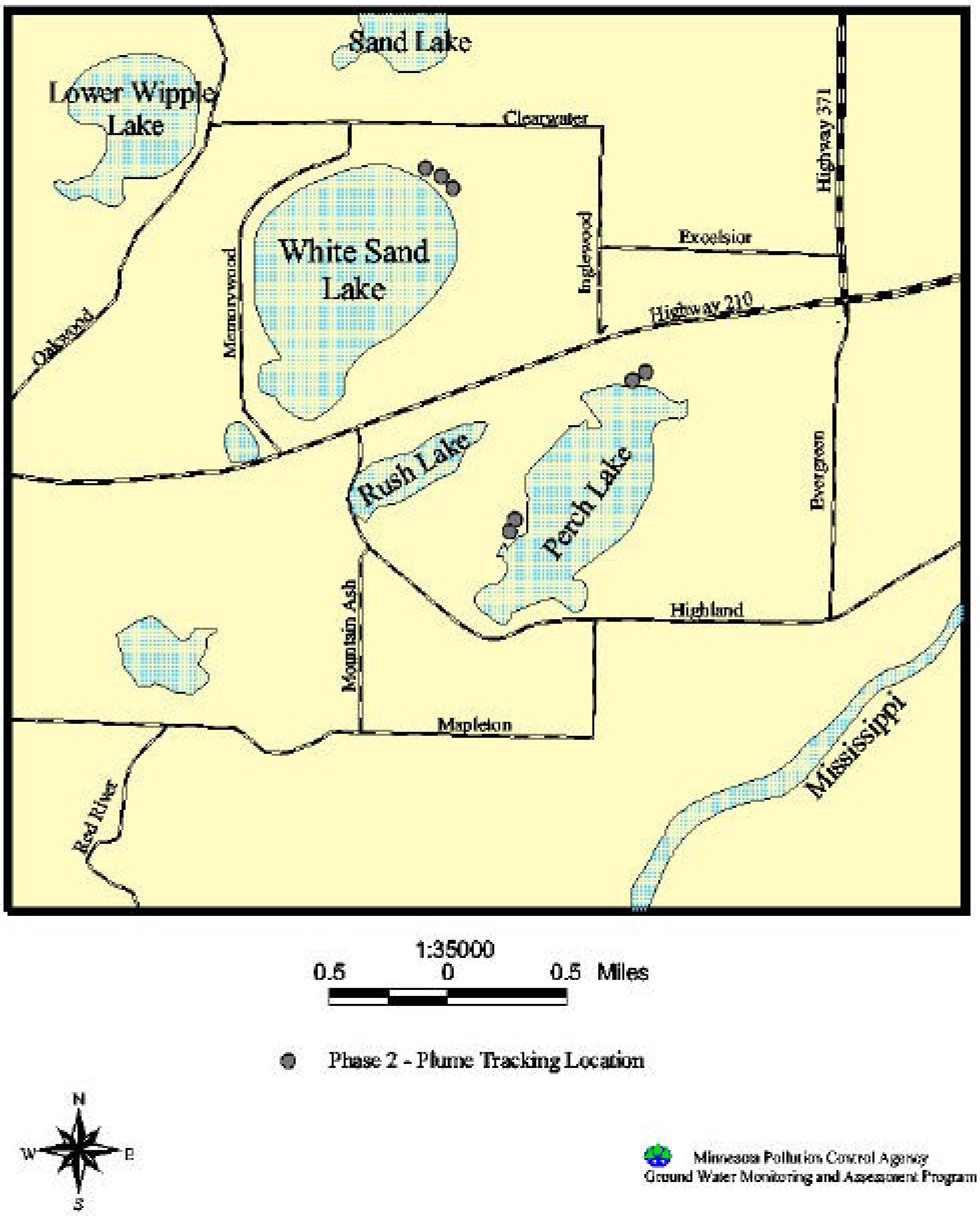


Figure 3 : Location of individual septic systems selected for sampling.

		Conforming	Number of	Last

Site	Description	system	samples collected	pumped
1	Approx. 25 people; > 15 years old[1]	no	16	Sept., 1998
2	2 people; 5 years old	-	9	July, 1995
3	5 people; 15 years old	-	14	-
5	2 people; > 20 years old	no[2]	11	-
6	2 people; 15-20 years old	yes	16	Oct., 1997
7	5 people; 13 years old	no[2]	17	July, 1997
8	2 people; > 20 years old	-	12	July, 1998

[1] System ages are approximate
[2] Less than three feet of unsaturated soil below the soil treatment system to the seasonally saturated layer

Table 3 : Summary information for the plume sites.

Initially, we located the septic tank and installed three temporary wells at each site. We used a regional ground water flow map for Baxter (see Figure 2) and site observations of topography and location of lakes to site wells. One well was installed at the assumed down-gradient edge of the septic system, a second farther down-gradient of the septic system, and a third up-gradient of the system. Well casing tops were surveyed to 0.1 foot and referenced to a fixed benchmark at the site. Depth to water was measured and static water elevations calculated. We conducted similar measurements for each successive temporary well. All well locations were determined with a Global Positioning System.

At each of the first three wells, a five foot screen was installed across the water table. A peristaltic pump was used to purge the well of water. Tubing from the pump was attached to a YSI 600XL multiparameter probe. The wells were pumped until the water was not turbid and pH, specific conductance, and temperature stabilized to 0.1 pH unit, 10%, and 0.1 ^{o}C, respectively, for three consecutive readings. After the well stabilized, samples for laboratory analysis were collected for nitrogen species, major cations and anions, total and dissolved organic carbon, coliform bacteria, and volatile organic compounds (VOCs). Alkalinity, sulfate, and chloride were measured in the field using commercially available test kits.

We drilled additional wells to define the horizontal and vertical extent of the plume. Wells were completed in a manner similar to the first three wells. Field-measured specific conductance and chloride concentrations were used to identify ground water impacted by the septic system. Samples for laboratory analysis included major cations and anions, total and dissolved organic carbon, nitrogen species, VOCs, total coliform bacteria, and *Escherichia coli (E. Coli)* bacteria.

A sample from the septic tank was taken at each site using a hand bailer. Laboratory analysis of septic tank samples included major cations and anions, coliform bacteria, *E. Coli* bacteria, VOCs, nitrogen species, and total and dissolved organic carbon. Cation and dissolved organic carbon samples were filtered with a 0.45 micron in-line filter (well samples) or a bottle top vacuum filter (tank samples).

We collected two aquifer sediment samples at each site. One of these was in the septic drainfield and another down-gradient of the drainfield. Cation exchange capacity, organic carbon content, and carbonate content were determined for each sediment sample. Following sampling at each site, the drainfield was examined to determine if it met the appropriate criteria for vertical separation between the bottom of the drainfield and the top of the seasonal high water table and between the land surface and and the top of the drainfield (see Table 3).

Data Analysis

Statistical methods included the Mann-Whitney test for comparisons of septic tank effluent and background ground water concentrations, and for comparisons of septic tank effluent and maximum concentrations observed in ground water at each site. Chemicals in which concentrations differed between background and the septic tank were considered to represent chemicals of potential concern associated with discharge from septic systems. We estimated the horizontal migration distance for each chemical and plume by plotting data in Surfer and determining the point where concentrations reached background. Correlation analysis included the Spearmann rank method.

Results and Discussion

Results are discussed separately for Phase 1 and Phase 2.

