Eastern Shore of Virginia Groundwater Resource Protection and Preservation Plan

By Accomack-Northampton Planning District Commission and the Eastern Shore of Virginia Groundwater Committee

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Table of Contents

Figures

Table of Contents

Tables

1.0 INTRODUCTION

The original Groundwater Supply Protection and Management Plan for the Eastern Shore of Virginia was adopted by the Groundwater Committee on May 5, 1992. The plan included the following components:

A. Identification of the water resources on the Shore focusing on:
   a. Fresh water aquifers;
   b. The recharge spine for the Yorktown-Eastover aquifer; and
   c. Water budget and water balance for the Yorktown-Eastover aquifer
B. Identification of contaminant threats with an emphasis on land use activities;
C. Plan to monitor groundwater use
D. Identification of measures to manage existing and future land use
E. Delineation of Groundwater Protection Areas

Specific recommendations from the 1992 Plan were:

- ✓ Manage Wellhead Protection and Recharge Areas
- ✗ Restrict Mass Drainfields in Recharge Areas
- ✓ Implement Chesapeake Bay Program
- ✗ Private Well Ordinance
- ✓ Review Zoning, Subdivision Regulations, and Site Plans to address groundwater quality and quantity
- ✗ Registration of ALL USTs
- ✓ Monitor Groundwater Withdrawals
- ✓ Develop Land Use/Water Quality Database
- ✓ Promote Research and Education

✓ *(Indicates partially or fully complete)*
✗ *(Indicates incomplete)*

A comprehensive review of Plan implementation was completed by the Groundwater Committee in 2008 and found that of the nine recommendations, three were not completed and, based on current conditions, did not require further action:

1) <u>Restrict mass drainfields in recharge areas</u>: The Virginia Department of Health (VDH) were found to provide adequate protection to the groundwater resource and additional restrictions were unnecessary. Additionally, advancements in on-site treatment technology improves treatment of the wastewater, further reducing the need to restrict this technology in the recharge areas.
2) <u>Private well ordinance</u>: The VDH regulates private wells. Private well ordinances for other communities within the Commonwealth were generally enacted before VDH adopted the private well regulations. These ordinances were found to be largely duplicative of the VDH regulations. With the statutory restrictions on local community implementation of private well ordinances and

VDH regulations already in place, the need to additional private well ordinance was not deemed necessary.

3) Registration of all USTs: This recommendation preceded significant changes in the VDEQ UST regulations that greatly increased both construction and monitoring requirements. The new UST regulations were fund to provide adequate protection of the groundwater resource.

1.1 RESOURCE CONSTRAINTS

1.1.1 Eastern Shore Dependence on Groundwater as a Resource

The Eastern Shore of Virginia depends entirely on ground water for potable water supplies, as well as most non-potable supplies such as irrigation water. Because the peninsula is surrounded by large bodies of saltwater, ground water becomes brackish at relatively shallow depths (< 350 feet) in most areas, and the total available ground water supply is more limited than on the mainland.

Threats to ground water on the Eastern Shore may be placed into three general categories: (1) saltwater intrusion; (2) hydraulic head depression; and (3) contamination from surface sources. Intrusion of saltwater into fresh ground water aquifers can be caused by wells that are screened too close to the freshwater-saltwater interface, are too close to the shore, and/or pump at an excessive rate. Depression of the hydraulic head occurs around every pumping well, but if pumping rates are too high or if wells are too close to each other, water levels in some wells can drop so low that well yields are reduced. In extreme cases, the head can fall so low that the aquifer is partially dewatered, which in turn can cause consolidation and a permanent loss of transmissivity (which will also reduce well yield).

1.1.2 DEQ Groundwater Management Area

Effective November 1, 1976, the Eastern Shore of Virginia was declared a "*Critical Ground Water Area*", (9VAC25-620-10 - Repealed) subject to regulation under the Ground Water Management act. On June 17, 2013, the State Water Control Board adopted amendments (9VAC25-600-20) that included the Eastern Shore in the "*Eastern Virginia Groundwater Management Area*". This action consolidates all localities in the Coastal Plain of Virginia under one Groundwater Management Area. The declaration of the Eastern Shore as part of the Groundwater Management Area is based on the following findings:

- *Groundwater level declines have been observed in two sections of Accomack County;*
- *Interference between wells has been observed in the same two sections of Accomack County;*
- *Some evidence of localized groundwater contamination has been observed in the water table aquifer in Accomack County but not in the confined aquifers;*
- *Even though groundwater supplies in Accomack County are not overdrawn and are not expected to be in the near future, it should be recognized that they may overdraw in some areas in the future if water withdrawals are not distributed throughout the region. Further, saltwater intrusion has not been observed to date but may occur in the future if heavy groundwater withdrawals are concentrated in any one area*.

This designation allows the Virginia Department of Environmental Quality to regulate through permits groundwater withdrawals that equal or exceed 300,000 gallons in a single month in order to "*conserve, protect and beneficially utilize the groundwater resource and to ensure the public welfare, safety and health"*. The Groundwater Withdrawal Regulations (*http://lis.virginia.gov/cgi-bin/legp604.exe?000+reg+*

9VAC25-610) include minimum requirements for applications for a Groundwater Withdrawal Permit that include:

1) documentation of the beneficial use and an evaluation of the lowest quality of water needed;

2) water demand;

3) a Water Conservation and Management Plan;

4) Potential impact to the groundwater resource; and

5) a Mitigation Plan (if the potential impacts extend beyond the applicants property boundary).

Minimum reporting requirements for Permitted groundwater withdrawals is monthly water use. Additional requirements that include water quality testing is common for permits on the Shore.

1.1.3 EPA Sole Source Aquifer

The Eastern Shore of Virginia is one of six areas designated as a Sole Source Aquifer within the Mid-Atlantic (Region 3) area. The US Environmental Protection Agency (USEPA) designated the Columbia – Yorktown-Eastover Multiaqufier System a sole source aquifer, effective May 9, 1997. Information on the designation is provided on the USEPA Region 3 website at *http://www.epa.gov/reg3wapd/drinking/ssa/ columbiayorktown.htm*.

The Sole Source Aquifer (SSA) Program, which is authorized by Section 1424(e) of the Safe Drinking Water Act, allows communities to petition the USEPA for protection when a community is dependent on a single source of drinking water and there is no possibility of a replacement water supply to be found. USEPA regional offices review the petitions and, if merited, the Regional Administrator will designate an area as a Sole Source Aquifer. The SSA program provides federal overview of federally-funded projects within the designated area. Projects and land uses which are not federally-funded are not subject to federal overview.

Useful Definitions:
USEPA Sole Source Aquifer (SSA): an aquifer that is the principle or exclusive source or drinking water, supplying at least 50% of the drinking water consumed in the area overlying the aquifer. USEPA guidelines also stipulate that these areas can have no alternative drinking water source(s) which would physically, legally, and economically supply all those who depend upon the aquifer for drinking water.
Usage data and other technical and administrative information are required for assessing designation criteria. In general, the designation decision process takes a minimum of 6 months from the time that the petitioner submits a completed petition to USEPA.

SSA designations increase the public's awareness on the nature and value of local ground water resources by demonstrating the link between an aquifer and a community's drinking water supply. Often the realization that an area's drinking water originates from a vulnerable underground supply can lead to an increased willingness to protect it. The public also has an opportunity to participate in the SSA designation process by providing written comments to USEPA or by participating in an USEPA sponsored public hearing prior to the designation decision.

Although designation aquifers have been determined to be the "sole or principal" source of drinking water for an area, this does not imply that they are more or less valuable or vulnerable to contamination than other aquifers which have not been designated by USEPA. Many valuable and sensitive aquifers have not been designated simply because nobody has petitioned USEPA for such status or because they did not qualify for designation due to drinking water consumption patterns over the entire aquifer area. Furthermore, ground water value and vulnerability can vary considerably both between and within designated aquifers.

Basis for the USEPA decision is:

1. The Columbia and Yorktown-Eastover aquifers are high-yielding aquifers which the service area population relies on for more than 50% of its drinking water needs.
2. There exists no viable economical alternative drinking water source or combination of sources to supply the designated service area.
3. The USEPA has found that the Bi-County Ad Hoc Citizens Committee on Oversight has appropriately delineated the boundaries of the aquifer project review area.
4. While the quality of the Columbia and Yorktown-Eastover aquifer's ground water is considered to be good, it is highly vulnerable to contamination due to its geological characteristics and possible land-use activities. The designated area is a multiaquifer system with a surficial aquifer (Columbia aquifer) consisting of shallow sand and gravel deposits and a deeper confined aquifer (Yorktown-Eastover aquifer) which is recharged by water from the surficial aquifer. The shallow nature of the surficial aquifer allows contaminants to be rapidly introduced into the ground water with minimal assimilation. It is this high vulnerability to contamination, especially on the central "spine" of the peninsula, coupled with the aquifer's value as the principal source of drinking water for the residents served, that could pose a significant public health hazard.
5. Definable Aquifer Boundaries: USEPA guidance allows designations to be made for entire aquifers, hydrologically connected aquifers (aquifer systems), or part of an aquifer if that portion is hydrologically separated from the rest of the aquifer. The Yorktown-Eastover Multiaquifer System boundary is based on hydrological principles and USEPA's interpretation of available data.

1.1.4 Groundwater Committee Formation and Mandate

The Eastern Shore of Virginia Groundwater Committee was formed as a bi-county committee in 1990 by Accomack County and Northampton County. The committee includes elected officials, citizens, and local government staff.

Mandate:

- Assist local governments and residents in understanding, protecting, and managing ground water resources
- Prepare a ground water resources protection and management plan

- Serve as an educational and informational resource
- Initiate special studies concerning the protection and management of the Eastern Shore ground water resource
- Coordinate and communicate among parties responsible for ground water protection, management, and research

Figure 1.1-1: Extent of Sole Source Aquifer

http://www.epa.gov/reg3wapd/presentations/ssa/columbia/index.htm

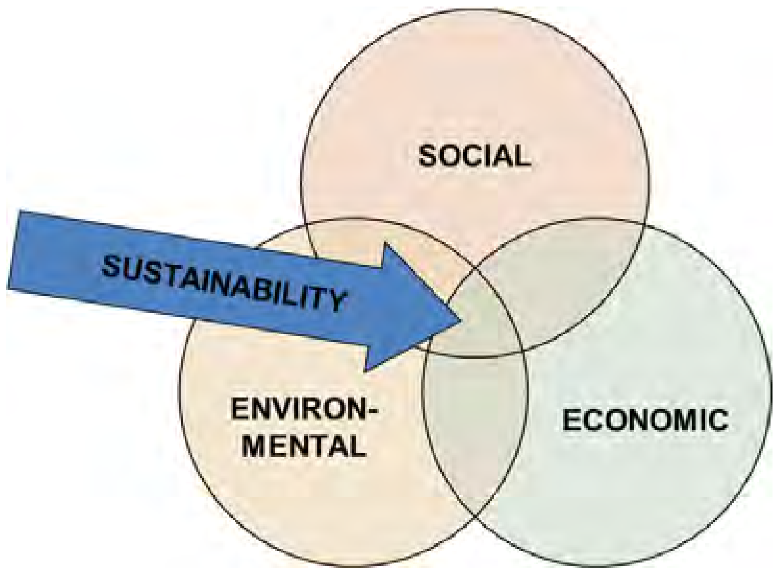
1.2 SUSTAINABLE APPROACH

Sustainability is the capacity to endure. A more formal definition of "sustainability", in the context of the present Groundwater Management Plan, is the systematic approach to using and managing the groundwater resource:

> *"…that meets the needs of the present without compromising the ability of future generations to meet their own needs" (*United Nation's World Commission on Environment and Development, 1987)

subject to the following conditions:

1. *"Renewable resources such as fish, soil, and groundwater must be used no faster than the rate at which they regenerate."*
2. *"Pollution and wastes must be emitted no faster than natural systems can absorb them, recycle them, or render them harmless." (*Herman E. Daly, 1971)



1.3 REPORT FORMAT

The Groundwater Management Plan (Plan) incorporates a modular design to facilitate frequent updates. As such, the Plan will remain current through routine or periodic modification of specific report sections. The Plan, to the extent possible, references outside sources of information, such as County Comprehensive Plans, such that when the Comprehensive Plans are modified minimal changes to the Plan is required. The Plan directly links to frequently updated information, such as permitted groundwater withdrawals, water use, groundwater level trends, and research activities to maintain current information on Water Resources on the Shore.

2.0 WATER RESOURCES

This section of the Groundwater Management Plan describes the freshwater and groundwater resources of the Eastern Shore of Virginia.

2.1 SURFACE WATER

Surface features characteristic of the Coastal Plain of the Eastern Shore include terraces, stream channels, drowned valleys, Carolina bays, swamps and marshes, remnant dunes, and bar-like features formed during the Pleistocene time. The central portion of the Eastern Shore peninsula forms a broad, low ridge which trends northeast-southwest and stands at an elevation ranging from about +25 to +50 ft msl. This central highland area is the principal fresh ground water recharge area for the peninsula and is referred to as the "recharge spine" of the Eastern Shore (**Error! Reference source not found.**). The terrace has maintained the same strand line for almost the entire length of the Atlantic Coastal Plain and is divided into a lower and upper terrace which directs the drainage of the Eastern Shore.

The lower terrace, generally located west of Route 13, consists of broad flats broken by large meandering tidal creeks and bordered by tidal marshes. The topography of the upper terrace, more complex than the lower terrace, is characterized by shallow sand-rimmed depressions known as Carolina bays. The bays, predominantly oval in shape, exert an influence on the infiltration, retardation of runoff, and movement of ground water. Between the mainland and the barrier islands are extensive tidal marshes flooded regularly by saltwater and drained by an extensive system of creeks[1]. These systems accept ground water discharge.

2.1.1 Freshwater Streams and Creeks

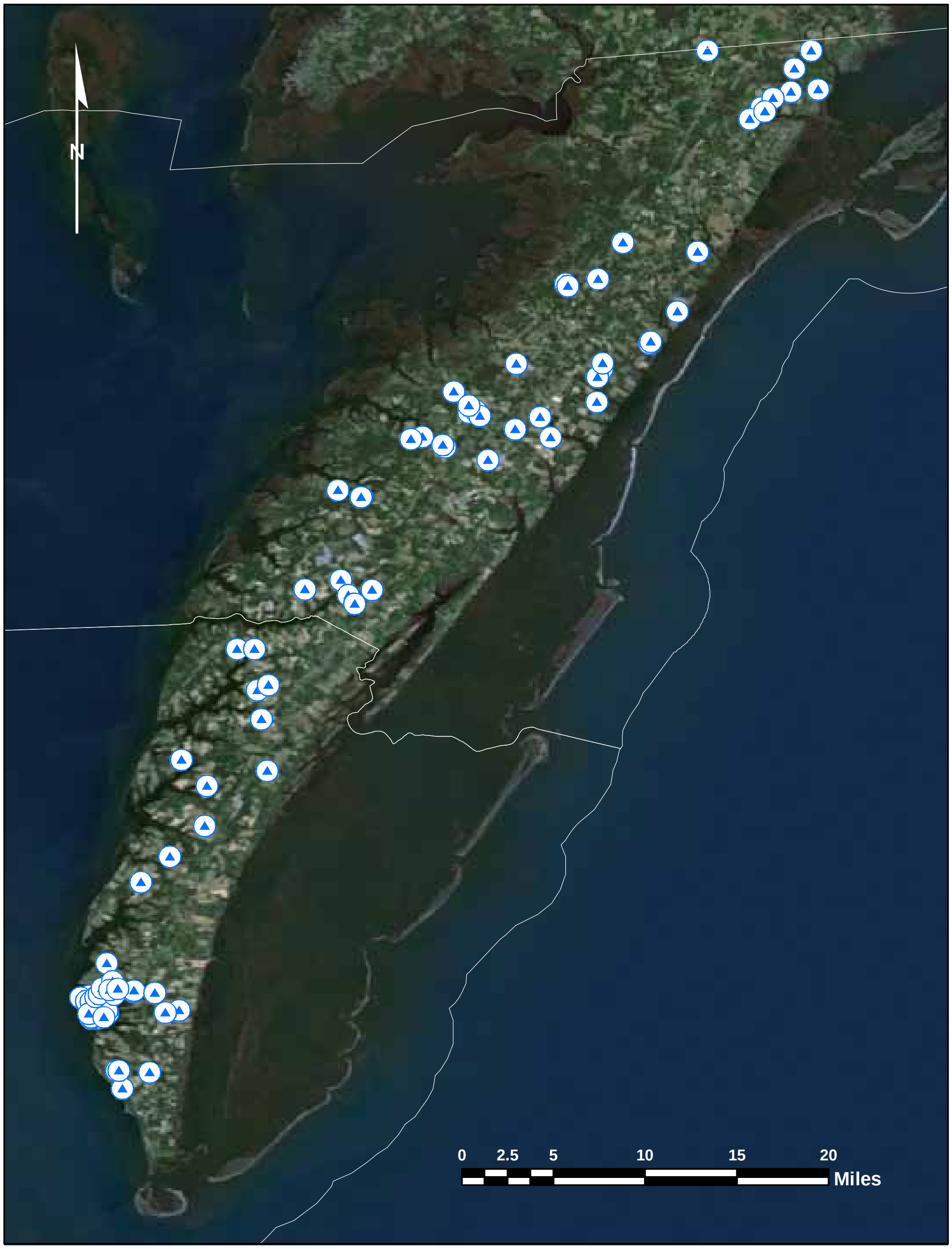
The Eastern Shore is drained by a total thirty small creeks flowing bayward or seaward from the drainage divide which passes the length of the peninsula. The lower reaches of the creeks form tidal estuaries fed by narrow, meandering branches. Because of the low topography and low inflow of freshwater, the creeks are brackish to saline everywhere except for the upper reaches. The estuaries are more pronounced on the Chesapeake Bay side and receive more of the surface and ground water drainage than the smaller creeks on the ocean side.