Phase 1

Table 4 summarizes concentrations of chemicals in geoprobe samples. pH and concentrations of nitrate, dissolved organic carbon, and total organic carbon were greater in unsewered areas than in sewered areas. All three exceedances of the Health Risk Limit (HRL) of 10000 ug/L for nitrate were in unsewered areas. This represents 25 percent of the geoprobe samples collected from unsewered areas. There was one exceedance of the HRL from a domestic well. The elevated concentrations of dissolved and total organic carbon provide evidence of septic impacts since carbon is associated with septic discharge.

Chloride and sodium, often considered to be tracers of septic plumes, did not differ in concentration between sewered and unsewered areas. Human wastes are enriched in sodium and chloride, but road salts are also an important input in sewered areas. Phosphorus concentrations did not differ between sewered and unsewered areas. This is not surprising since phosphorus from septic systems is attenuated near the drainfield. Specific conductance also did not differ between sewered and unsewered areas, even though specific conductance was a good indicator of septic plumes (see Results for Phase 2). Finally, concentrations of ammonia and Kjeldahl nitrogen did not differ between sewered and unsewered areas. Like phosphorus, reduced forms of nitrogen are attenuated close to the drainfield.

Age of development appears to be an important factor affecting the distribution of nitrate in ground water (Figure 4). The highest concentrations of nitrate in shallow ground water were observed northwest of Perch Lake. This is an area that was developed prior to 1990. Development west of this occurred in the 1990's, and nitrate concentrations are lower despite similar lot sizes. Developments dated in the 1960's and 1970's are scattered throughout the study area. We collected an insufficient number of samples to assess nitrate distribution in these older areas. Inputs from individual systems should be similar regardless of age. Consequently, age of development should not be a factor affecting nitrate concentrations under unsewered areas unless plumes have not stabilized. We conclude, therefore, that plumes have not yet stabilized in areas developed since about 1980.

Parameter	Unsewered	Sewered
Alkalinity (ug/L)	148000	96000
Ammonia (ug/L)	75	73

Boron (ug/L)	15	13
Calcium (ug/L)	60306	35301
Chloride (ug/L)	12450	13970
Dissolved organic carbon (ug/L)	3100*	2125
Dissolved Oxygen (ug/L)	4330	3330
Eh (mV)	259	270
Iron (ug/L)	72	62
Magnesium (ug/L)	12033	7746
Manganese (ug/L)	205	131
Nitrate (ug/L)	1980*	778
pH	7.37*	6.99
Phosphorus (ug/L)	34	35
Potassium (ug/L)	1493	839
Sodium (ug/L)	7341	6105
Specific conductance (umhos/cm)	444	286
Sulfate (ug/L)	2725	2365
Temperature (°C)	11.2	13.3
Total Kjeldahl nitrogen (ug/L)	440	323
Total organic carbon (ug/L)	3550*	2400
Zinc (ug/L)	6.6	3.8

Table 4 : Median chemical concentration from geoprobe samples in sewered and unsewered areas. An "*" indicates concentrations that differed between sewered and unsewered areas (at the 0.05 significance level).

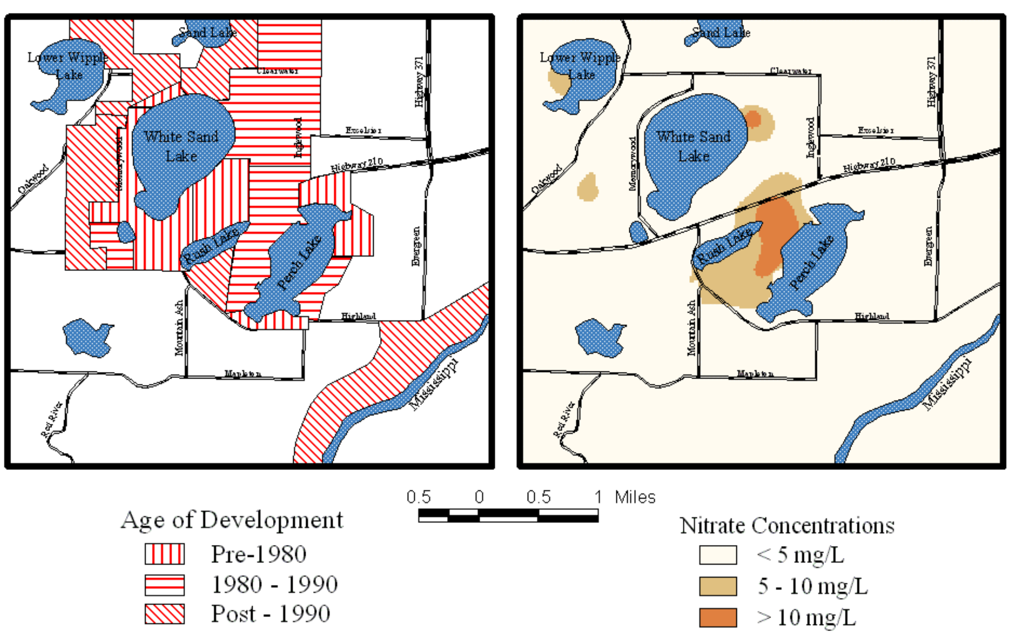


Figure 4: Age of development and distribution of nitrate across the study area.

The median nitrate concentration of 1980 ug/L is lower than concentrations found in other unsewered areas (Anderson et al., 1987; Baumann and Schafer, 1984; Hantzsche and Finnemore, 1992; Miller; MPCA 1998c; Quan et al., 1974; Tinker, 1991). There may be several reasons for this. First, ground water flow paths through unsewered subdivisions are relatively short. Tinker (1991) observed nitrate concentrations of approximately 1000 ug/L at the upgradient edge of an unsewered subdivision, compared to concentrations greater than 10000 ug/L at the down-gradient edge. The subdivisions in the Baxter area cluster around lakes and do not cover large geographical areas. Second, Miller observed increasing nitrate concentrations with increasing age of the subdivision. In Baxter, expansion of unsewered subdivisions has not occurred uniformly. Much of the development in the area has occurred since 1990 and most since 1980 (Figure 4). Third, there is lake water seepage to the aquifer from late summer through winter. This may dilute ground water nitrate concentrations on down-gradient sides of the lakes. Fourth, systems with the saturated zone near the bottom of the treatment system will not contribute significant amounts of nitrate to ground water because they remain anaerobic. Information from Phase 2, however, suggests that systems are contributing quantities of nitrate similar to concentrations found in the literature. Fifth, geochemical conditions within the aquifer may not support high nitrate concentrations. This is not supported by the data, however, which show a median Eh of 265 mV and a median dissolved oxygen content of 4300 mg/L at the water table. Nitrate will be stable under these geochemical conditions. Finally, nitrogen inputs may be less in Baxter than in other unsewered areas because of reduced inputs from individual systems or increased lot size compared to other unsewered areas. Concentrations of nitrate in individual plumes, however, are similar to concentrations found in other studies. We conclude that nitrate concentrations are relatively low compared to other unsewered areas primarily because the area is small in geopgraphic extent. Dilution from lake outflow and the young age of development also contribute to the low nitrate concentrations.

Nitrate concentrations in geoprobe samples were not correlated with concentrations of any other chemical. Consequently, nitrate concentrations in the upper few feet of the aquifer are directly related to nitrogen inputs. Organic carbon, which was higher in unsewered areas, was correlated with concentrations of ammonia (R^2 = 0.492) and Kjeldahl nitrogen (R^2 = 0.804). Septic systems are a potential source of reduced nitrogen and organic carbon when the seasonal high water table is close to the bottom of treatment system.