Numerous drainage basins exist on the shore ranging in size from approximately four to six square miles. These basins consist of several small creeks and interconnected ditches. Primary drainage basins of the Eastern Shore of Virginia are Gargathy Creek, Folloy Creek, Finney Creek, Occohannock Creek, and Pungoteague Creek basins in Accomack County; and Mattawoman Creek and Nassawadox Creek basins in Northampton County. The Pocomoke River basin borders Worcester County, Maryland and Accomack County, Virginia and serves as a major drainage divide for this area.

2.1.2 Fresh Water Impoundments

An important source of water for agricultural and other irrigation supply is from dug farm ponds and, to a much lesser extent impounded creeks and streams (**Figure 2.1-1**). Most of the impounded creeks and streams are historical, many created before 1980 and most of the dug ponds post-date 1980. Source of water in these impoundments is a combination of storm water and groundwater recharge from the Columbia aquifer. While the contribution from storm water and groundwater varies widely between impoundments, from a water balance, availability of water from storm water and the Columbia aquifer is far greater than the underlying confined Yorktown-Eastover aquifer. As a consequence, use of these impoundments as a source of water in preference to the Yorktown-Eastover aquifer is far more sustainable.

Figure 1.1-1: Surface Water Impoundments



Data Source: Virginia Water Use Database System (VWUDS) updated August 2013

References

1. Hulme, A. E., 1955. *The Water Resources of Somerset, Wicomico, and Worcester Counties*. Maryland Department of Geology, Mines, and Water Resources: Bulletin 16

2.2 GROUNDWATER

This section provides a description of the groundwater resource system on the Eastern Shore of Virginia.

Useful Definitions:

Hydrostratigraphy: the structure and layering of underground porous materials (gravels, sands, silts, clays, rocks, and other natural materials including shells) in reference to the flow of groundwater.

Permeability: the property of a hydrostratigraphic layer which measures the ability of the layer to conduct water and other fluids.

Aquifer: an underground layer of water-bearing porous materials (often comprised largely of gravels, sands, and/or shells) which conducts water and from which groundwater can be readily extracted using a well.

Confining Unit: an underground layer of fine grained material (often comprised largely of silts and/or clays) which restricts the flow of water between aquifers

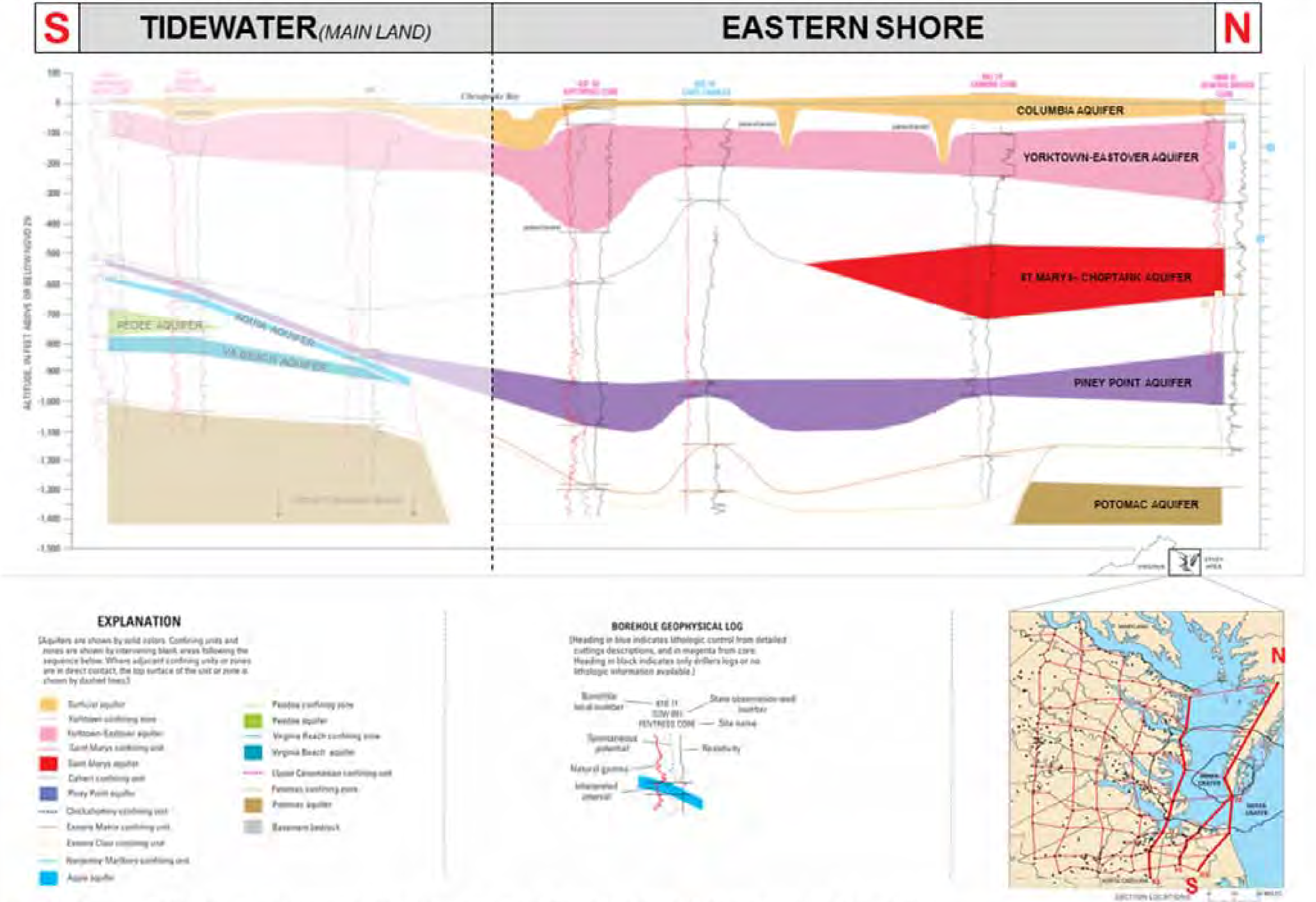
Water Table Aquifer: the uppermost aquifer which contains groundwater at atmospheric pressure.

Confined Aquifer: an aquifer where the groundwater is pressurized due to the presence of a confining unit above.

2.2.1 General Hydrostratigraphy

There have been a substantial number of local and regional studies on the geologic and hydrologic characteristics of the sediments on the Eastern Shore of Virginia and adjacent areas of Maryland. Many of these studies have dealt principally with geologic descriptions of the formational units. The geology of the Eastern Shore consists of unconsolidated deposits of interbedded clay, silt, sand, and gravel, with variable amounts of shell material. These deposits thicken and slope eastward, and form a system of layered aquifers and confining units. The total sediment thickness ranges from approximately 2,000 feet in the western areas to as much as 7,000 feet to the east[1]. These sediments generally overlie a bedrock basement that also dips northeastward.

The hydrostratigraphic layers of the Eastern Shore are divided into the unconfined Columbia aquifer (water table aquifer), and a series of confined aquifers and intervening semi-confining units (**Figure 2.2-1**). The low permeability confining units restrict downward groundwater movement. The confined aquifers, in order of increasing depth, are: Yorktown-Eastover (includes upper, middle, and lower Yorktown aquifers), St. Marys-Choptank aquifer, Brightseat aquifer, and upper, middle, and lower Potomac aquifers. Fresh groundwater generally occurs only in the upper 300 feet of sediments and at shallower depths along the coastlines of the Eastern Shore and is limited to the Columbia and Yorktown aquifers where the freshwater forms a perched lens above the deeper salt-water (**Figure 2.2-2**). These aquifers have been designated by the EPA as the sole source aquifers for the Eastern Shore, excluding Tangier and Chincoteague Islands. The water supply of Tangier Island consists of groundwater wells screened in the Potomac aquifer since the interface between freshwater from the mainland and saltwater occurs to the east of Tangier Island but west of the Eastern Shore.



Adapted from: Richardson, D., 1992. *Hydrogeology and Analysis of the Ground-Water-Flow System of the Eastern Shore, Virginia.* U.S. Geological Survey Open File Report 91-490.

A-NPDC

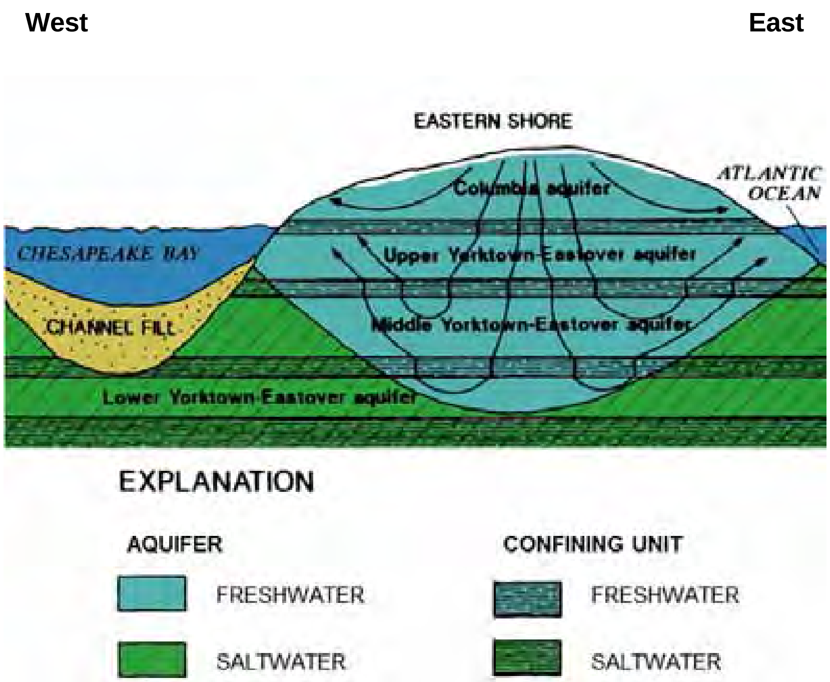
Cross-Section of Eastern Shore Hydrostratigraphic Units

Groundwater Resources Management Plan
Accomack-Northampton Planning District Commission

September 16, 2013

Figure 2.2-1

Figure 2.2-2: Generalized Schematic Diagram of Aquifer, Confining Units, and Generalized Flow Lines of the Virginia Eastern Shore Groundwater System



Source: Richardson, 1992[2].

2.2.1.1 Columbia Aquifer

The Columbia aquifer is the uppermost aquifer and is unconfined over most of the area. Sediments comprising this aquifer unconformably overlie the Yorktown aquifers, and are in turn, unconformably overlain by Holocene sediments. The properties of the Columbia aquifer are primarily dependent on the lithology and thickness of the water-producing sands, gravels and shell materials. Thickness of the Columbia aquifer and depth to water vary with topography and the water table is generally subparallel to the land surface.

The Columbia Aquifer is present throughout the Eastern Shore of Virginia.

Beneath most of the Eastern Shore of Virginia, thickness of the Columbia aquifer generally ranges from 20 feet near the coast to 60 feet inland (**Figure 2.2-3**). Thickness near the central corridor of the Eastern Shore can exceed 100 feet in some areas, and depth to groundwater is typically within 10 feet of the surface. To the northwest, the Columbia aquifer generally does not exceed 20 feet in thickness, and to the south and east, the aquifer thickness typically ranges from 40 to 140 feet.

The Columbia aquifer on the Eastern Shore subcrops into the Chesapeake Bay to the west and Atlantic Ocean to the east. Where it subcrops, freshwater discharges directly from the aquifer into the estuarine and ocean water, respectively.

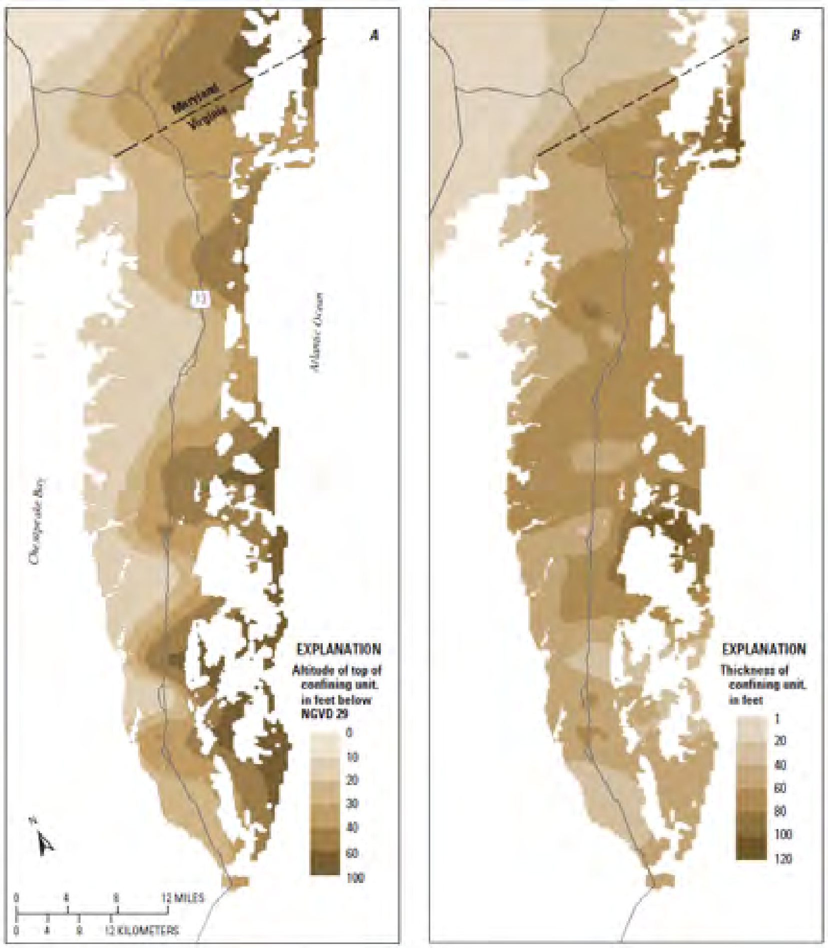
Figure 2.2-3: Thickness of the (surficial) Columbia Aquifer

Source: Sanford, et al, 2009[1]

2.2.1.2 Upper Yorktown Confining Unit

The upper Yorktown confining unit consists predominately of marine fine sandy silt with some clay and averages 15 to 30 ft thick (**Figure 2.2-4**). These sediments are for the most part reworked sediments from the upper Yorktown Formation and may locally contain fluvial silts and clays. The upper Yorktown confining unit typically consists of a sequence of lenticular interbedded silts, clays, and fine sands and is not massive. In some locations, sandy channel deposits have breached the confining unit and cut into the underlying upper Yorktown aquifer, forming what are known as paleochannels. There are two known paleochannels on the Eastern Shore of Virginia located near Exmore and Eastville. While this unit is aerially extensive, and only locally absent, it serves to restrict vertical movement of groundwater and not effectively preclude it, as evidenced by the fact that the principal source of freshwater recharge and discharge for the Yorktown aquifers on the Eastern Shore is through the confining units. Recharge is discussed in the section below.

Figure 2.2-4: Top elevation (a) and thickness (b) of the Upper Yorktown Confining Unit

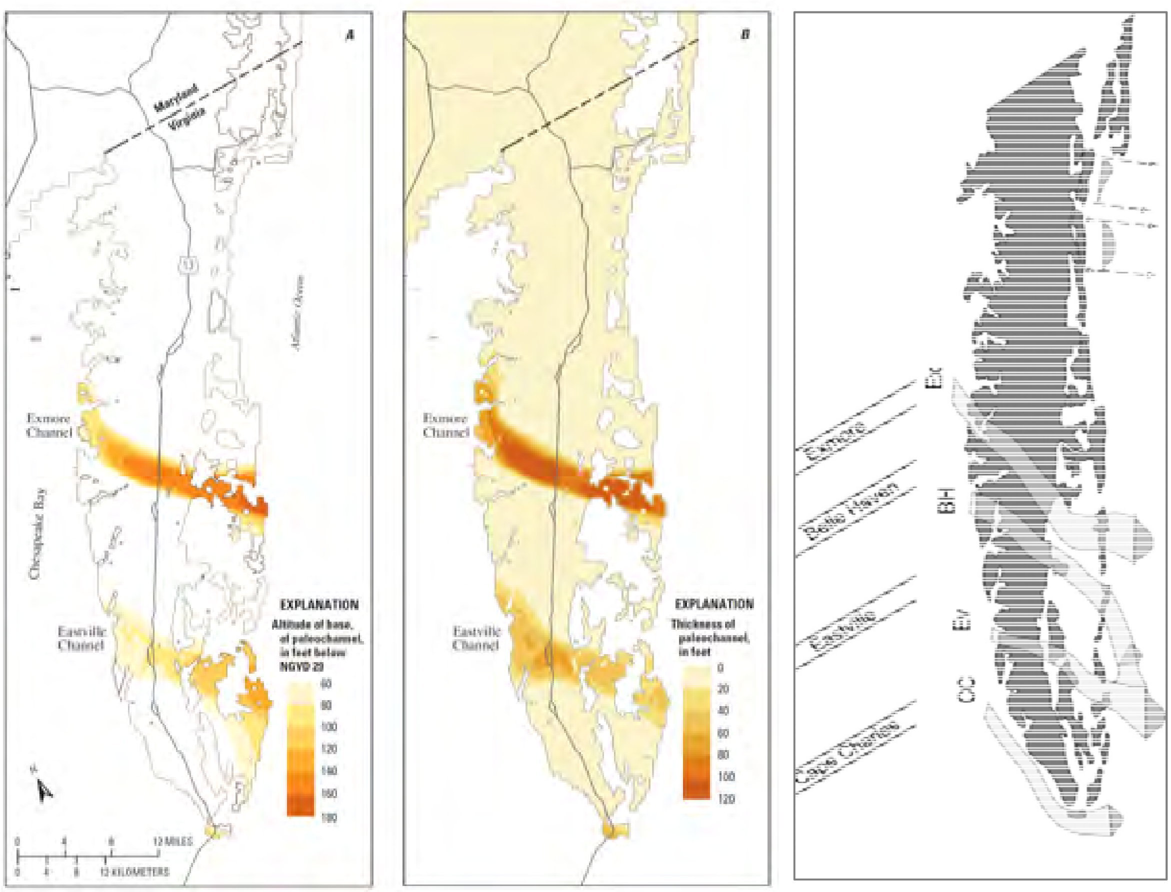


Source: Sandford, et al, 2009[1].