Median values for specific conductance, pH, Eh, and for concentrations of chloride, nitrate, dissolved oxygen, and iron for different sampling depths are illustrated in Table 5. Mann-Whitney tests indicate no significant differences in any sampled parameter between shallow and deep geoprobe samples. Median values for pH, Eh, and for concentrations of chloride, nitrate, dissolved oxygen, and iron differed between the shallow temporary wells and deeper domestic wells, however. There are significant changes in geochemistry at depths of 20 feet or more within the aquifer. Oxygen and nitrate concentrations decrease, Eh decreases, and iron and manganese concentrations increase with depth. Figure 5 illustrates the presence of an oxygenated zone to a depth of about 20 feet in the aquifer. The general pattern of decreasing oxygen and nitrate with depth is similar to results for St. Cloud (MPCA, 1998c), although the thickness of the oxygenated zone was less than 10 feet in St. Cloud. Chloride distribution and tritium sampling from the St. Cloud study indicate post-1953 water extends deeply (up to 80 feet) into surficial aquifers. Since nitrate is mobile but not found below 20 feet, denitrification most likely accounts for the loss of nitrate with depth. The change in geochemical conditions at some depth was abrupt for both the St. Cloud and Baxter studies.

Parameter	Geoprobe < 5 feet below water table	Geoprobe > 5 feet below water table	Wells < 30 feet deep	Wells > 30 feet deep
Chloride (ug/L)	12500 b	19700 ab	28000 a	17000 ab
Dissolved oxygen (ug/L)	3330 ab	6050 a	1870 b	390 c
Eh (mV)	249 a	270 a	316 a	77 b
Iron (ug/L)	77 b	47 b	200 b	3700 a
Nitrate (ug/L)	950 a	780 ab	700 ab	< 100 b
pH	7.22 b	7080 b	7.90 a	7.50 a
Specific Conductance (umhos/cm)	418	286	223	281

Table 5 : Median chemical concentrations for different sampling depths. Different letters within a row indicate concentrations that differed at a significance level of 0.05.

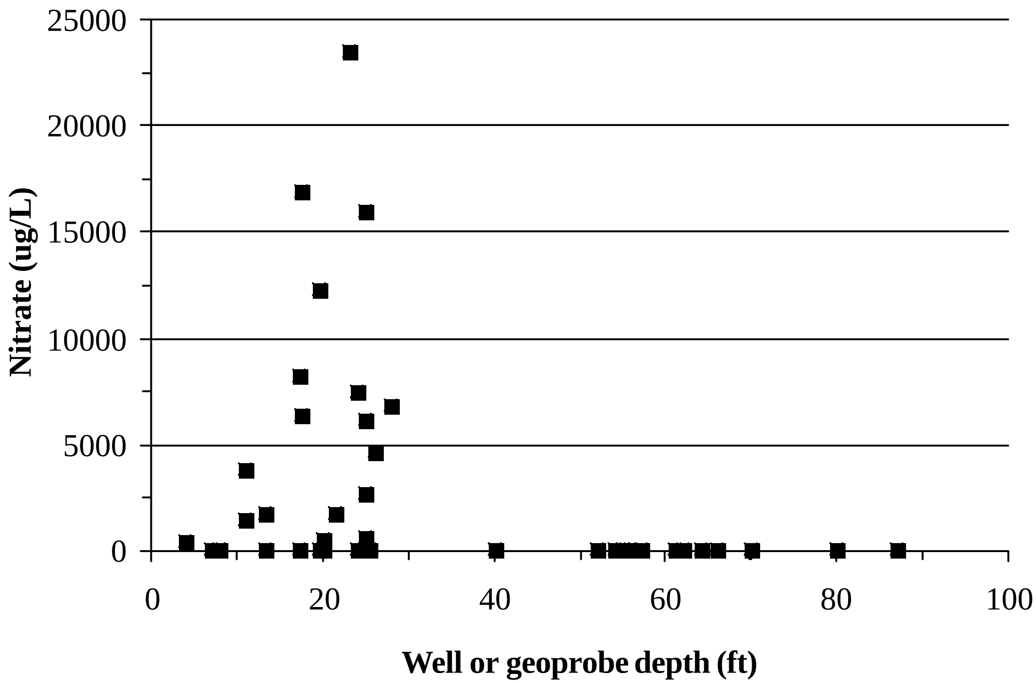


Figure 5 : Nitrate concentrations as a function of well or geoprobe depth.

Considering samples from domestic wells, nitrate was negatively correlated with well depth (R^2 = -0.449) and positively correlated with oxidation-reduction potential (R^2 = 0.385). These are not particularly strong correlations, but they reflect the decrease in nitrate concentrations with depth in the aquifer. The lack of correlations for nitrate in geoprobe samples indicates concentrations of nitrate in the upper portion of the aquifer are controlled by inputs at the top of the aquifer. Unless suitable conditions for denitrification exist within the aquifer, as occur below about 20 feet in the aquifer underlying the study area, nitrate is conservative in ground water.

Phase 2

The discussion of results for Phase 2 is divided into sections on inorganic chemicals, bacteria, and Volatile Organic Compounds (VOCs).

Inorganic Chemicals

Septic tank effluent is reducing, with high concentrations of iron, ammonia, Kjeldahl nitrogen, and low concentrations of nitrate (Table 6). Calcium and magnesium concentrations were low at Site 8 compared to other sites, while sodium, nickel, copper, zinc, iron, aluminum, and lead concentrations were high. Concentrations of zinc, aluminum, and lead at site 8 are at levels of potential concern if effluent reaches ground water. Site 4 also had high concentrations of most chemicals. Concentrations of magnesium, bicarbonate, calcium, ammonia, sulfate, and total phosphorus were similar among the seven sites. Concentrations of total organic carbon, chloride, aluminum, boron, fluoride, iron, nitrate, sodium, total Kjeldahl nitrogen, and zinc differed between sites.

Median effluent concentrations for all chemicals are within the range found in the literature (Table 7). Orthophosphate and ammonia in septic tanks accounted for about 80 and 40% of the total phosphorus and nitrogen, respectively. Wilhelm et al. (1994) and Brown (1980) report that most phosphorus and nitrogen go into tanks in organic forms, but that orthophosphate and ammonia account for about 80 and 50% of the total phosphorus and nitrogen in the tank effluent, respectively.

Chemical	Site 1	Site 2	Site 3	Site 5	Site 6	Site 7	Site 8
Alkalinity	-	432000	260000	461000	315000	-	443000
Aluminum	< 50	< 50	55	559	< 50	160	7936
Ammonia	59850	41880	22280	51590	65780	31600	73790
Boron	944	68	13248	76	470	55	763
Bromide	< 200	< 200	< 200	< 200	< 200	-	< 200
Cadmium	< 1.5	< 1.5	< 1.5	< 1.5	< 1.5	< 1.5	2.4
Calcium	34746	60669	60323	82272	50983	101470	69277
Chloride	45720	365200	31840	46730	54540	1140910	701140
Chromium	3.1	9.9	3.0	3.8	4.2	< 3.1	9.2
Copper	< 5.5	< 5.5	18	< 5.5	12	20	80
Fluoride	< 200	< 200	1020	< 200	< 200	100	1200
Iron	282	94	140	2064	725	257	17153
Lead	< 25	< 25	< 25	< 25	< 25	< 25	51
Magnesium	7125	45657	13936	17637	11558	20318	15603
Manganese	103	74	101	760	282	942	414
Nickel	< 6.0	< 6.0	< 6.0	< 6.0	< 6.0	< 6.0	13
Nitrate	30	10	20	50	50	1060	20
Orthophosphate	7150	90	4120	8100	10640	-	12030
Potassium	13450	981	11636	17958	19231	10649	23743
Sodium	103810	19119	42693	88613	49784	645480	466450
Sulfate-S	1300	350	200	3160	1220	510	570
Total Kjeldahl nitrogen	67440	630	32280	72170	113080	41100	119310

Total organic carbon	92600	299600	2900	-	162900	54700	271500
Total Phosphorus	7149	6309	6202	10465	10984	6546	19104
Zinc	12	7.7	63	389	48	256	1597

Table 6 : Concentrations of chemicals in septic tank effluent. Concentrations are in ug/L.

There were a large number of correlations between concentrations of different chemicals in septic tanks. Metal concentrations were often correlated, including lead with cadmium (R^2 = 1.000), cadmium with nickel (R^2 = 1.000), and aluminum with zinc (R^2 = 0.845). This is primarily due to a large number of non-detections for these metals, however. Most of the remaining significant correlations were between chemicals typically found at elevated concentrations in septic tank effluent. Examples include ammonia with potassium (R^2 = 0.941) and sodium (R^2 = 0.824).

Median concentrations of bicarbonate, boron, ammonia, chloride, iron, sodium, orthophosphate, and total organic carbon were higher in septic effluent compared to background concentrations in the aquifer (Table 8). Concentrations of nitrate and sulfate

Chemical	Robertson et al., 1991	Harmon et al., 1996	Robertson et al., 1991	This study
Alkalinity	365000	802000	316000	432000
Ammonia	30000	128000	59000	55720
Calcium	40000	137000	14000	60496
Chloride	45000	207000	55000	50635
Dissolved organic carbon	37000	19200	50000	10800
Magnesium	14000	25000	3000	14769
Nitrate	1000	< 100	100	25
Phosphate	8000	9000	13000	7625
Potassium	12000	43000	21000	15704
Sodium	98000	107000	90000	69198
Sulfate-S	27000	59000	42000	895
Total Kjeldahl nitrogen	-	152000	-	69805

Table 7 : Comparison of chemical concentrations in septic tanks from different studies. Concentrations are in ug/L.

were lower in the tank effluent compared to background concentrations in the aquifer. Approximately 80 percent of ammonia nitrogen was converted to nitrate in the unsaturated zone beneath the drainfield. Within individual systems, the percentage of ammonia converted to nitrate ranged from 37 to 100 percent. This compares with values of 70 to 100 percent reported in the literature (Brown, 1980; Gold et al., 1992).

Bicarbonate, nitrogen, boron, iron, sodium, phosphate, and organic carbon are potential contaminants of ground water because concentrations in septic tank effluent are higher than background concentrations in the aquifer. Median concentrations of boron, ammonia, chloride, sodium, phosphorus, and nitrate were higher directly below the drainfield compared to background concentrations (Table 9). These are chemicals that may increase in concentration in ground water under unsewered areas compared to background concentrations. Consequently, these represent potential chemicals of concern in unsewered residential areas of Baxter.

Chemical	Maximum in plume	Tank	Background
Alkalinity	22000	432000	130000
Aluminum	< 49.9	< 49.9	< 49.9
Ammonia-nitrogen	60	55720	55
Boron	267	616	33
Bromide	< 200	< 200	< 200
Cadmium	< 1.5	< 1.5	< 1.5
Calcium	45749	60496	46722
Chloride	107485	50635	20130
Chromium	< 3.1	6.7	4.1
Copper	5.5	< 5.1	5.8
Dissolved organic carbon	6400	10800	2100
Dissolved oxygen	1815	-	2600
Fluoride	-	< 200	-
Iron	228	1395	75
Lead	-	< 24.5	-
Magnesium	11584	14769	9910
Manganese	65	348	103
Nickel	13	< 6.0	5.7
Nitrate	43435	25	2065
Orthophosphate	2275	7625	30
Oxidation-reduction potential	104	52	67
pH	6.37	6.94	6.89

Phosphorus	4423	7625	58
Potassium	13204	15704	4687
Sodium	145066	69198	12216
Specific conductance	1134	616	343
Sulfate-S	9250	895	4135
Temperature	13.6	15.0	11.6
Total Kjeldahl nitrogen	775	69805	585
Total organic carbon	6850	271500	3350
Zinc	9.8	30	7.4

Table 8 : Comparison of median chemical concentrations in septic tanks, maximum concentrations found in ground water plumes, and background concentrations. Data from all sites was pooled for the analysis. Concentrations are in ug/L except pH, specific conductance (umhos/cm), temperature (^{o}C), and oxidation-reduction potential (mV).

Chemical	1	2	3	5	6	7	8
Alkalinity	301000	190000	-	45000	301000	-	26000
Alkalinity (lab)	-	234000	379000	22000	282000	-	432000
Aluminum	< 50	504	< 50	154	404	84	82
Ammonia	60	70	580	3110	8260	360	1360
Boron	89	432	4924	70	313	195	1614
Bromide	< 200	< 200	< 200	< 200	< 200	-	< 200
Cadmium	< 1.5	< 1.5	< 1.5	< 1.5	< 1.5	2.4	< 1.5
Calcium	102760	90352	119920	48203	104600	106140	116210
Chloride	360580	651860	91620	57460	285130	313240	651860
Chromium	50	5.1	8.7	7.7	5.1	4.0	9.9
Copper	7.1	8.6	16.3	21.3	6.6	5.6	13
Dissolved organic carbon	-	7900	13200	15100	9200	5100	10800
Dissolved oxygen	18200	8760	15280	3880	2590	3810	8760
Fluoride	< 200	< 200	590	< 200	< 200	< 200	540
Iron	302	344	3181	876	233	278	325
Lead	< 24.5	< 24.5	< 24.5	< 24.5	< 24.5	< 24.5	< 24.5
Magnesium	16522	21681	38526	14038	24180	17320	45657
Manganese	2091	979	812	1499	800	546	678
Nickel	81	14	60	22	16	149	19
Nitrate	22140	54420	24500	51430	36530	16540	54420
Orthophosphate	990	550	3520	1040	5140	-	5030
Oxidation-reduction potential	697	347	82	152	107	119	152

pH	8.25	7.83	7.38	7.00	8.08	7.71	7.90
Phosphorus	872	5110	4234	1103	5153	72	5110
Potassium	5053	23743	13252	16449	16290	21861	20674
Sodium	296210	412980	81252	70143	129210	78134	412980
Specific conductance	2260	2576	1069	761	1242	10840	2576
Sulfate-S	17560	7910	9910	11230	15140	17400	7460
Temperature	11.9	14.9	19.0	13.9	12.4	11.6	14.0
Total Kjeldahl nitrogen	1010	930	7170	4070	970	1410	2330
Total organic carbon	14000	12600	126500	18800	13000	12500	13100
Total phosphorus	870	300	40	-	60	-	10
Zinc	35	18	24	55	31	18	25

Table 9 : Maximum concentrations observed in plumes for each site.