2.2.1.3 Yorktown Paleochannels

In some locations, sandy channel deposits have breached the Yorktown confining unit and cut into the underlying upper Yorktown aquifer, forming what are known as paleochannels. Two major channels are present onshore – the Exmore channel to the north and the Eastville channel to the south. Although the Cape Charles channel is present in the area, the majority of it lies just offshore at the southern end of the peninsula and is not expected to have an significant influence on groundwater . The Exmore channel is estimated to be more than 160 ft deep, and the Eastville channel is more than 120 ft deep. Their thicknesses in the central Eastern Shore are approximately 100 ft and 60 ft, respectively. The Belle Haven channel was only relatedly recently described by Oertel and Foley (1995) and is estimated to be between 110 and 180 ft deep with a thickness less than 70 feet. The exact spatial configuration of these channels is not known in detail. **Figure 2.2-5** shows approximate locations of the edges of the channels and approximate thicknesses of the deposits within them.

Figure 2.2-5: Top elevation (a) and thickness (b) of the Yorktown-Paleochannels



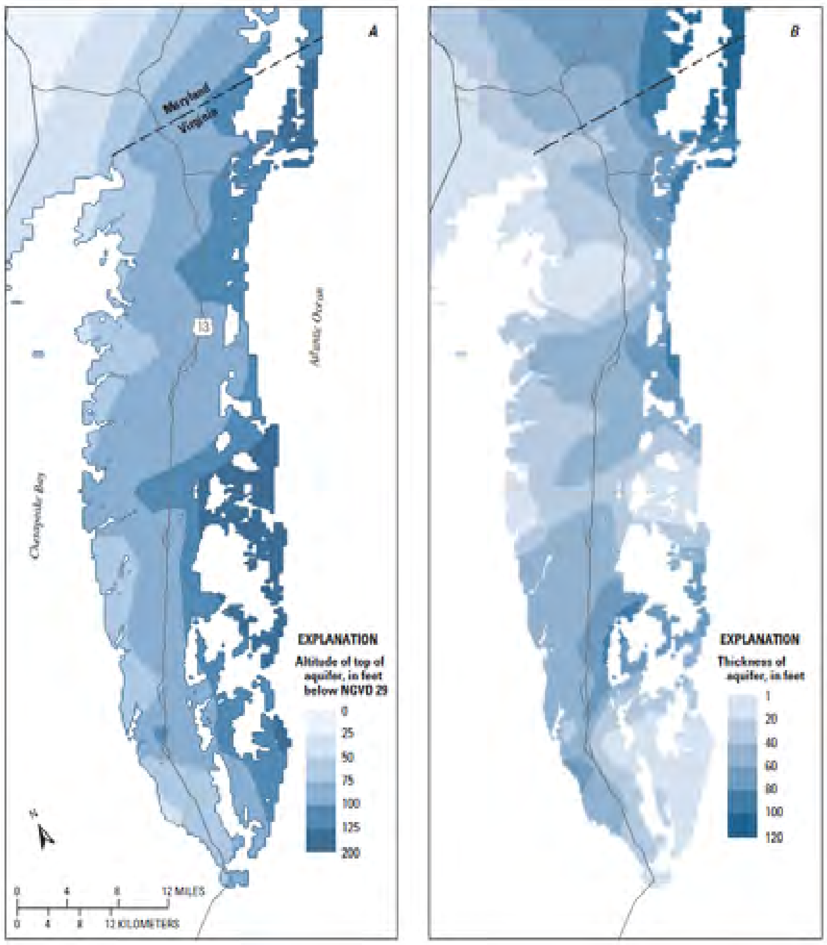
Source: Sandford, et al, 2009[1].

Source: Hobbs, et. al. 2008

2.2.1.4 Upper Yorktown Aquifer

The upper Yorktown aquifer is the uppermost unit of the Yorktown-Eastover aquifer system, and is generally defined as the first significant sand unit occurring below the unconformity separating the basal Columbia Group sediments from the Chesapeake Group sediments (**Figure 2.2-6**). Sediments deposited in channel fills which incised into the Yorktown Formation have also been identified as the upper Yorktown aquifer, even though it is not clear if there is a good hydraulic connection between the channel fill sediments and the Yorktown Formation sediments. These channel fill deposits have been identified in the Eastern Shore near Exmore and Eastville. Over most of its extent, the Upper Yorktown aquifer consists of gray fine to medium sand with shell fragments commonly present. Locally, discontinuous coarse sand and gravel layers and thin lenses of blue clayey silt are often present.

Figure 2.2-6: Top elevation (a) and thickness (b) of the Upper Yorktown Aquifer

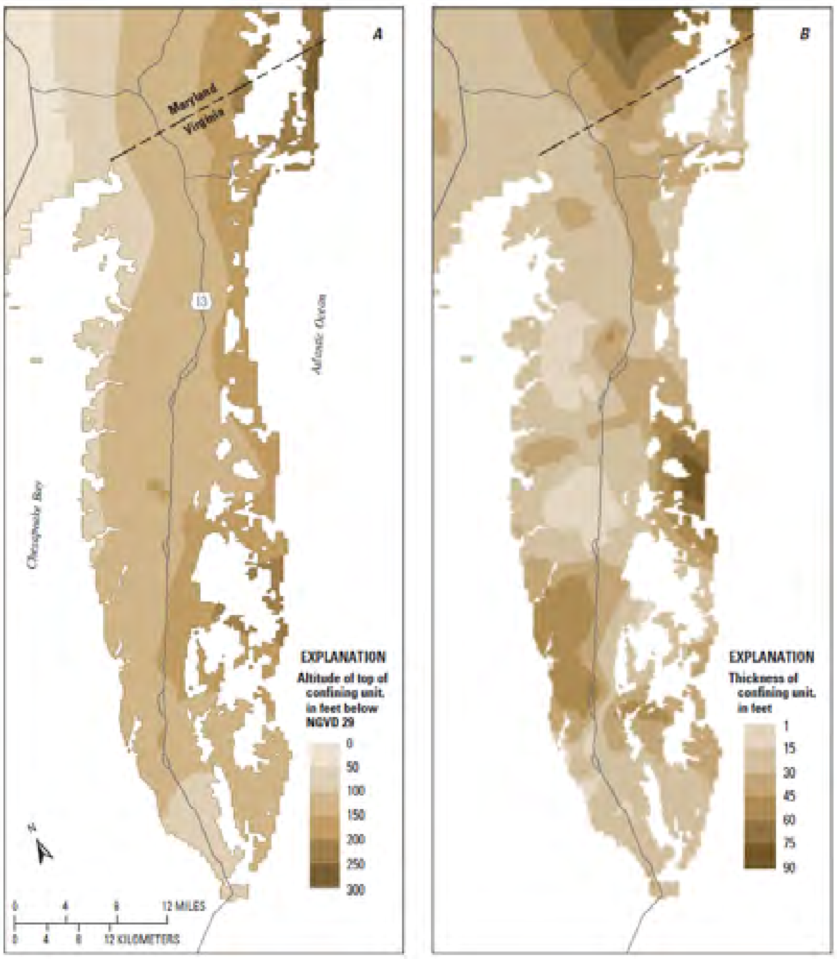


Source: Sanford, et al, 2009[1]

2.2.1.5 Middle Yorktown Confining Unit

The middle Yorktown confining unit is not as continuous or impermeable as the upper Yorktown confining unit, and has been described as allowing substantial leakage between the upper and middle Yorktown aquifers (**Figure 2.2-7**). In some areas this confining unit is absent, and over most of the Eastern Shore, it consists of a zone of interbedded silts and clays with numerous fine sand layers. Thickness of the middle Yorktown confining unit ranges between 15 and 100 ft, and tends to be thinner to the west and south.

Figure 2.2-7: Top elevation (a) and thickness (b) of the Middle Yorktown Confining Unit

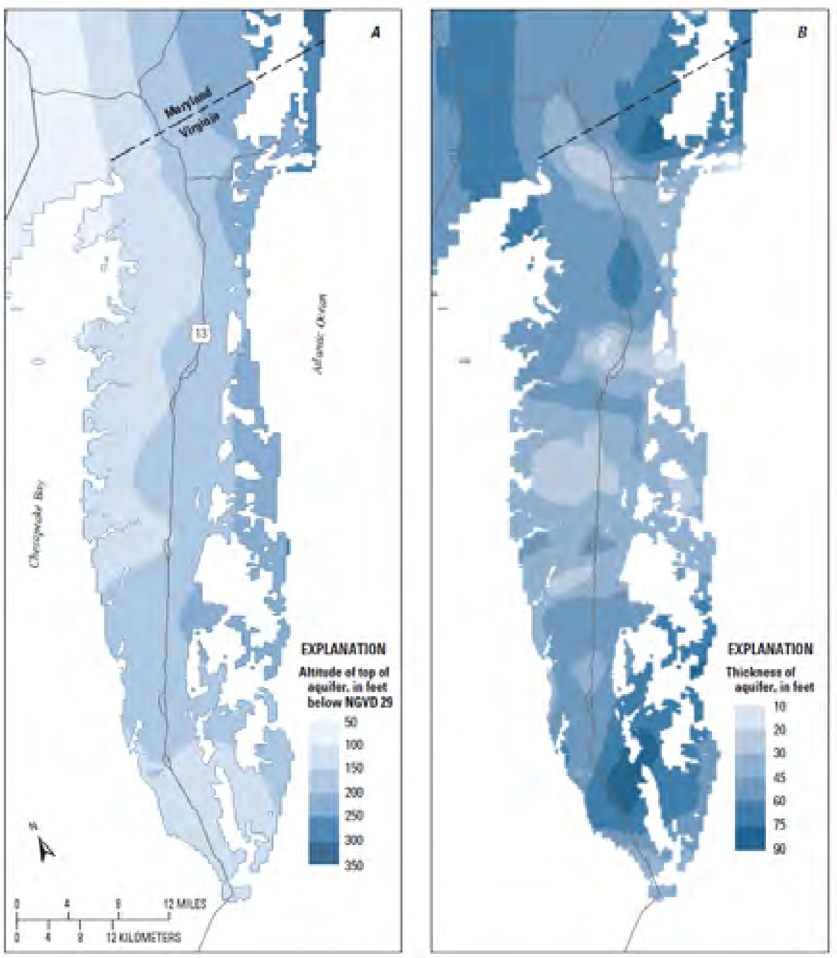


Source: Sanford, et al, 2009[1]

2.2.1.6 Middle Yorktown Aquifer

The middle Yorktown aquifer is an aerially extensive hydrologic unit of the Yorktown-Eastover aquifer system. The middle Yorktown aquifer, over most of its extent in the Eastern Shore is a gray fine sand to silty fine sand with shell fragments prevalent. In some areas, such as near the southern tip of the Eastern Shore, the middle Yorktown aquifer is coarser, consisting of gray medium to fine sand. This unit fines toward central Northampton County to a silty fine sand. Thickness of the middle Yorktown aquifer typically ranges between 30 ft and 60 ft, although locally is can be absent or up to 100 feet thick (**Figure 2.2-8**). The top of the aquifer in the Eastern Shore is between -125 ft msl to -150 ft msl along the western coast increasing to -225 to -250 ft msl to the east. The dip of the middle Yorktown is approximately 6 feet per mile, or roughly twice the dip as the overlying Upper Yorktown aquifer beds. As with the other units, strike is northeast, parallel with the peninsula.

Figure 2.2-8: Top elevation (a) and thickness (b) of the Middle Yorktown Aquifer

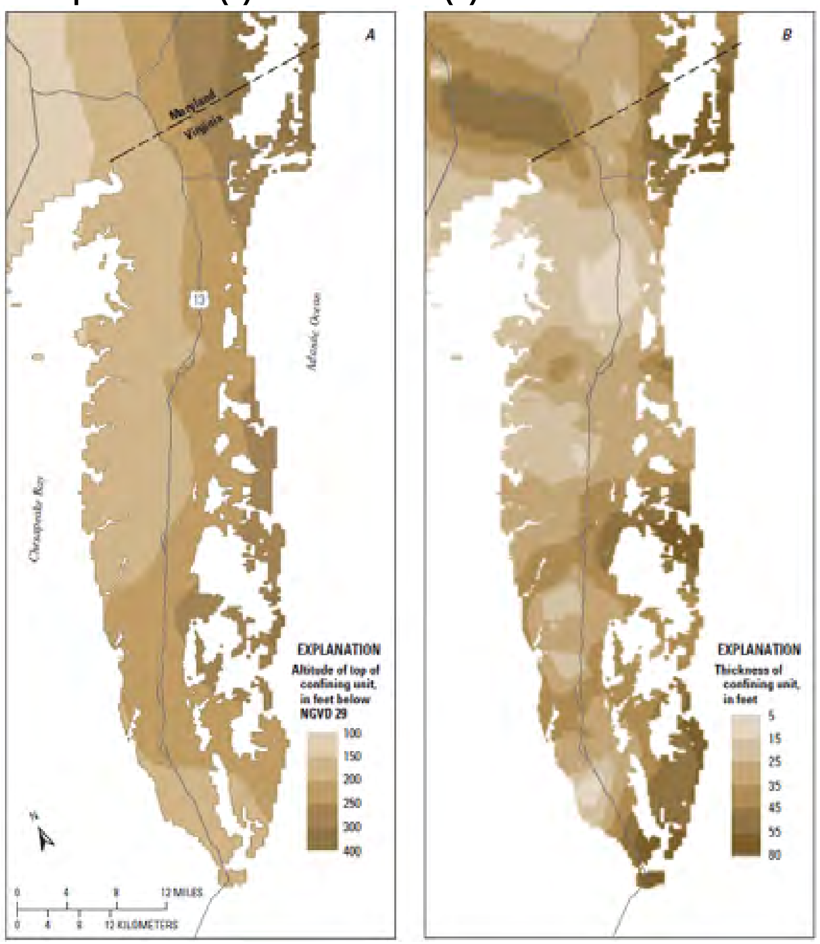


Source: Sanford, et al, 2009[1]

2.2.1.7 Lower Yorktown Confining Unit

The lower Yorktown confining unit has been described only in the Eastern Shore and has not been identified to the north in Maryland. The confining unit is thickest in central and northern Accomack County, thinning to the south and pinching out to the north in Maryland. Over the Eastern Shore area, the sediments comprising lower Yorktown confining unit tend to be finer grained than sediments from the middle Yorktown confining unit. As such, the lower Yorktown confining unit appears to restrict vertical flow more than the middle Yorktown confining unit (**Figure 2.2-9**).

Figure 2.2-9: Top elevation (a) and thickness (b) of the Lower Yorktown Confining Unit

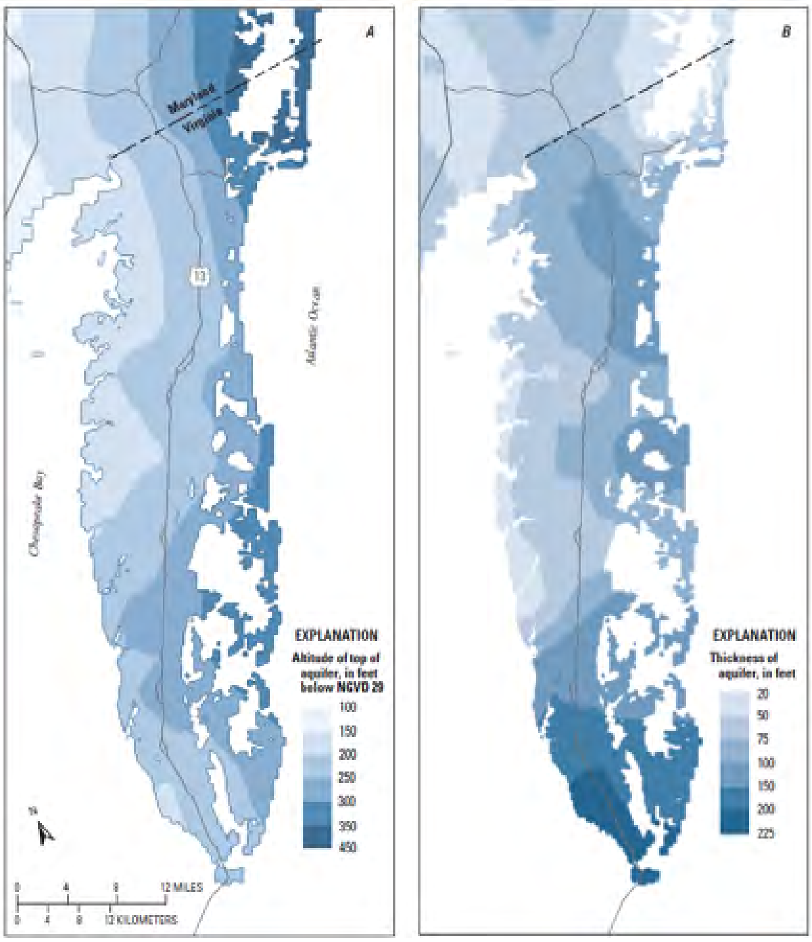


Source: Sanford, et al, 2009[1]

2.2.1.8 Lower Yorktown Aquifer

The lower Yorktown aquifer in the Eastern Shore typically consists of a fining upward sequence of gray fine sand to silty fine sand with shell fragments. In the Eastern Shore, the lower Yorktown aquifer is usually slightly thicker than the overlying middle Yorktown aquifer, and is generally between 60 and 80 feet thick throughout the area. The top of the lower Yorktown ranges between -175 and -225 ft msl along the western coast to -300 to -350 ft msl along the eastern coast (**Figure 2.2-10**). The dip of the lower Yorktown aquifer is approximately 8 feet per mile, continuing the progressive increase in bed dip with depth exhibited by the overlying units.

Figure 2.2-10: Top elevation (a) and thickness (b) of the Lower Yorktown Aquifer



Source: Sanford, et al, 2009[1]

2.2.1.9 Saint Marys Confining Unit

The Saint Marys confining unit is defined by the top of the Saint Marys Formation and is the most correlative stratigraphic horizon for the sediments in the Eastern Shore and Maryland. The Saint Marys confining unit consists of offshore marine very fine sandy silts and clays with abundant shells. This unit comprises sediments from the Saint Marys Formation, and separates the lower Yorktown aquifer from the underlying Choptank aquifer. Thickness of the Saint Marys confining unit is greater than 100 feet across the entire area, and in most locations exceeds 150 feet (**Figure 2.2-11**). Owing largely to the thickness of this unit, the Saint Marys forms an effective confining layer restricting flow between the two aquifers.

Figure 2.2-11: Top elevation of the St Marys Confining Unit

Source: Sanford, et al, 2009[1]

2.2.1.10 Deeper Hydrostratigraphic Layers

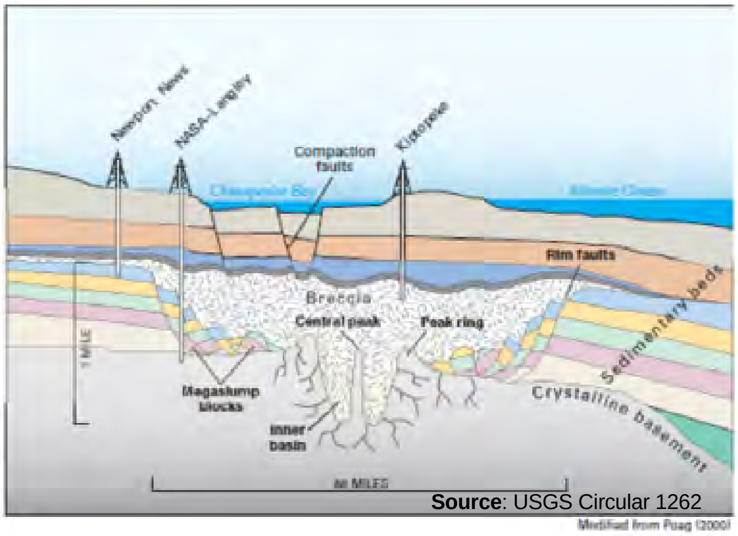
Information on the deeper hydrostratigraphic units is very limited, with only four borings on the shore penetrating to basement (bedrock), north to south: Jenkins Bridge core, Exmore core, Cape Charles core, and Kiptopeke core. Underlying the Saint Marys confining unit is the Saint Marys aquifer, Calvert confining unit, Pine Point aquifer, the Exmore Matrix confining unit, Exmore Clast confining unit, and Potomac confining zone, and Potomac aquifer.

The Saint Marys aquifer was present in only the two northern cores (Exmore and Jenkins Bridge) at depths between 500 and 700 feet BGS and was absent in the Cape Charles and Kiptopeke Core. From this limited information it is likely the Saint Marys aquifer is present throughout Accomack County and is only present over the northern portion of Northampton County.

The underlying Piney Point aquifer was present in all four cores, although this aquifer was less than 100-ft thick in all the cores. Top of the Potomac aquifer was encountered in only the northern most core (Jenkins Bridge) at a depth of 1200 ft BGS. This The Exmore core may not did not extend deept

2.2.1.11 Chesapeake Bay Impact Crater

A large comet or meteor (bolide) crashed into the Earth approximately 35 million years ago near present-day Cape Charles. The resulting impact crater displaced and mixed geologic units from the upper Potomac confining unit down several hundred feet into the basement rock.



Source: USGS Circular 1262

Useful Definitions:

Precipitation: water falling from the sky in the form of rain, sleet, snow, and/or hail.

Recharge: the amount of precipitation that infiltrates to the water table aquifer.

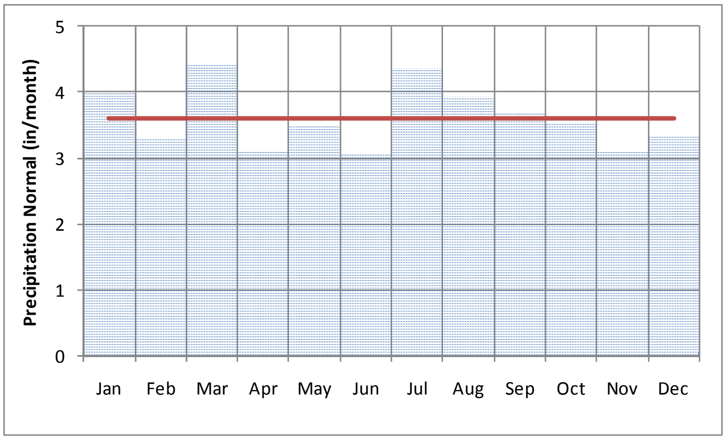
Discharge: the amount of water that flows from groundwater aquifers to surface water bodies, such as streams, rivers, ponds, lakes, bays, and oceans.

Evapotranspiration: the amount of water that evaporates directly from the land surface and shallow soils or indirectly through the leaves of plants.

2.2.2 Recharge

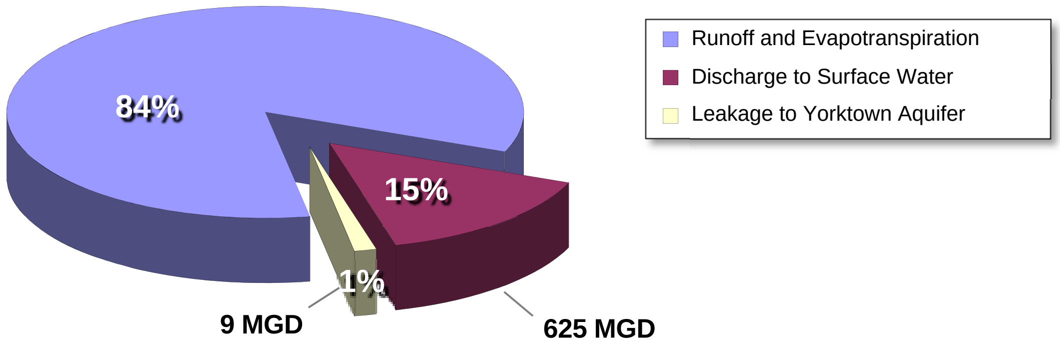
Fresh groundwater on the Eastern Shore of Virginia is replenished solely by precipitation that falls directly on the Shore. There is no fresh water contribution from the aquifers on the Mainland. Average annual precipitation on the Eastern Shore is approximately 44 inches. The precipitation normals vary seasonally between 3.0 and 4.5 inches; with the highest months being March and July and the lowest being June and November (**Figure 2.2-12**). While 44 inches of precipitation, on average falls on the Shore, the majority of the precipitation is lost to runoff and evapotranspiration, and only a small fraction reaches the Columbia aquifer (**Figure 2.2-13**). The portion of recharge reaching the Columbia aquifer remaining recharge water goes into storage (in the water table aquifer) or recharges the underlying confined aquifers.

Figure 2.2-12: Precipitation Normals for the Eastern Shore of Virginia



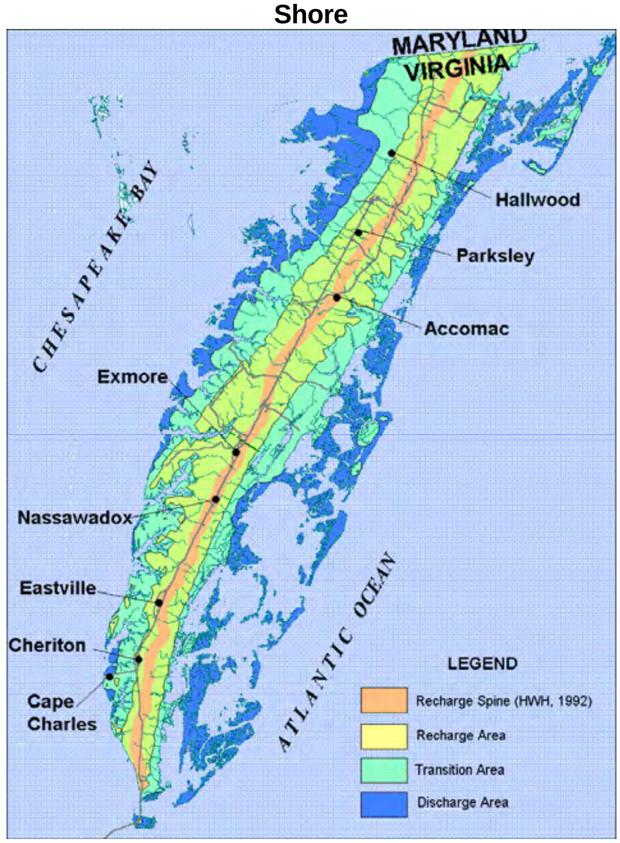
Source: NOAA, 2002[3].

Figure 2.2-13: Recharge Rates on the Eastern Shore



There have been a number of groundwater recharge values previously estimated for the Eastern Shore. Holme[4] conducted a detailed two year study of ground water recharge from monthly ground water budgets in the Beaverdam Creek basin in Maryland, near the border with Accomack. From his work a recharge value of 12 in/yr was determined, after subtracting ground water loss through evapotranspiration. The 12 in/yr estimate includes recharge which is later lost through discharge to surface waters. Harsh and Laczniak conducted a study of the regional aquifer system of the Northern Atlantic coastal Plain[5]. In this study, they estimated that ground water recharge to the water table aquifer is approximately 15 inches/year. A digital-flow-model study in the Coastal Plain of central and southern Delaware[6] used 14 inches/year as an estimate of ground water recharge for the area and other studies on the Eastern Shore have estimated that recharge to the unconfined aquifer ranges between 8.5 and 15 in/yr[2] and 12 and 26 in/yr[7]. The most recent estimate was developed by the USGS as part of the Eastern Shore Model[10] and is currently the best estimate for recharge on the Shore. The current estimates of recharge are presented on Figure 2.2-13, with 6.6 in/yr recharging the Columbia aquifer.

Figure 2.2-14: Recharge Areas of the Eatern Shore



Fresh groundwater recharge to the underlying confined Yorktown-Eastover aquifer is generally greatest near the central “spine recharge” area of the peninsula, where the difference in water level between the Columbia aquifer and Yorktown-Eastover aquifer is greatest (**Figure 2.2-14**). Some of the water that recharges near the center of the peninsula flows vertically through the water table aquifer and underlying confining units to recharge the confined aquifers. This downward flow component decreases with distance from the central recharge area. The Yorktown-Eastover aquifers are recharged at a much lower rate than the Columbia aquifer. Current estimates for recharge rate to the Upper Yorktown-Eastover aquifer is ½ in/yr (less than 1% of the precipitation falling on the Shore. Recharge to the Middle and Lower Yorktown-Eastover aquifers are progressively lower with depth. Age measured from groundwater samples collected from the Columbia and Yorktown-Eastover aquifers[10] illustrates these low recharge rates with average ages as follows:

- Columbia aquifer ≈ 50 years
- Upper Yorktown-Eastover ≈ 4,500 years
- Middle Yorktown-Eastover aquifer ≈ 9,700 years
- Lower Yorktown-Eastover aquifer ≈ 13,900 years

Ground water flow in the confined aquifers is also primarily horizontal, with some downward flow in the central peninsula and upward flow in coastal discharge areas (**Figure 2.2-2**).

Recharge to the Yorktown-Eastover aquifer along the recharge spine is not uniform across the Shore, and can vary significantly depending on:

- Local thickness and composition (amount of silt and clay) of the confining unit,
- Presence of Paleochannels, and
- Local Yorktown-Eastover groundwater use that lowers the water level in the confined aquifer creating a higher downward hydraulic gradient (higher downward flow rate).

The degree the above factors influence recharge to the Yorktown-Eastover aquifer is poorly understood.

Useful Definitions:
Hydraulic conductivity: a property indicating the ability of water to flow through a standard volume of aquifer due to differences in pressure across the aquifer.

Transmissivity: the hydraulic conductivity measured across the water-bearing thickness of an aquifer. It is a common metric indicative of the amount of water that can be withdrawn from an aquifer. An aquifer with a high transmissivity is likely to produce more water than an aquifer with a low transmissivity.

2.2.3 Hydraulic Characteristics

2.2.3.1 Columbia Aquifer

Groundwater levels in the Columbia aquifer are generally subparallel to the land surface of the Eastern Shore, with depths to water ranging from 20 ft along the recharge spine to intersecting the land surface at streams, rivers, ponds, the Bay and the Atlantic.

The hydraulic conductivity of the Columbia aquifer ranges from approximately 10 to 200 ft/day and generally increases northward. Transmissivities reported for the Columbia aquifer range from 100 to 50,000 ft^2/day. On the Eastern Shore of Virginia, transmissivities are somewhat lower, typically ranging between 1,000 and 4,000 ft^2/day. The general increase in transmissivity to the north appears to be a function of both increasing thickness and increasing hydraulic conductivity.

2.2.3.2 Upper Yorktown Aquifer

Groundwater levels on the Eastern Shore follows the same general pattern as the overlying Columbia aquifer, since recharge to this aquifer is from the Columbia. Because the confining unit separating the two aquifers is consistently present over most of the area, there is significant pressure loss between the two aquifers. A maximum groundwater level of +25 ft msl occurs in south central Accomack County, decreasing radially from this point. In Northampton County, the groundwater level is between +5 and +10 ft , and in central Accomack County, groundwater level is +15 to +20 feet MSL, decreasing to +8 to +12 ft msl near the state boundary with Maryland. At the eastern and western coastline, groundwater level decreases to approximately +5 ft msl. A short distance offshore, vertical groundwater flow direction is expected to reverse, with fresh groundwater flow from the upper Yorktown aquifer into the overlying Columbia aquifer.

There are several prominent cones of depression resulting from significant groundwater withdrawals centered around Temperanceville (Tyson Food), Accomack (Perdue), Exmore, and Cape Charles.

Transmissivity for the upper Yorktown aquifer is generally lower than the Columbia aquifer, and has a lower variability. Transmissivity for this aquifer typically ranges between 1,000 to 5,000 ft^2/day.

2.2.3.3 Middle Yorktown Aquifer

Groundwater levels for the middle Yorktown aquifer on the Eastern Shore are only slightly lower in the central portion than the upper Yorktown, with a maximum groundwater elevation between +20 and +25 ft msl near Accomack. At the coast and a short distance offshore, the groundwater level in the middle Yorktown is expected to be slightly higher than the upper Yorktown, with the vertical groundwater flow reversed to an upward direction. In Northampton County, groundwater level typically ranges between +10 and +5 ft msl.

Transmissivities for the middle Yorktown in the Eastern Shore range between 1,000 and 3,000 ft^2/day.

2.2.3.4 Lower Yorktown Aquifer

Transmissivity for this aquifer in the Eastern Shore is roughly the same or slightly lower than the middle Yorktown, averaging around 1,200 ft^2/day in areas where the sediments are productive. There are only a few pumping tests conducted in the lower Yorktown of the Eastern Shore and the lower and middle Yorktown aquifer are not differentiated in Maryland. Therefore, there is not a great deal of information on areal variability in transmissivity of the Lower Yorktown.

2.2.3.5 Deeper Aquifers

Currently there is no information on the hydraulic characteristics for the deeper aquifer on the Eastern Shore of Virginia.