Ammonia-nitrogen within each plume down-gradient of the drainfields did not exceed background concentrations. Ammonia-nitrogen can thus be eliminated as a chemical of potential concern in unsewered areas of Baxter. The maximum concentrations of nitrate down-gradient of the septic drainfields exceeded the drinking water criteria (Health Risk Limit or HRL) of 10000 ug/L at all sites (Table 9). Maximum concentrations ranged from 22140 to 54420 ug/L. These concentrations are similar to values found in the literature (Robertson et al., 1991; Harmson et al., 1996; Wilhelm et al., 1994; and Walker et al., 1973). The health-based criterion of 1000 ug/L for manganese differs from the current HRL of 100 ug/L (Minnesota Department of Health, 1997). The value of 1000 ug/L was exceeded at two sites. Secondary Maximum Contaminant Levels were exceeded for aluminum, chloride, and iron at four, four, and five sites, respectively. Septic systems increase the risk of exceeding drinking criteria for nitrate and chloride. Elevated concentrations of aluminum, iron, and manganese cannot be attributed to septic systems because there was no difference in concentrations between septic systems and background for these chemicals.

Boron was the only chemical for which concentrations in the septic tank were correlated with the concentration beneath the drainfield. Concentrations of nitrate beneath the drainfield did not correlate with ammonia concentrations in the septic tank. These results are surprising, since higher concentrations in the tank should result in higher concentrations in ground water for conservative chemicals such as chloride and nitrate. The data indicate rates of nitrification vary beneath different septic systems.

A plume is the portion of ground water impacted by a septic system. Chloride concentrations two or more times greater than background concentrations represented a sample collected from a septic plume. Plume travel distances are illustrated in Table 10 for boron, nitrate, chloride, phosphorus, and sodium. Plume lengths, as indicated by elevated chloride concentrations, were less than 15 meters at Sites 3, 6, and 8 and more than 140 meters at Site 5. Using static water elevations from field measurements, the head gradient in the aquifer was about 0.002 m/m. Assuming a conductivity of 1.5 meters per day and a porosity of 0.25 cm^3/cm^3, the estimated time for chloride to move 140 meters is about 32 years. The septic system at Site 5 is more than 20 years old but less than 30 years old, so it is possible this plume has not yet stabilized. Sodium attenuated slowly within the aquifer, while boron was attenuated only at Site 5. Lee and Bennett (1998) demonstrate that boron is a good indicator of septic tank inputs to ground water, since concentrations of boron in effluent are higher than background concentrations in ground water and because boron is fairly conservative in ground water. Phosphorus moved less than 12 meters at all sites.

Data from other studies indicate plume lengths of 30 to 130 meters (Robertson et al., 1991; Harman et al., 1996; Wilhelm et al., 1994; and Walker et al., 1973). Nitrate is conservative in most studies. Elevated phosphorus concentrations rarely exceed 15 meters in length within the plume, and are generally less than 5 meters in length (Wilhelm et al., 1994; Reneau and Pettry, 1976; Rea and Upchurch, 1980).

Site	Chloride	Boron	Nitrate	Sodium	Phosphorus
			meters		
1	> 50	30	45	40	12
2	40	40	40	40	< 5
3	9	9	9	9	5
5	140	75	110	80	10
6	15	15	15	11	12
7	35	15	30	25	< 5
8	13	13	13	11	5

Table 10 : Down-gradient distance from the drainfield at which chemical concentrations approached background concentrations.

Phosphorus is an important chemical of concern in northern Minnesota. Lakes in this part of the state have recreational value that can be easily diminished with excessive inputs of phosphorus. There were no differences in phosphorus concentrations in ground water under sewered and unsewered areas (Table 4) despite very high phosphorus concentrations in septic tank effluent (Table 6). Phosphorus in ground water traveled less than 12 meters from the drainfield at all seven sites, and traveled five or fewer meters at sites 2, 3, 7, and 8. Phosphorus in the septic plumes sampled in this study has not traveled far enough to reach lakes. Additional investigations should include studies of plume stability, phosphorus movement in areas with a large number of nonconforming systems, and phosphorus movement in low pH and low buffering capacity environments.

Nitrate remained above background concentrations for the entire length of each plume, except at Sites 5 and 7 (Table 10). The ratio of nitrate to chloride is an indicator of nitrate attenuation, since chloride is conservative and should decrease in concentration only by dilution. Nitrate to chloride ratios in the plume decreased at all sites. Maximum and minimum ratios for each site are illustrated in Table 11. The average background ratio in the aquifer was 0.07 for all sites combined. The data in Tables 10 and 11 indicate nitrate is being attenuated within the plume. If dilution were the only mechanism of dilution, the ratio would decrease slowly. The rapid decrease in the ratio indicates nitrate is being consumed by microbes through denitrification, is taken up by plants, or is attenuated through anion adsorption. The mechanism of nitrate loss is unclear. Aravena and Robertson (1998) observed that about 30% of nitrate loss was attributable to oxidation of reduced sulfur, with the remaining 70% due to oxidation of organic carbon. Steinheimer et al. (1998) attributed nitrate loss to autotrophic denitrification in a loess soil, with ferrous iron being the electron donor.

Site	Maximum NO^3:Cl ratio	Minimum NO^3:Cl ratio
3	0.58	< 0.03
5	1.04	0.01
6	1.23	0.06
7	0.33	0.04
8	1.23	0.05

Table 11 : Nitrate to chloride ratios in septic plumes.

Results indicate nitrate is the primary inorganic chemical of concern associated with septic systems. Management of ground water quality in unsewered areas must therefore focus on nitrate. If nitrate is being attenuated within septic plumes, data in Table 9 provides an estimate of approximate nitrate plume lengths in Baxter. For a nitrate plume that is 100 meters in length from a septic system located on a one acre lot, and assuming a horizontal dispersivity of 0.1, 7.3 percent of the upper portion of the aquifer under that lot would have nitrate concentrations in excess of the drinking water criteria. With a lot size of 2.5 acres, this percentage decreases to 2.9 percent. The percentage of exceedances observed in this study is 25, considerably higher than the calculated rates. There are several factors that may contribute to the high rate of exceedance. First, sampling may have been biased toward intercepting septic plumes since samples were collected where access could be easily obtained. These are areas where septic systems will be located. Second, the average lot size in Baxter may be less than one acre. Even with a lot size of one-half acre, however, the exceedance rate would be only 14.6 percent. Third, there may be other nitrogen inputs, such as lawn fertilizers. These were not measured. Finally, the plumes sampled during this study may not be representative of plumes in the remaining unsewered areas of Baxter. Two factors may account for this. First, dilution of the plumes occurs from lake discharge during certain times of the year. Second, denitrification occurs in riparian zones along the lakeshore. Five of the sampled plumes were located along Perch Lake, which has an extensive riparian buffer and discharges to ground water during late summer.

Figure 6 illustrates concentrations of nitrate along the plume at site 5. The plume length was estimated by measuring the distance over which chloride concentrations remained more than two times greater than the background concentration. Curves for boron and chloride were similar, as would be expected since these are anions that are generally attenuated only through dilution with recharge water. The nitrate plume extends vertically to about 10 meters below the soil treatment system. The plume then appears to move primarily in a lateral direction, although the information collected is insufficient to verify this. A similar plume shape is evident for total phosphorus (Figure 7). The phosphorus plume does not extend as deeply into the aquifer and is attenuated within about 12 meters of the soil treatment system. The shape of these plumes is similar to those observed in other studies (Robertson, 1995; Robertson and Blowes, 1995; Robertson et al., 1991).