2.2.3.6 Local and Regional Hydrostratigraphic Features

There are several hydrostratigraphic features which interrupt the sequence of layers described above at local and regional scales and play an important although less understood role in the groundwater system of the Eastern Shore. These include several identified paleochannels which have replaced portions of the Yorktown confining unit with more permeable sediments and the impact crater which displaced and mixed sediments from the upper Potomac confining unit down into the basement rock.

2.2.4 Water Quality

The Columbia aquifer and Yorktown-Eastover aquifers over most of the Shore has very good water quality. As part of development of the USGS Eastern Shore Model (USGS SIR 2009-5066), water quality samples were collected from the Columbia and Yorktown-Eastover aquifers, and the Shore-wide water quality for these aquifers are summarized on **Table 2.2-1**. The following summarizes the general water quality from the shallow Columbia aquifer to the deeper Lower Yorktown-Eastover aquifer:

The Columbia, Upper Yorktown-Eastover, and Middle Yorktown-Eastover aquifer are largely fresh, with increasing levels of sodium and chloride with depth (**Table 2.2-1** and **Figure 2.2-15**). The Lower Yorktown-Eastover aquifer is significantly more brackish, with average chloride levels exceeding the Drinking Water (SMCL) Maximum Contaminant Level. Consistent a transition from fresh to brackish groundwater, alkalinity likewise increased with depth (**Figure 2.2-15**). . High bicarbonate alkalinity is most often associated with white deposits and scale formation in water systems The Columbia aquifer contains freshwater almost exclusively, with chloride levels less than the Drinking Water Secondary Maximum Contaminant Level of 250 mg/L over most of the Shore (**Figure 2.2-15**).

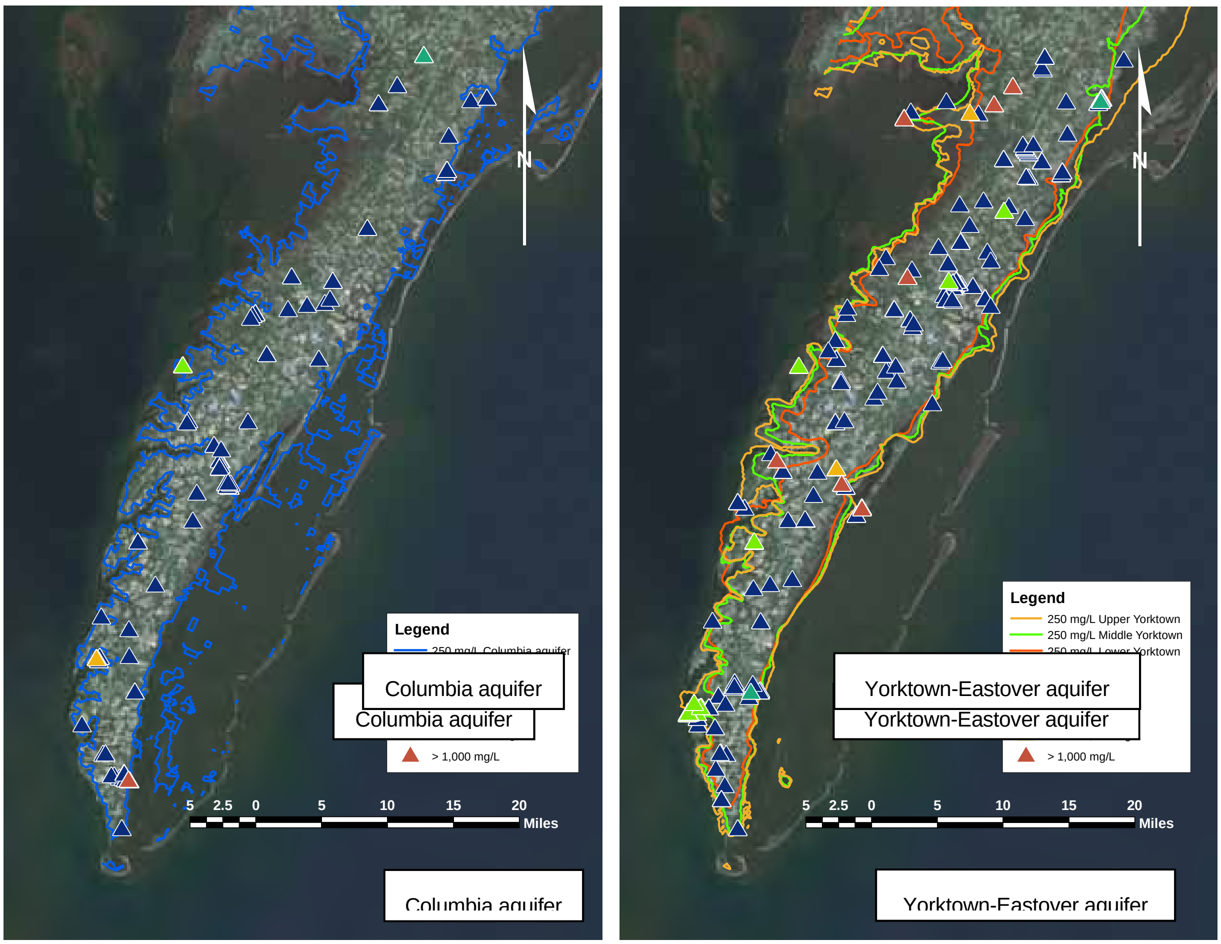
Where the Columbia aquifer subcrops, freshwater discharges from the aquifer to the Chesapeake Bay, Atlantic Ocean, and intervening tidal creeks and bays. While the Yorktown-Eastover aquifer has, as expected, more brackish water (chloride levels greater than 250 mg/L), it likewise is fresh throughout most of the Shore.

Table 2.2-1 Summary Groundwater Quality on the Eastern Shore of Virginia

Constituent	Columbia aquifer	Upper Yorktown-Eastover aquifer	Middle Yorktown-Eastover aquifer	Lower Yorktown-Eastover aquifer
Well depth (ft)	33	142	227	301
Specific conductance (µS/cm)	289	412	709	2,952
Dissolved oxygen (mg/L)	0.8	0.14	0.22	0.24
pH	5.9	7.8	8	7.8
Ca (mg/L)	28	36	21	32
Mg (mg/L)	5	9	12	32
Na (mg/L)	15	31	109	526
Cl (early 1980s)	47	20	89	637
Cl (2003)	47	33	110	575
SO (mg/L)	35	26	11	26
Alkalinity (HCO_3) (mg/L)	51	156	249	331
NO_3 (mg/L)	23	1	3	2
Recharge temperature (°C)	13.5	8.3	7.3	5.9
Adjusted ^{14}C age (yrs)	N/A	4,500	9,700	13,900

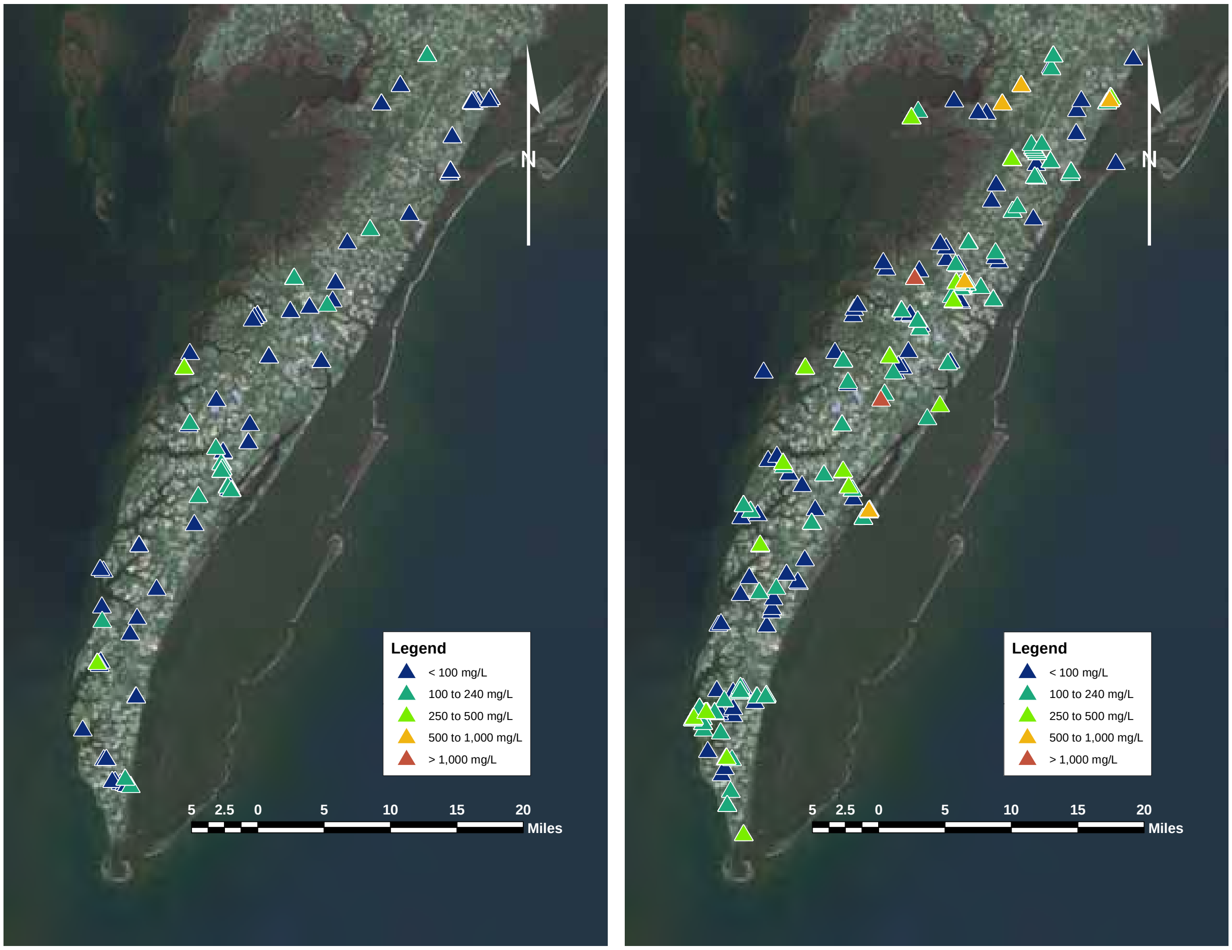
The aquifers deeper than the Yorktown-Eastover are believed to be brackish, although there is a lack of water quality measurements for confirmation. Based on one sample collected from the Jenkins Bridge core the Saint Marys aquifer is brackish, with a chloride level exceeding 3,000 mg/L. There are no water quality samples from any of the other deeper aquifers on the Shore.

Figure 2.2-15 Groundwater Chlorides



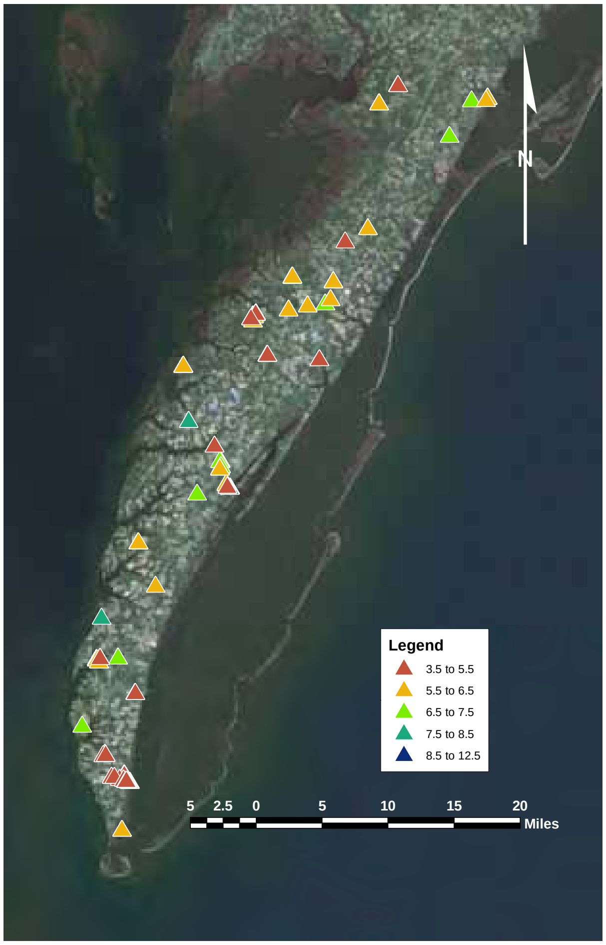
Note: Chloride contours from USGS Eastern Shore Model for Simulation Year 2006 (USGS SIR 2009-5066). Chloride samples from USGS PP 1772

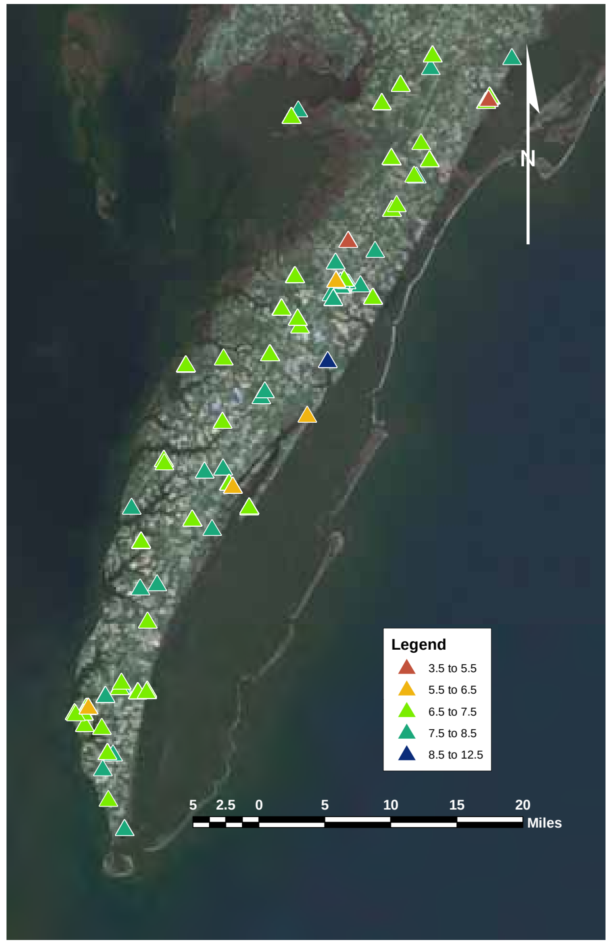
Figure 2.2-16 Groundwater Bicarbonate Alkalinity



Typical of coastal plain water table aquifers, pH of the Columbia aquifer is slightly acidic, averaging 5.9 and typical of confined aquifers, the Yorktown-Eastover is near neutral to basic, averaging 7.8 to 8 (**Figure 2.2-16**). Acidic water can be corrosive to some water systems, in particular older water systems with that may have galvanized piping or copper piping with poor lead soldering that exposes the lead to water. It is also important to recognize that other water quality characteristics can be corrosive to some water systems, such as high sodium and chloride (salt) levels. Water with high salt levels, such as levels that can be found in the Lower Yorktown-Eastover aquifer typically has a basic pH.

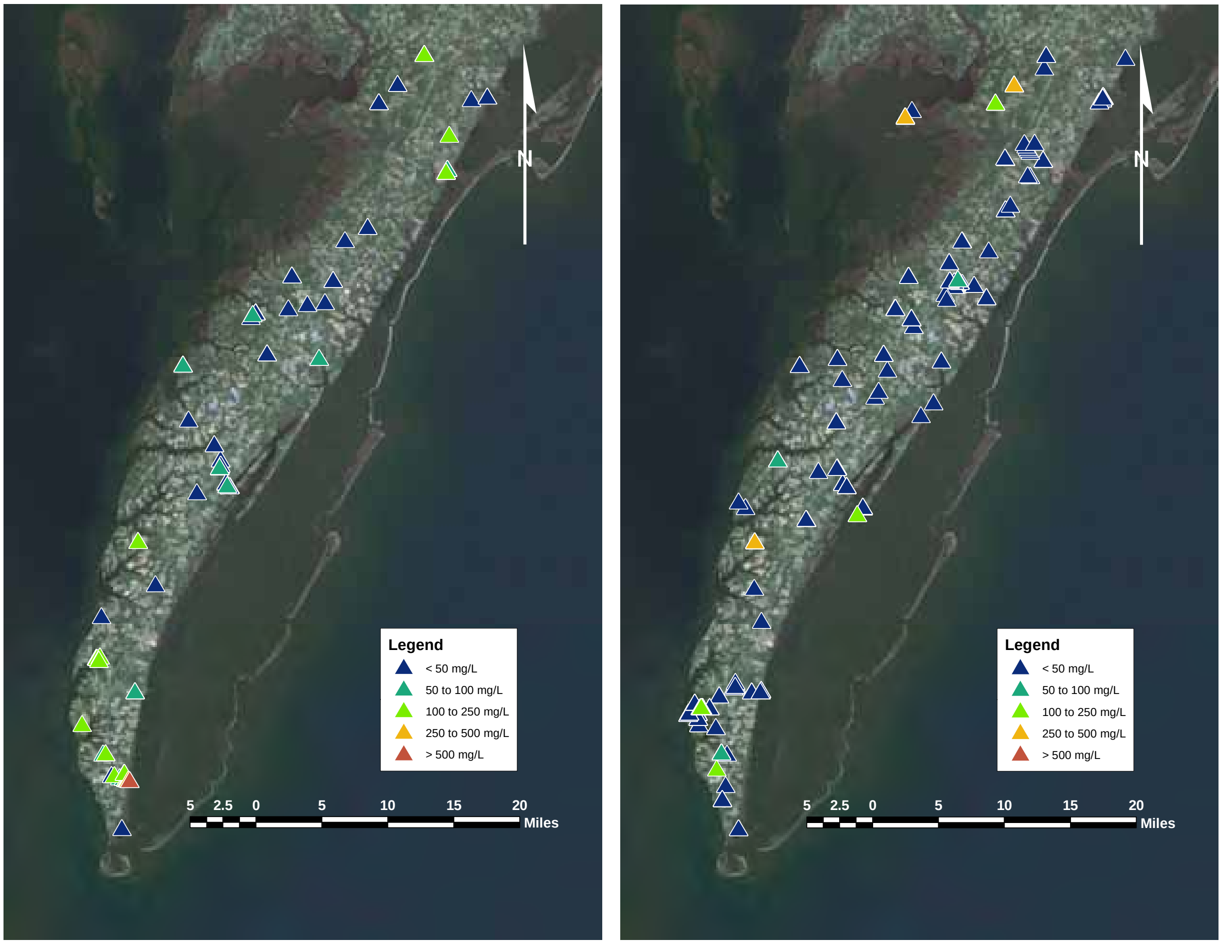
Figure 2.2-17 Groundwater pH





Sulfide in groundwater is, locally, a common problem for some groundwater supplies on the Shore. Relatively low concentrations of sulfide in the water are associated with objectionable odors (rotten egg). While sulfide measurements are not available, sulfate is (**Table 2.2-1**). There is no significant difference in sulfate levels between the unconfined Columbia and confined Yorktown-Eastover aquifer. There are not many groundwater samples where the sulfate levels exceed the Drinking Water Secondary Maximum Contaminant Level of 250 mg/L (**Figure 2.2-18**).