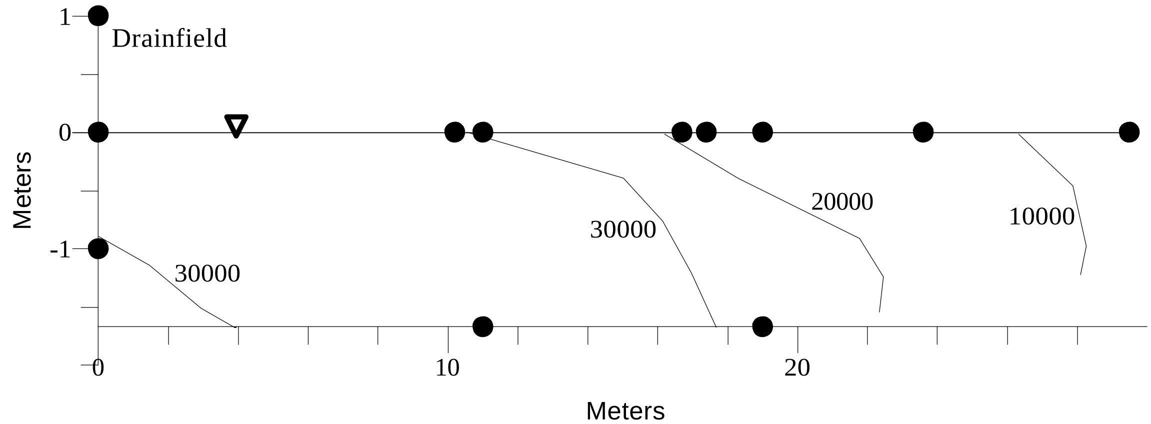


Figure 6 : Nitrate concentration, in ug/L, in the septic plume at site 5. Filled circles represent sampling locations.

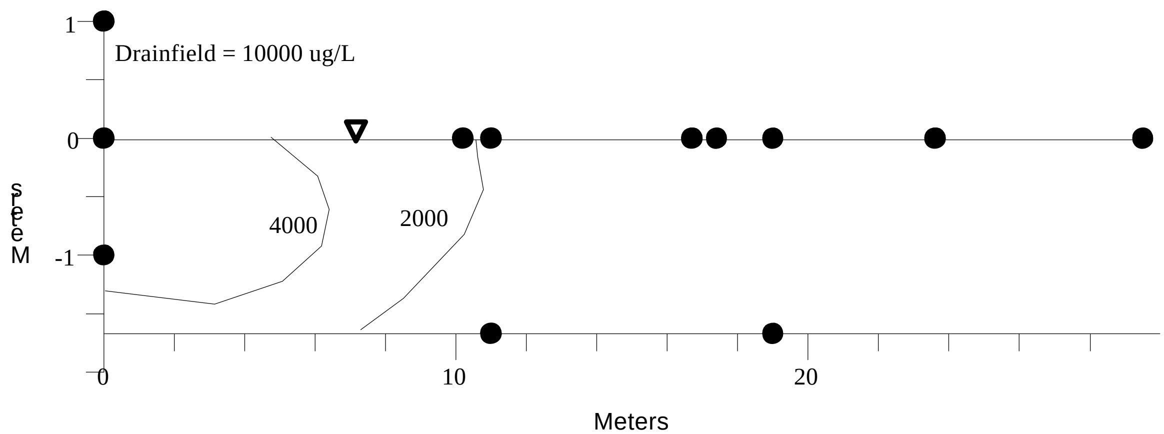


Figure 7 : Total phosphorus concentration, in ug/L, in the septic plume at site 5. Filled circles represent sampling locations.

Bacteria

Most probable number (MPN) concentrations of total coliform bacteria in septic effluent exceeded 200 per 100-mL at all seven sites, with concentrations greater than 240000 per 100-mL at site 2. Reneau (1978) and DeBorde et al. (1998) observed concentrations for total coliform bacteria of about 500000 per 100-mL. Concentrations of total coliform bacteria in effluent, the number of detections and non-detections, and concentration ranges in ground water are summarized in Table 12. Concentrations in ground water decrease rapidly from about 200 per 100-mL to less than 1 per 100-mL within 10 meters of the drainfield (Figure 8). Hagedorn et al. (1978) observed a decrease in total bacteria of more than two orders of magnitude within 15 meters of the drainfield. They also observed, however, that the greatest movement of bacteria from the drainfield down-gradient in the septic plume followed precipitation events. Bacteria always reached 3 meters and sometimes 5 meters within 24 hours of a rain event. Brown (1980) observed a flushing of bacteria through the biomat and underlying soil following rainfall, but bacteria survival in groundwater was less than 100 days. The current study provides a best-case scenario with respect to bacteria in ground water, since the period of sampling was relatively dry. Although bacteria concentrations in ground water are low, the presence of bacteria indicates additional sampling may be warranted to determine if there are temporal variations in population. To accomplish this objective, a monitoring network would need to be established around one or more septic systems and the network sampled periodically to determine temporal variability in bacteria populations.

Site	Septic tank effluent concentrations (MPN/100-mL)	Ground Water		
		No. of non-detections	No. of detections	Range in concentration (MPN/100-mL)
1	> 2000	3	4	1 to 200
2	> 200	1	10	1 to 140
3	> 2400	3	6	1 to 11
5	> 200	5	6	1 to 120
6	> 200	3	5	1 to >2000
7	> 240000	2	6	1 to 200
8	> 200	11	4	1 to 12

Table 12 : Summary information for total bacteria found in septic effluent and ground water down-gradient of individual septic systems.

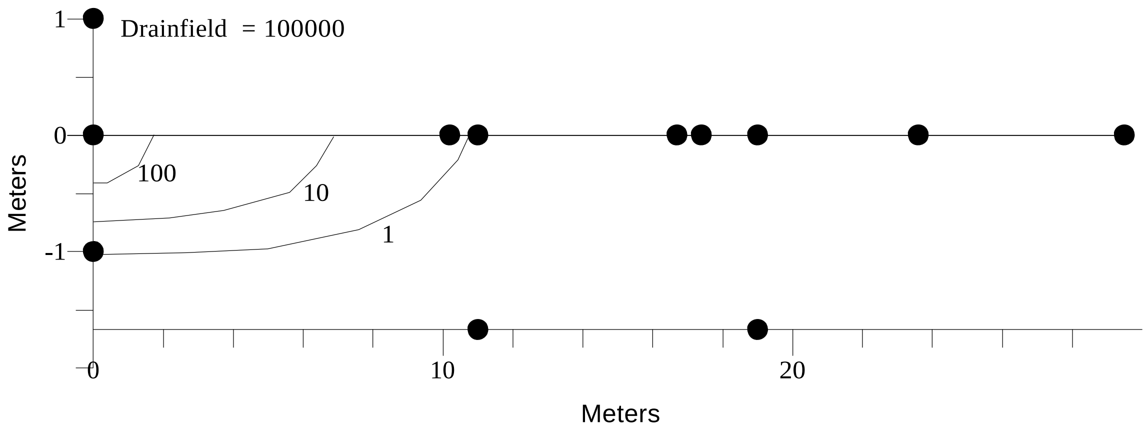


Figure 8 : Concentrations of total coliform bacteria, in MPN/100-ml, in the plume at site 5.

There were no detections of *E. Coli* in ground water at any site, except for a single detection of 2 per 100-mL at site 7. MPN concentrations in septic effluent were greater than 200 per 100-mL at all six sites, and appear to be greater than 2000 per 100-mL (Table 13). Reneau (1978) observed MPN concentrations of greater than 50000 per 100-mL.

Site	***E. coli* (MPN/100-mL)**
1	> 200
2	2500
3	> 200
5	> 200
6	> 200
7	> 2400
8	> 2000

Table 13: Concentrations of *E. Coli* in septic tank effluent.