Figure 2.2-18 Groundwater Sulfate



The groundwater constituent most commonly associated with objectionable water quality is iron, which is a common cause of staining at low concentrations and objectionable taste at higher concentrations. Iron as low as 0.3 mg/L can cause staining. Iron concentrations less than 5 mg/L can typically be treated using conventional home treatment systems. However, higher levels of iron can result in an unintended increase in salt levels resulting from the ion-exchange used in many of the conventional home treatment systems. While spatially iron is highly variable (**Figure 2.2-19**), average iron levels in the Columbia and Yorktown-Eastover aquifers are very similar.

Figure 2.2-19 Groundwater Iron

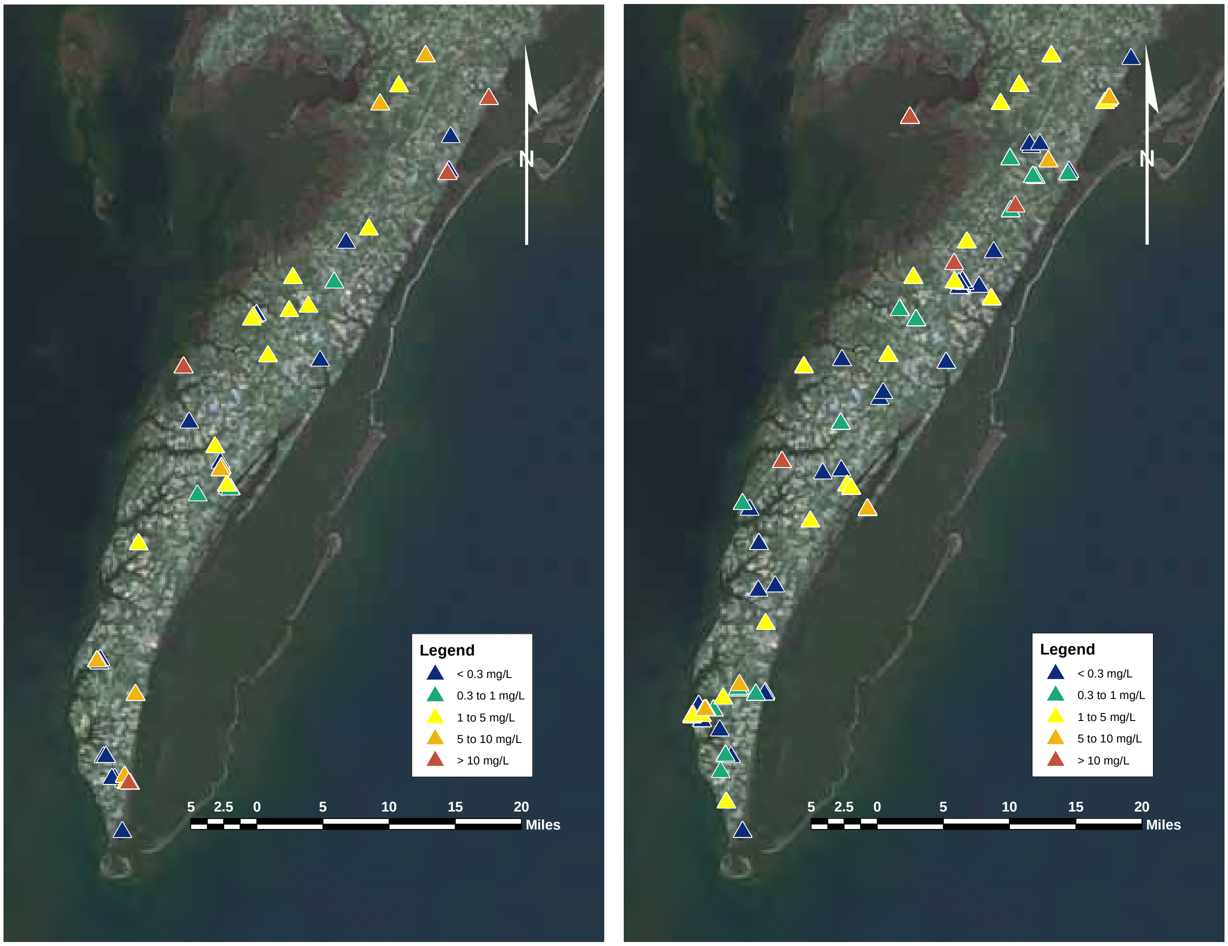
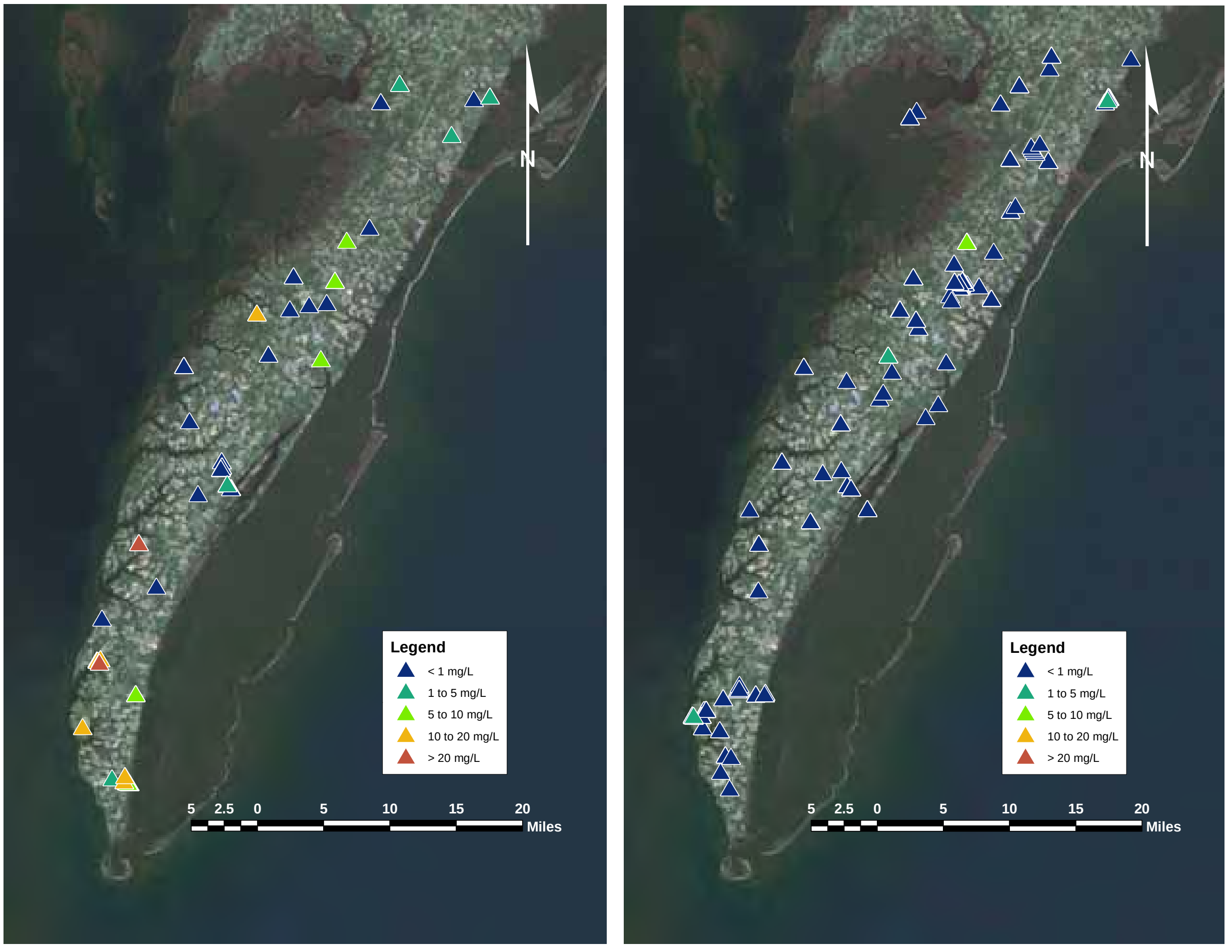


Figure 2.2-20 Groundwater Nitrate



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3.0 LAND AND WATER RESOURCE USE

This section of the Groundwater Management Plan describes the historic, current, and future use of land and water on the Eastern Shore of Virginia.

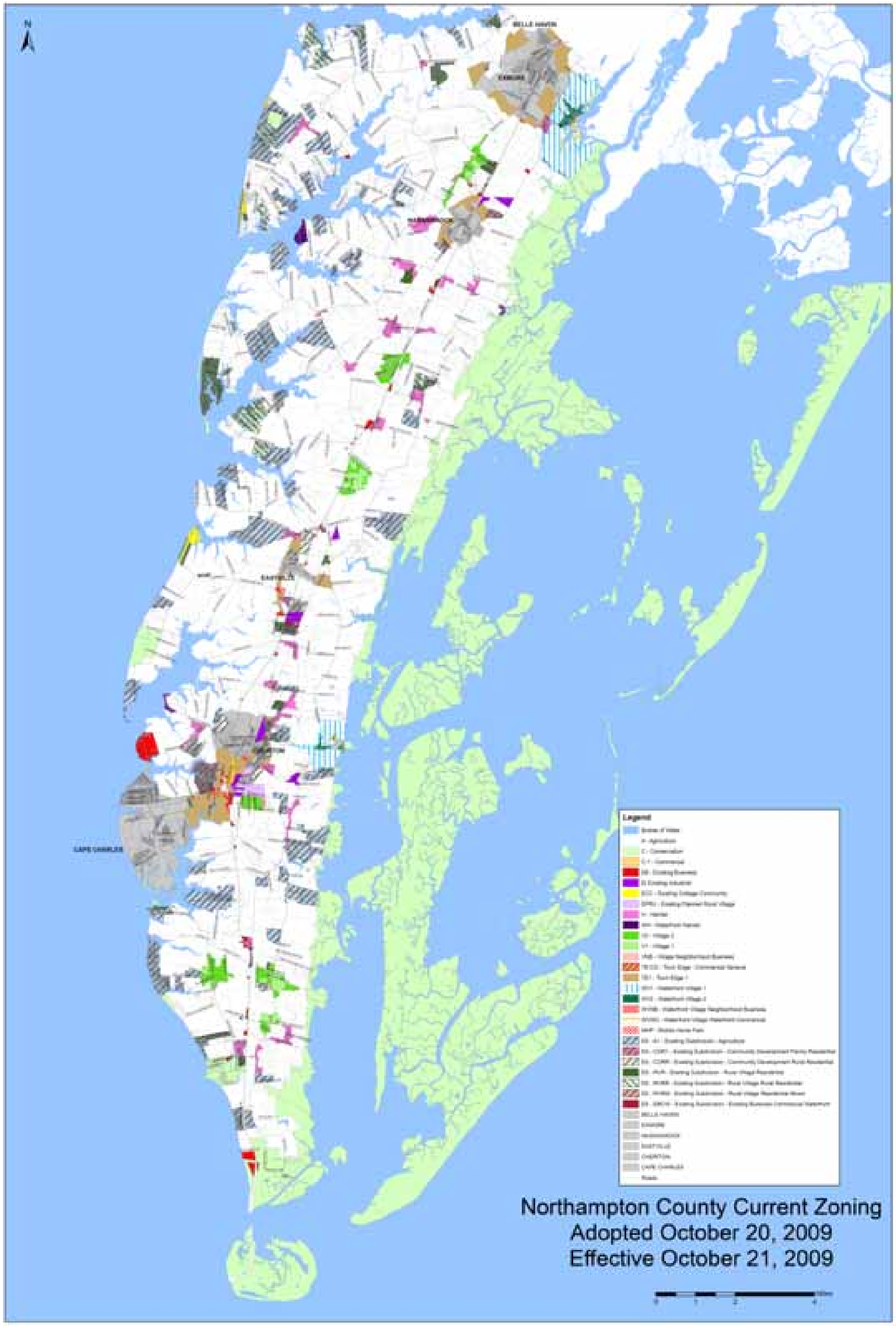
3.1 LAND USE

Land use and land cover can have a significant impact on local and regional hydrology and should play an important role in water supply planning. Variations in land use and land cover affect the geospatial variation of water demands and can have an impact on streamflow and groundwater water recharge, both in terms of quantity and quality. Land uses such as urban developments tend to have high proportions of impermeable land cover in the form of pavement and buildings. Without compensating design and planning, these areas will decrease the amount of rainfall percolating into the soil, and runoff rapidly into nearby streams and water bodies. This rapid runoff reduces the amount of water available for groundwater recharge and can impact water supply wells, particularly wells with shallow screens. Rapid runoff can also carry a greater sediment and contaminant load which can impact water quality in adjacent and downstream bodies of water. High sediment loads can also fill in downstream reservoirs and thereby reduce their yield over time. Approved land uses in Accomack County and Northampton County are shown in **Figure 3.1-1** and **Figure 3.1-2**, respectively.

Figure 3.1-1: Land Use in Accomack County

Source: Accomack Comprehensive Plan, 2008[1].

Figure 3.1-2: Land Use in Northampton County



Source: Northampton Department of Planning and Zoning, 2009[2].

3.1.1 Historic Land Use

Historically, the Eastern Shore has been predominantly zoned as agricultural. The amount of agricultural land on the Eastern Shore has remained largely stable during this time, comprising approximately 35%. Over time, more residential structures have been built mainly in and around towns and villages, with a 10% increase since the 1990 census. In 1989 only 2% of the Eastern Shore was classified as commercial or industrial while approximately 95% was classified as cropland, woodlands, and wetlands.