Although bacterial populations are low in the study, some research indicates viruses may be more persistent and travel farther than bacteria (Brown, 1980; DeBorde et al., 1998). Viruses generally represent a greater health risk to humans than bacteria. DeBorde et al. (1998) discuss some of the difficulties in sampling for viruses, including determining which viruses to sample for, high costs of sampling, and poor correlations between bacteria and virus populations. Considering results of this study, it would be useful to sample for viruses in septic effluent and in the sample closest to the drainfield.

Volatile Organic Compounds (VOCs)

Septic effluent contained VOCs at each site. Table 14 summarizes total VOC concentrations and the number of VOC detections in septic effluent. There was considerable variability in the number of detections, with three or fewer detections at sites 2, 3, 5, 6, and 8, but 11 and 7 detections at sites 1 and 7, respectively. Total concentrations of VOCs did not correlate with the number of detections. The highest total VOC concentrations were at sites 5 and 6, even though just one and two VOCs were detected in effluent at these sites.

Site	Total VOCs (ug/L)	No. VOCs detected
1	168	11
2	245	2
3	305	3
5	800	1
6	610	2
7	138	7
8	297	2

Table 14 : Total concentration of VOCs in septic tank effluent and number of compounds detected.

Toluene was the most commonly detected VOC in septic tank effluent, being found in 7 samples at concentrations ranging from 7 to 800 ug/L (Table 15). Substituted benzenes accounted for two-thirds of the total detections in effluent. These are commonly found in fuel oils, gasoline, paints, paint thinners, varnishes, and other solvents commonly used in households. No VOC in ground water exceeded a drinking water standard.

Chemical	No. of detections	Concentration range (ug/L)
Toluene	7	7 to 800
Xylene	4	0.2 to 0.8
Methyl isobutyl ketone	4	7.3 to 220
Chemical	**No. of detections**	**Concentration range (ug/L)**
Chloroform	4	0.1 to 0.5

n-Butyl benzene	3	2.5 to 39
p-Isopropyl toluene	3	6.2 to 76
n-Propylbenzene	2	1.1 to 2.7
1,3,5-Trimethylbenzene	2	1.4 to 24
Acetone	2	30 to 290
Naphthalene	2	1.2 to 2
sec-Butylbenzene	2	0.8 to 1.8
tert-Butylbenzene	1	10
1,2,4-Trichlorobenzene	1	0.8
1,4-Dichlorobenzene	1	13
Ethylbenzene	1	0.3
Methylene chloride	1	0.5
1,2,4-Trimethylbenzene	1	12

Table 15 : VOCs detected and concentration range in septic tank effluent.

Thirteen VOC detections occurred in ground water. Eleven of these were chloroform at concentrations ranging from 0.1 to 2.6 ug/L. Chloroform may be naturally occurring, particularly in septic effluent, which has high concentrations of organic matter and chloride. There was one detection of chloroethane at a concentration of 6 ug/L, and a detection of methylene chloride at 1 ug/L. These chemicals are used in some household products, but not to the extent they once were.

Although there were 35 detections of nonhalogenated VOCs in effluent, there were no detections of these compounds in ground water. Non-halogenated VOCs are degraded in the presence of oxygen. The results indicate VOCs are attenuated within septic drainfields. VOCs associated with septic systems do not represent a health concern despite their presence in septic waste.

Conclusions and Recommendations

Results from Phase 1 of the Baxter study indicates higher pH and concentrations of nitrate, total organic carbon, and dissolved organic carbon in unsewered areas compared to sewered areas. Since nitrate concentration in the upper 10 feet of the aquifer was not correlated with any parameter, differences in nitrate concentrations between sewered and unsewered areas are due to greater nitrogen inputs in unsewered areas. Concentrations of nitrate under unsewered areas in Baxter are less than concentrations under unsewered areas described in the literature. Concentrations of most chemicals in septic tanks and plumes were similar to concentrations found in the literature. Therefore, the most likely reason for the lower concentrations of nitrate is that unsewered developments are small in geographic extent compared to other studies in the literature. Although nitrate concentrations in this study were low compared to other studies, 25 percent of sampled geoprobes exceeded the drinking water criteria for nitrate.

Concentrations of nitrate decrease when ground water conditions become favorable for denitrification. Considering all well and geoprobe samples, nitrate concentration decreased with increasing well depth and with decreasing Eh (oxidation-reduction potential). Nitrate was detected in samples collected from the upper 20 feet of the aquifer, but not in any sample below that depth. There appears to be a zone between 10 and 20 feet where denitrification rapidly occurs. This denitrification zone is somewhat deeper than observed in the St. Cloud land use study. Denitrification also appears to occur in riparian zones along the lakes where sampling occurred.

The following general recommendations are based on the results of this study.

1. Additional Phase 1 investigations should be conducted in other areas. Age of development and lot size are two variables that need to be evaluated with respect to impacts of septic systems on ground water quality. Age of development may be an important factor if it takes several years for plumes to stabilize.
2. Additional plume investigations should focus on three areas of investigation. First is gaining an understanding of the relationship between plumes and lake water quality. Plumes which discharge to lakes must be identified. Rather than track plumes from

the septic tank to a lake shore, plumes should be identified near the shore-lake interface. This may be accomplished by probing parallel to this interface until a plume is encountered. Second, greater effort needs to be made to determine the behavior of microbes originating in the septic tank. Sampling should be expanded to include viruses. A permanent monitoring network should be established in a plume where bacteria have been identified in ground water. Temporal factors are likely to be important for understanding the behavior and fate of microbes in ground water. Sampling should therefore occur following significant precipitation events. Third, hydrologic relationships need to be assessed within individual plumes. A permanent network should be established within a plume. Recharge measurements should be made using continuous water level measurements. Slug tests would be performed in each well. Chemical concentrations would be measured quarterly and after significant precipitation effects. The objective of this study would be to evaluate temporal variability in ground water quality within a plume.

The following recommendations are made for the Baxter area.

1. A phase 3 study should not be conducted in Baxter. Phase 3 is a long-term study of ground water quality following a change in land use, such as unsewered to sewered. Even though the Baxter area will be sewered over the next few years, nitrate concentrations are too low to easily evaluate changes in water quality.
2. If portions of Baxter remain unsewered, or if unsewered development continues in the city, management plans should be developed to minimize risk to drinking water receptors and lakes. Management strategies would include minimum lot sizes, setback distances from lakes, minimum depths for domestic wells, and pumping restrictions from the aquifer underlying unsewered areas. Engineering strategies also limit impacts from septic systems by providing better treatment of wastes. Engineering strategies include separating grey and black water, maintaining appropriate separation distances in the unsaturated zone, and advanced treatment of waste.

References

Alhajjar, B.J., G. Chesters, and J.M. Harkin. 1990. *Indicators of Chemical Pollution from Septic Systems*. Ground Water. 28:559-568.

Anderson, D.L., J.M. Rice, M.L. Voorhees, R.A. Kirkner, and K.M. Sherman. 1987. *Ground Water Modeling with Uncertainty Analysis to assess the Contamination Potential from Onsite sewage Disposal Systems (OSDS) in Florida*. Proceedings from the National Symposium on Individual and Small Community Sewage Systems, December 14-15. Chicago, IL. 411 pp.

Aravena, R., and W.D. Robertson. 1998. *Use of Multiple Isotope Tracers to Evaluate Denitrification in Ground Water: Study of Nitrate from a Large-flux Septic System Plume*. Ground Water.

Bauman, B.J. and W.M. Schafer. 1984. *Estimating Ground-water Quality Impacts from On-site Sewage Treatment Systems*. Proceedings of the Fourth National Home Sewage Treatment Symposium. ASAE pp. 285-294.

Brown, K.W. 1980. *An Assessment of Impacts of Septic Leachfields, Home Lawn Fertilization, and Agricultural activities on Ground water Quality*. 104 p.

Childs, K.E., S.B. Upchurch, and B. Ellis. 1974. *Sampling of Variable, Waste-Migration Patterns in Ground Water*. Groundwater. 12:369-377.

DeBorde, D.C., W.W. Woessner, B. Lauerman, and P.N. Ball. 1998. Virus Occurrence and Transport in a School Septic System and Unconfined Aquifer. Ground Water

Fay, S.R., R.C. Spong, S.C. Alexander, and E.C. Alexander Jr. 1995. *Optical Brighteners: Sorption Behavior, Detection, Septic System Tracer Applications*. Published in: Proceedings of the International Association of Hydrogeologists XXVI International Congress, Edmonton, Alberta, Canada.

Fetter, C.W. Jr., W.E. Sloey, and F.L. Spangler. 1976. *Potential Replacement of Septic Tank Drain Fields by Artificial Marsh Wastewater Treatment Systems*. Groundwater 396-401.

Gold, A.J., B.E. Lamb, G.W. Loomis, J.R. Boyd, V.J. Cabelli, and C.G. McKiel. 1992. *Wastewater Renovation in Buried and Recirculating Sand Filters*. Jour. Environ. Qual. 21:720-725.

Hagedorn, C., D.T. Hansen, and G.H. Simonson. 1978. *Survival and Movement of Fecal Indicator bacteria in Soil under Conditions of Saturated Flow*. Jour. Environ. Qual. 7:55-59.

Hantzsche, N.N., and E.J. Finnemore. 1992. *Predicting Ground-Water Nitrate-Nitrogen Impacts*. Groundwater. 30:490-499.

Harman, J., W.D. Robertson, J.A. Cherry, and L. Zanini. 1996. *Impacts on a sand aquifer from an old septic system: nitrate and phosphate*. Ground Water 34:1105-1114.

Harmsen, E.W., J.C. Converse, B.H. Shaw, E.J. Tyler, and J.O. Peterson. 1996. *Spatial and Temporal Distribution of Groundwater Nitrate-N beneath Two Unsewered Subdivisions in the Central Wisconsin Sand Plain.*

Kaplan, B.O. 1987. *Septic Systems Handbook.* Lewis Publishers. Chelsea, Michigan. 290 p.

Lee, R.W., and P.C. Bennett. 1998. *Reductive Dissolution and Reactive Solute Transport in a Sewage-Contaminated Glacial Outwash Aquifer*. Ground Water 36:483-595.

Magner, J.A., and C.P. Regan. 1994. *Tools and Techniques for the Assessment of Ground Water/Surface Water Interactions in Glacial Hydrogeologic Settings*. In: Ground Water Management Series. National Ground Water Association. Dublin, OH 18:685-698.

Miller, J.C. *Nitrate Contamination of the Water-Table Aquifer by Septic Tank Systems in the Coastal Plain of Delaware*.

Minnesota Department of Health. 1997. *Health Based Value for Manganese.* Office Memorandum by Larry Gust, Supervisor, Health Risk Assessment Unit. St. Paul, MN. 1 p.

Minnesota Pollution Control Agency. 1998a. *GWMAP Field Guidance Manual*. St. Paul, MN 42p.

Minnesota Pollution Control Agency. 1998b. *Data Analysis Protocol for the Ground Water Monitoring and Assessment Program (GWMAP).* Draft in review.

Minnesota Pollution Control Agency. 1998c. *Effects of Land Use on Ground Water Quality. St. Cloud Area, Minnesota. 1997 Results*. St. Paul, MN 59 p.

Muszkat, Lea, Daniel Raucher, Mordeckai Magaritz, Daniel Ronen, and Abraham J. Amiel. 1993. *Unsaturated zone and ground-water contamination by organic pollutants in a sewage-effluent-irrigated site*. Ground Water. 31:556-565.

Noss, R.R., and M. Billa. 1988. *Septic System Maintenance Management*. Journal of Urban Planning and Development. 114:73-90.

Quan, E.L., H.R. Sweet, and J.R. Illian. 1974. *Subsurface Sewage Disposal and Contamination of Ground Water in East Portland, Oregon*. Groundwater 12:356-366.

Rea, R.A., and S.B. Upchurch. 1980. *Influence of Regolith Properties on Migration of Septic Tank Effluent*. Groundwater 118-125.

Reneau, R.B. Jr. 1978. *Influence of Artificial Drainage on Penetration of Coliform Bacteria from Septic Tank Effluents into Wet Tile Drained Soils*. Jour. Environ. Qual. 723-30.

Reneau, R.B., and D.E. Pettry. 1976. *Phosphorus Distribution from Septic Tank Effluent in Coastal Plain Soils*. Jour. Environ. Qual. 5:34-39.

Robertson, W.D. 1995. *Development of Steady-state Phosphate Concentrations in Septic System Plumes.* Journal of Contaminant Hydrology. 19:289-305.

Robertson, W.D., and D.W. Blowes. 1995. *Major Ion and Trace Metal Geochemistry of an Acidic Septic-System Plume in Silt*. Groundwater. 33:275-283.

Robertson, W.D. 1994. *Chemical Fate and Transport in a Domestic Septic System: Site Description and Attenuation of Dichlorobenzene*. Environ. Toxicol. and Chem. 13:183-191.

Robertson, W.D., and J.A. Cherry. 1995. *In Situ Denitrification of Septic-System Nitrate using Reactive Porous Media Barriers: Field Trials*. Groundwater. 33:99-111.

Robertson, W.D, J.A. Cherry, and E.A. Sudicky. 1991. *Ground-water contamination from two small septic systems on sand aquifers*. Ground Water. 29:82-92.

Steinheimer, T.R., K.D. Scoggin, and L.A. Kramer. 1998. *Agricultural Chemical Movement through a Field-Size Watershed in Iowa: Subsurface Hydrology and Distribution of Nitrate in Groundwater*. Environ. Sci. Tech. 32:1039-1047.

Tinker, J.R. Jr. *An Analaysis of Nitrate-nitrogen in Ground Water beneath Unsewered Subdivisions.* Ground Water Monitoring Review. 11:141-150.

Wahl, T. E., and R. G. Tipping. 1991. *Ground-water Data Management - The County Well Index*. Minnesota Geological Survey. Minneapolis, MN. 38 p.

Walker, W.G., J. Bouma, D.R. Keeney, and P.G. Olcott. 1973. *Nitrogen Transformations during Subsurface Disposal of Septic Tank Effluent in Sands: II. Ground Water Quality*. Jour. Environ. Qual. 4:521-525.

Wilhelm, S.R., S.L. Schiff, and W.D. Robertson. 1994. *Chemical Fate and Transport in a Domestic Septic System: Unsaturated and Saturated Zone Geochemistry*. Environ. Toxic. Chem. 13:193-203.

Wilhelm, S.R., S.L. Schiff, and W.D. Robertson. 1996. *Biogeochemical Evolution of Domestic waste Water in Septic Systems: 2. Application of Conceptual Model in Sandy Aquifers*. Groundwater 34:853-864.

Yates, M.V. and S.R. Yates. 1988. *Septic Tank Setback Distances : A Way to Minimize Virus Contamination of Drinking Water*. Ground Water 202-208.