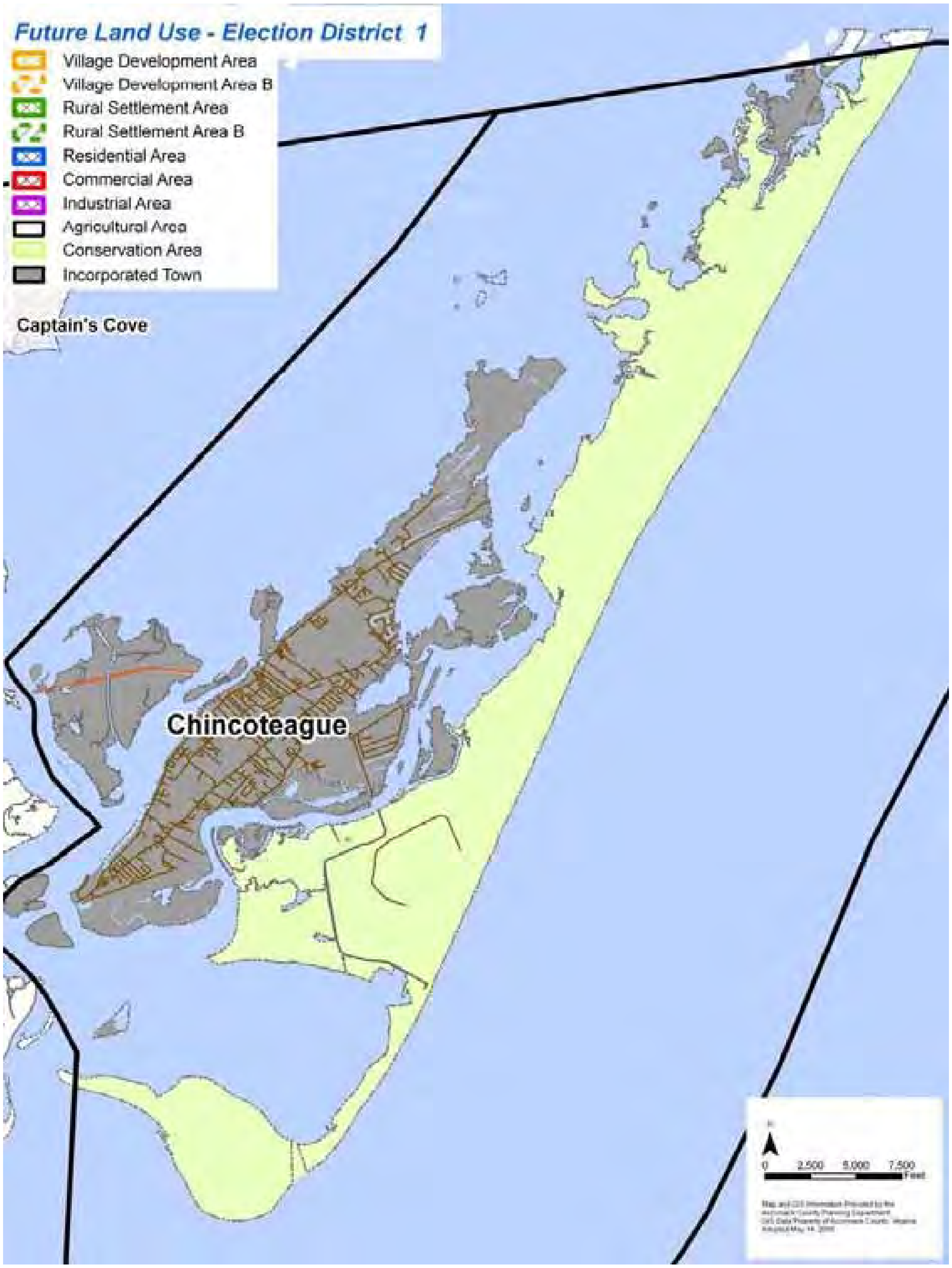
3.1.2 Current Land Use

In recent years on the Eastern Shore, rural subdivisions have become more common as has commercial and industrial developments located outside of traditional towns and village centers. This increase has caused a nearly 2.8 percent decrease in the amount of land identified in the agricultural and forestal districts since 1997. This reduction reflects the removal of land from districts due to no longer meeting minimum area requirements or for residential subdivisions and other land development. The percentage of total housing units has increased 23% since 1990. The amount of industrial activity on the Eastern Shore has also increased. The most sizeable commercial additions include a hatchery expansion at the Tysons poultry processing plant and three new starts at the 360 acres industrial park located in Melfa. Permits were issued for 43 poultry houses from 2001 to 2007.

3.1.3 Future Land Use Trends

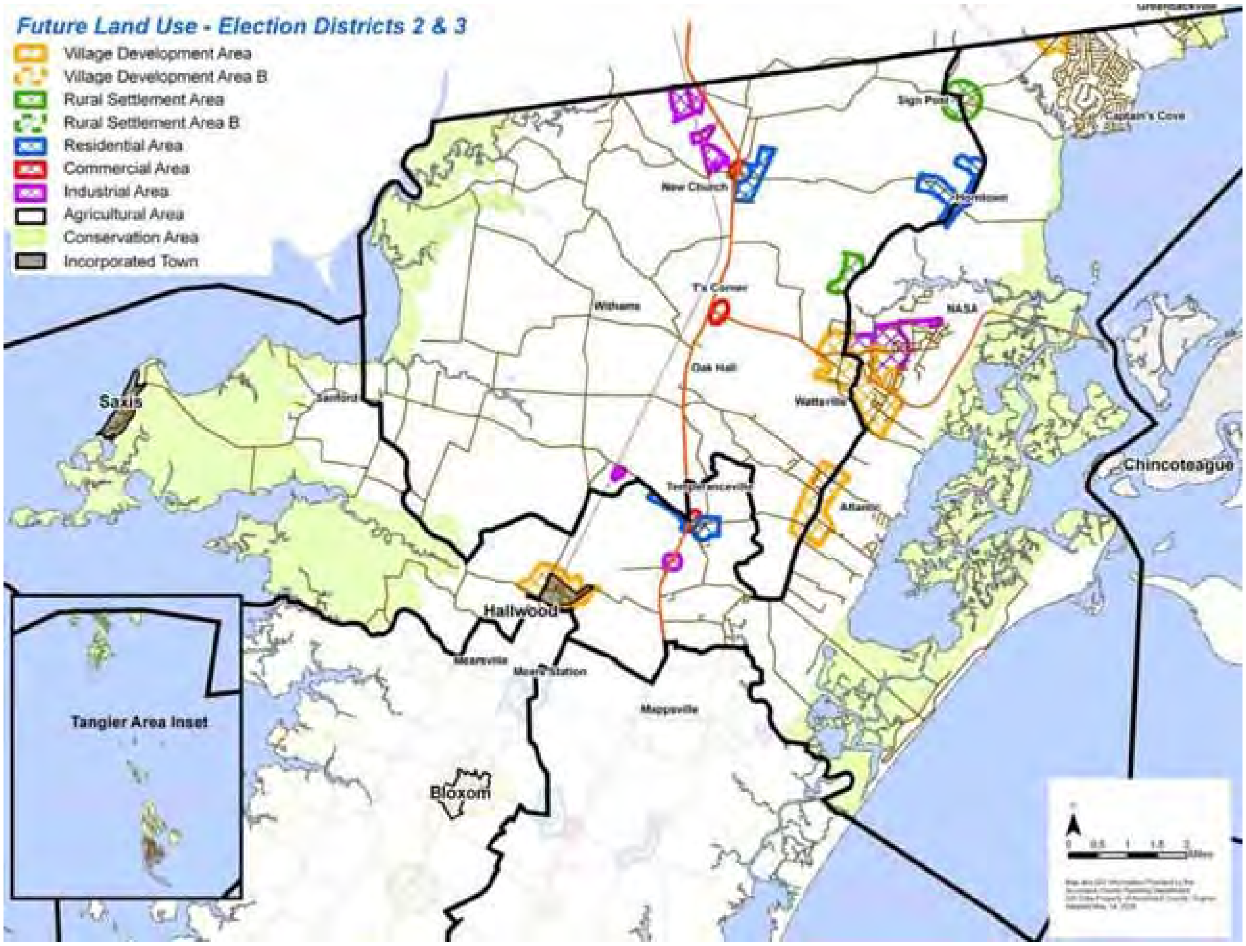
The future land use plans for the Eastern Shore incorporate some groundwater quality and quantity protection measures to control the density, location and the pattern of development. Future land use will focus on public infrastructure investments in and around existing towns and villages and limits develop in outlying areas such as agricultural and forestal districts and in conservation districts including marshland and undeveloped barrier islands. The groundwater recharge spine along the Eastern Shore is also an area that will be preserved to the extent feasible. Approved future land uses in Accomack County and Northampton County are shown in **Figure 3.1-1** through **Figure 3.1-2**, respectively.

Figure 3.1-3: Future Land Use in Accomack County – District 1



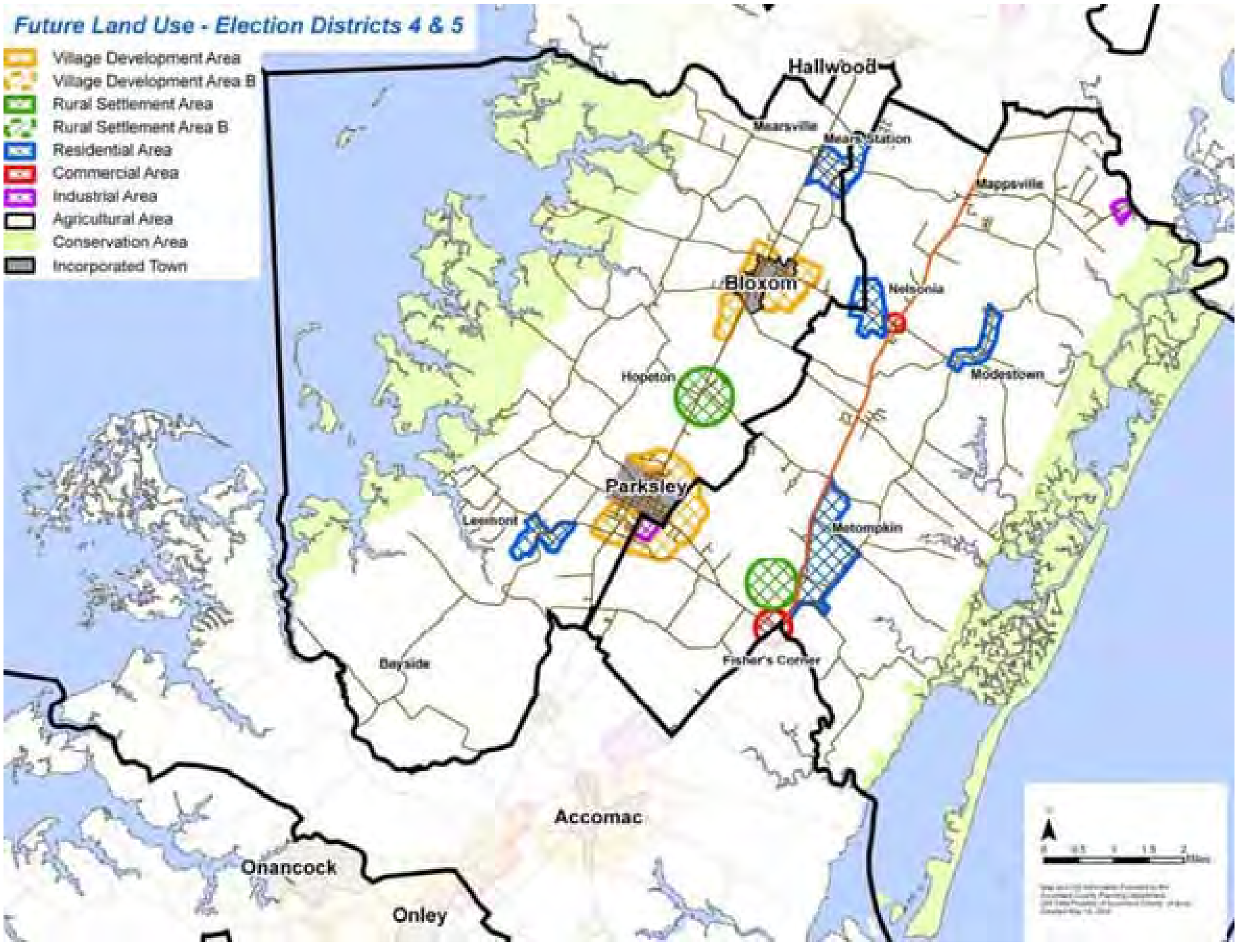
Source: Accomack Comprehensive Plan, 2008[3].

Figure 3.1-4: Future Land Use in Accomack County – Districts 2 and 3



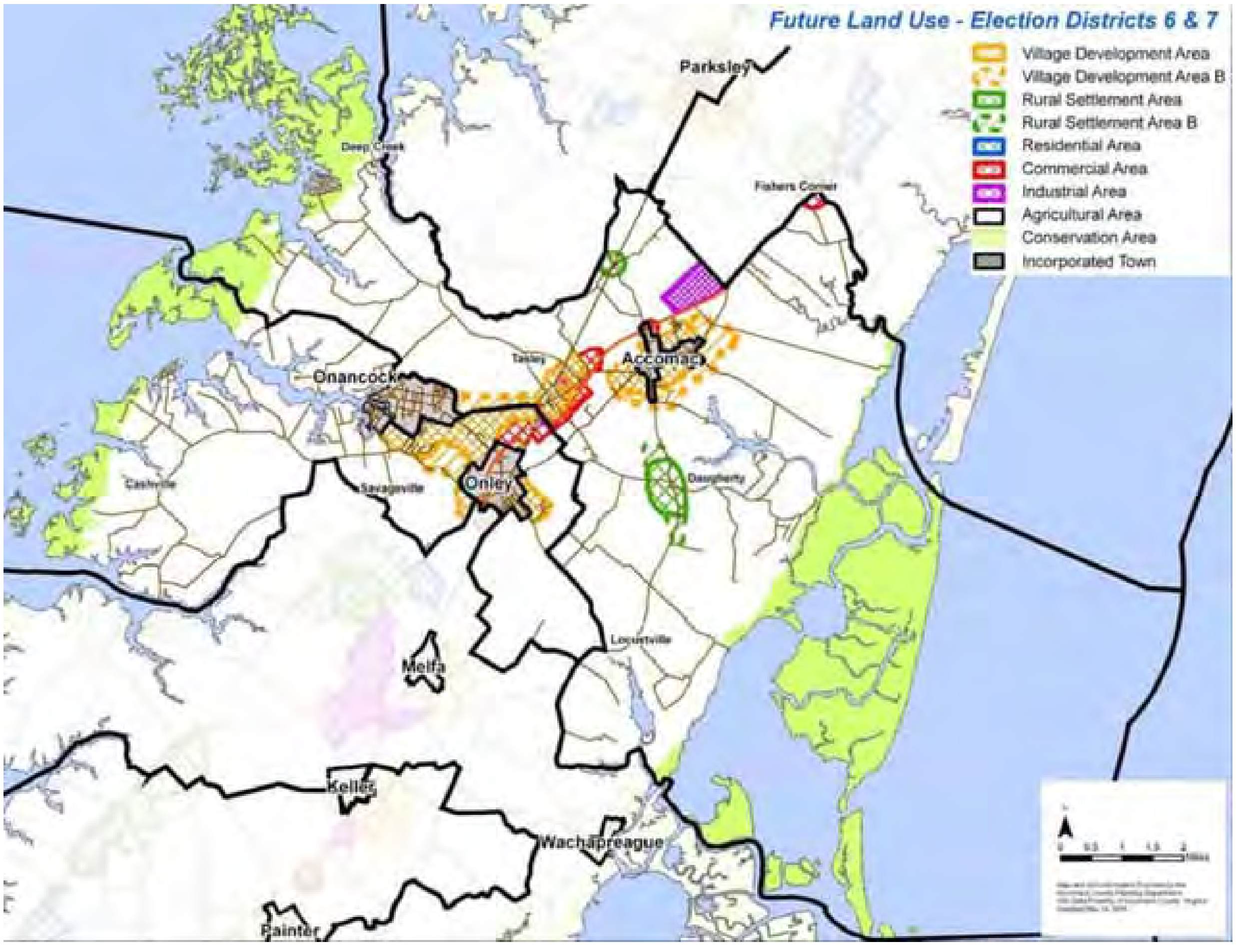
Source: Accomack Comprehensive Plan, 2008[4].

Figure 3.1-5: Future Land Use in Accomack County – Districts 4 and 5



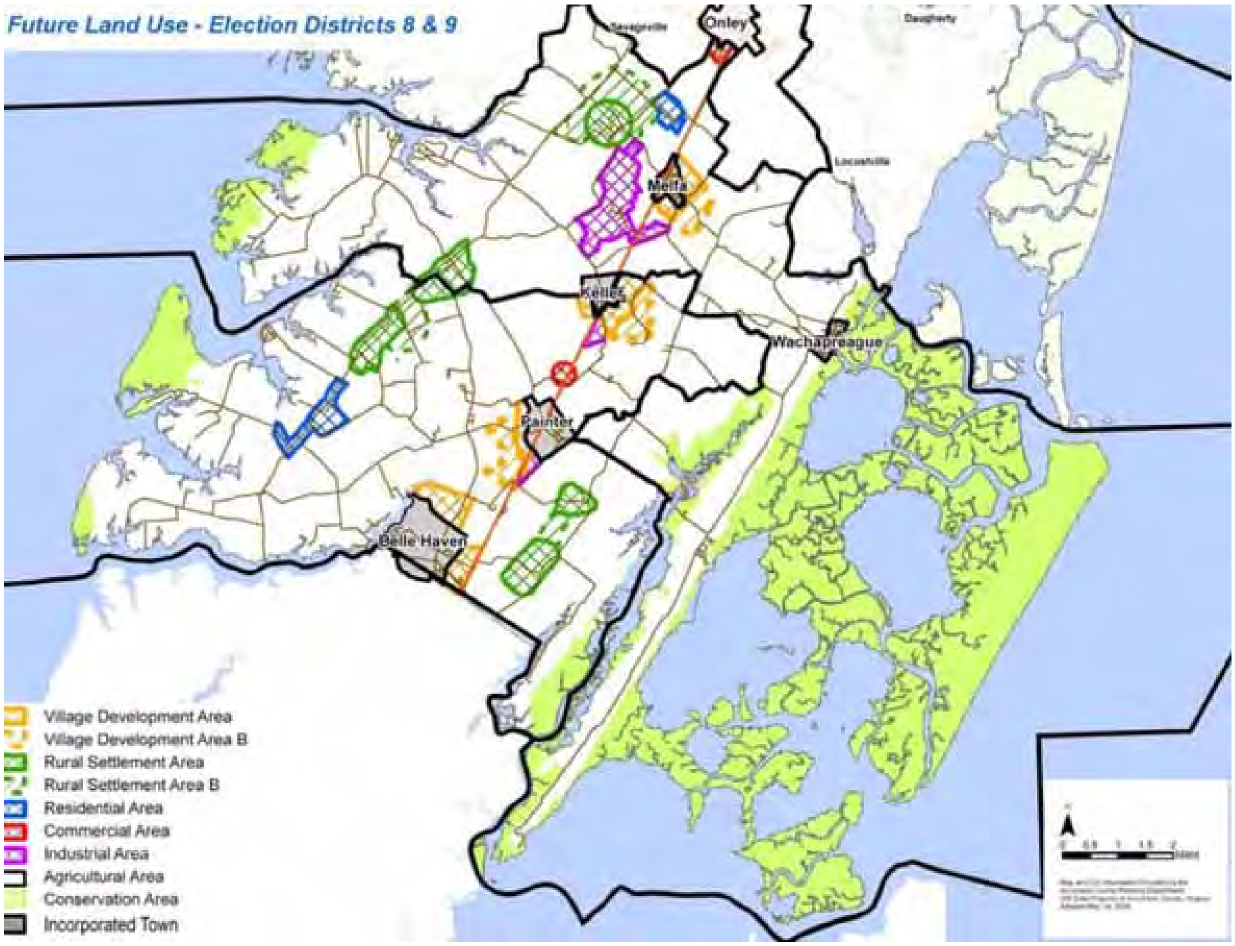
Source: Accomack Comprehensive Plan, 2008[5].

Figure 3.1-6: Future Land Use in Accomack County – Districts 6 and 7



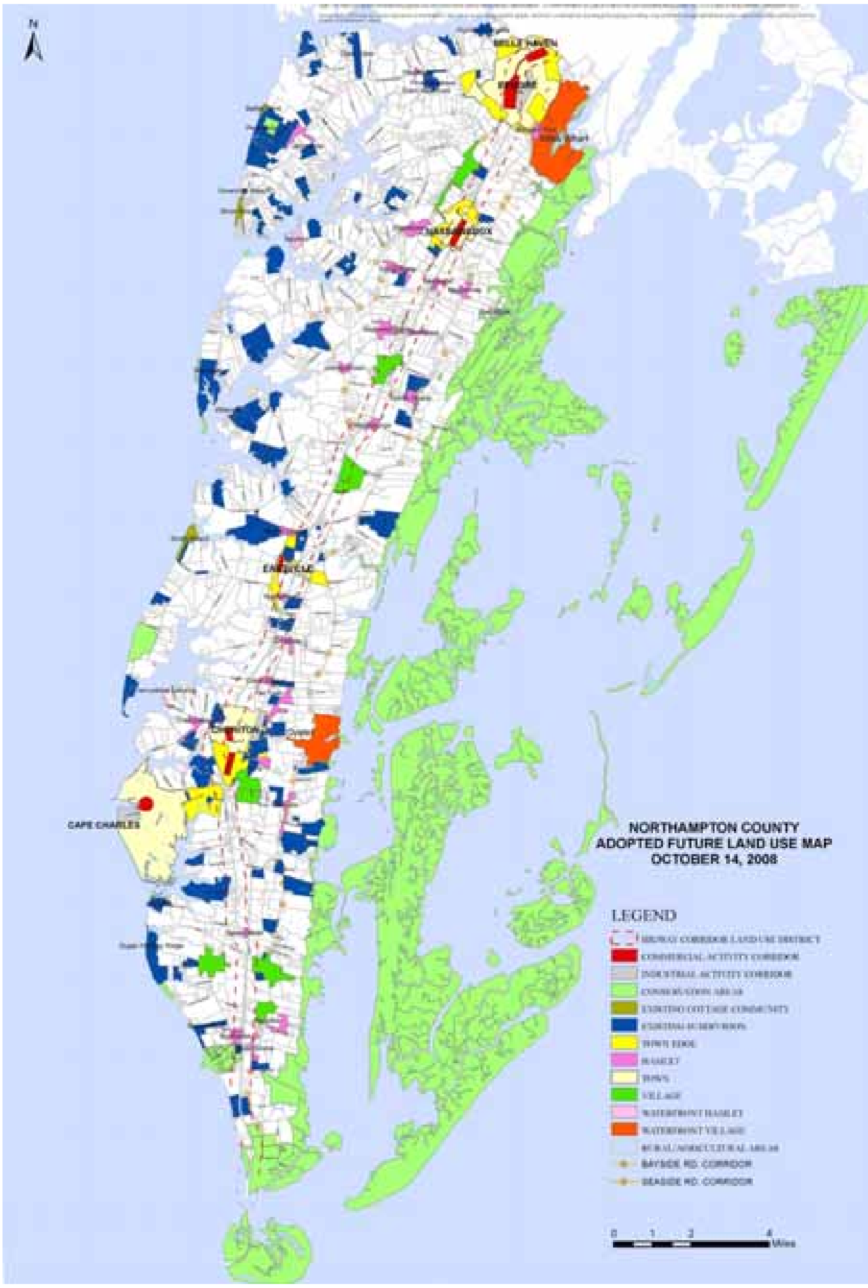
Source: Accomack Comprehensive Plan, 2008[6].

Figure 3.1-7: Future Land Use in Accomack County – Districts 8 and 9



Source: Accomack Comprehensive Plan, 2008[7].

Figure 3.1-8: Future Land Use in Northampton County



Source: Northampton Department of Planning and Zoning, 2009[8].

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6 Accomack County, 2008. *Accomack County Comprehensive Plan*. Adopted May 14, 2008.

7 Accomack County, 2008. *Accomack County Comprehensive Plan*. Adopted May 14, 2008.

8. Northampton County, 2009. *Northampton County Planning and Zoning Regulations*. Adopted Oct 21, 2009. http://www.co.northampton.va.us/ departments/planning_zoning.html

3.2 WATER USE

Placeholder for optional preamble.

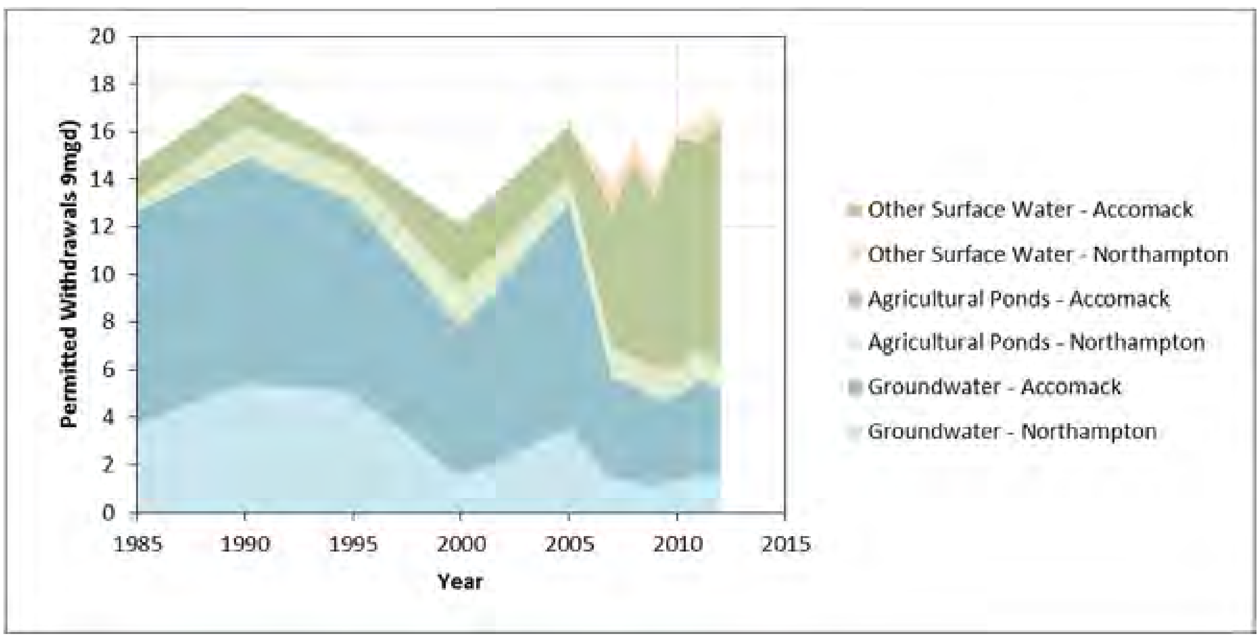
3.2.1 Historic Water Use

The United States Geological Survey (USGS) has compiled water usage information by county throughout the United States in 5-year increments since 1985 through the National Water-Use Information Program (NWUIP)[1]. These water usage studies include estimated usage by source (i.e., groundwater versus surface water) and by type (e.g., public, industrial, agricultural, and individual domestic) for the Accomack and Northampton Counties on the Eastern Shore. The totals presented in these studies are approximate and provide estimates of water usage sufficient to evaluate trends in water usage.

More recent (2007 - 2012) data of freshwater use on the Eastern Shore has been compiled annually into the Virginia Water Use Data System (VWUDS) by the State Water Control Board (SWCB) to provide water withdrawal information to facilitate the management of water resources. Water users with average monthly withdrawal volumes greater than 0.1 MGD (~30,000 gallons per month) are required to report usage to the VWUDS. The VWUDS data is generally considered to be more accurate than data from the NWUIP; however, the VWUDS does not include withdrawals from individual users below the 0.1 MGD reporting limit.

Estimated water use on the Eastern Shore has ranged between 12 million gallons per day (mgd) and 18 mgd over the period between 1985 and 2012 (**Figure 3.3-1**). Historically, the majority of water on the Eastern Shore was obtained from groundwater; however, the more recent trend of promoting the use of agricultural ponds rather than wells to supply agricultural water needs, has resulted in a significant shift away from groundwater use towards surface water, particularly in Accomack County.

Figure 3.2-1: Historical Water Use on the Eastern Shore



3.2.2 Current Water Use

Average water use from the previous five year period (2007-2012) has been compiled from the VWUDS to define current and recent water use on the Eastern Shore. Water use has been categorized by source, end use, and county to identify demonstrate how and where water is being used. Each category is discussed below.

The average water use in the county over the past 5 years was 15.4 mgd, ranging between 13.8 mgd and 16.9 mgd.

3.2.2.1 Water use by Source

Water usage was divided into three source and three end use categories as shown in **Figure 3.3-2**, summarized in **Table 3.3-1**, and discussed below. The three sources include: groundwater, ponds, and other surface water; while the three end use types include: irrigation, commercial/industrial, and municipal. The commercial/industrial and municipal end users obtain water exclusively from groundwater wells, while irrigation end users obtain water from all three source types. As discussed in more detail below, ponds on the Eastern Shore usually receive the most significant portion of their water from groundwater discharge and the rest from run off and direct precipitation.

Figure 3.2-2: Recent Water Use on the Eastern Shore by Source and End Use

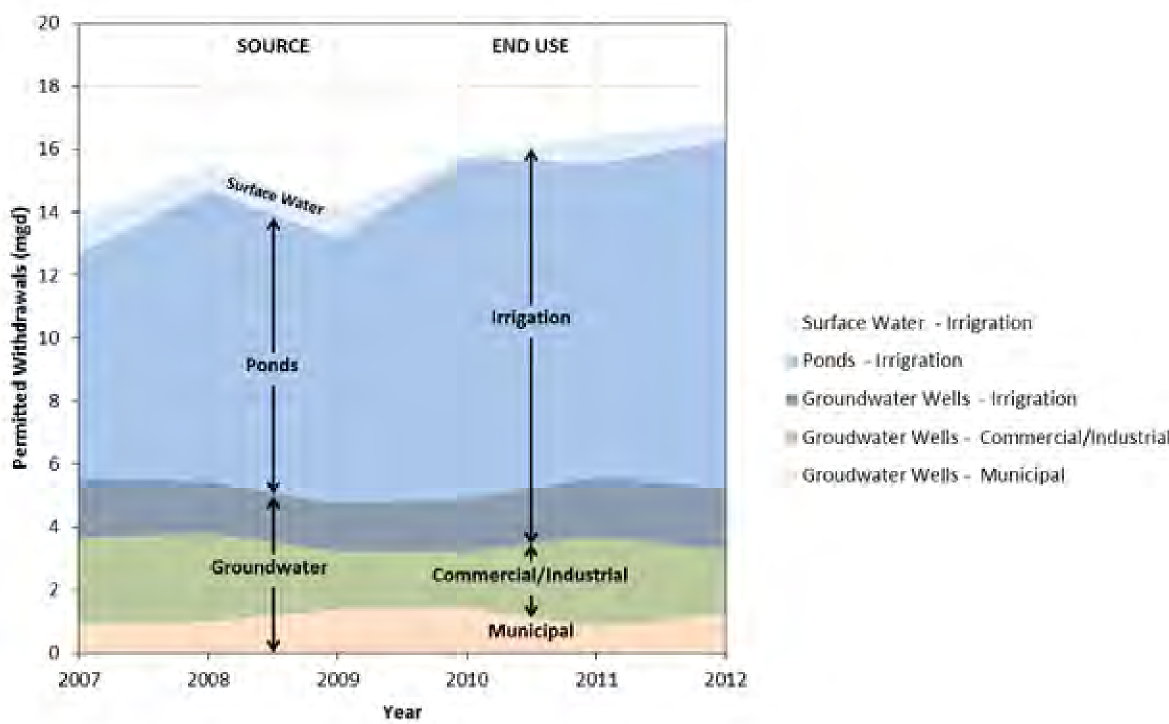


Table 3.2-1: Recent Water Use on the Eastern Shore by Source and End Use

Source	Year	Agriculture	Commercial/Industrial	Municipal	Total
Groundwater	2007	1.90	2.76	0.90	5.55
	2008	1.65	2.80	1.00	5.46
	2009	1.51	1.85	1.38	4.74
	2010	1.70	1.77	1.44	4.91
	2011	1.87	2.88	0.82	5.57
	2012	1.99	2.03	1.23	5.25
	Average	**1.77**	**2.35**	**1.13**	**5.25**
Agricultural Ponds	2007	7.15	--	--	7.15
	2008	9.24	--	--	9.24
	2009	8.46	--	--	8.46
	2010	10.82	--	--	10.83
	2011	9.98	--	--	9.98
	2012	11.03	--	--	11.02
	Average	**9.45**	**0.00**	**0.00**	**9.45**
Other Surface Water	2007	1.07	--	--	1.07
	2008	0.85	--	--	0.86
	2009	0.88	--	--	0.88
	2010	0.08	--	--	0.08
	2011	0.87	--	--	0.87
	2012	0.60	--	--	0.60
	Average	**0.73**	**0.00**	**0.00**	**0.73**
Total Water Use	2007	10.11	2.76	0.90	13.77
	2008	11.74	2.80	1.00	15.56
	2009	10.85	1.85	1.38	14.08
	2010	12.60	1.77	1.44	15.82
	2011	12.72	2.88	0.82	16.42
	2012	13.62	2.03	1.23	16.87
	Average	**11.94**	**2.35**	**1.13**	**15.42**

3.2.2.1.1 Ground water

The average groundwater withdrawal by permitted users over the past five year period (2007-2012) has been approximately 5.25 mgd, which is approximately 34% of the total water use on the Eastern Shore. End uses for the groundwater withdrawals consisted of agriculture (1.77 mgd or 33.7% of groundwater usage), commercial/industrial (2.35 mgd or 44.8% of groundwater usage), and municipal (1.13 mgd or 21.5% of groundwater usage).

3.2.2.1.2 Surface Water

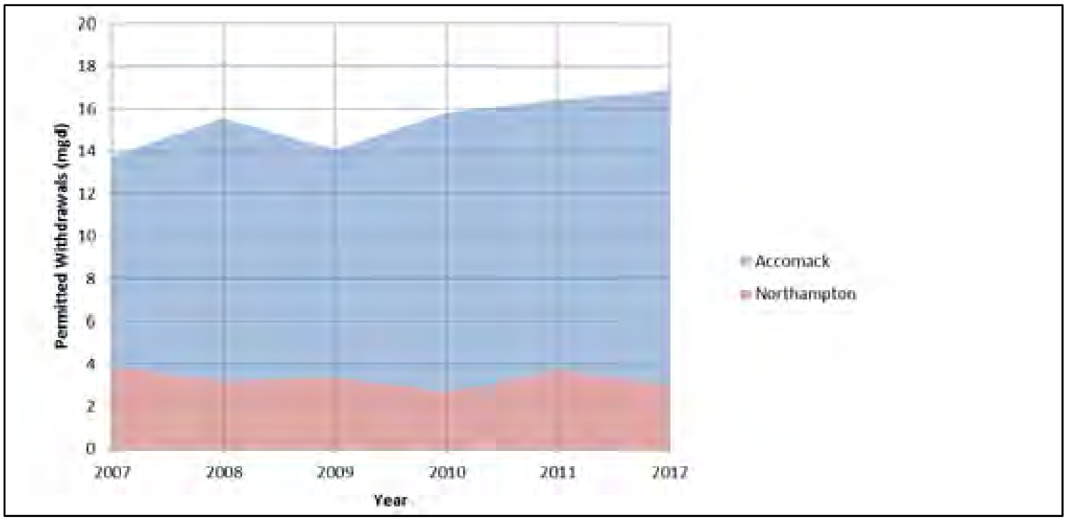
Surface water on the Eastern Shore is used exclusively for agricultural purposes. The average surface water withdrawal by permitted users over the past five year period (2007-2012) has been approximately 10.2 mgd, which is approximately 66% of the total water use on the Eastern Shore. However, 93% of the surface water (9.45 mgd, 61% of total water use) is derived from agricultural ponds, which rely primarily on groundwater discharge for replenishment. The rest (0.73 mgd, 5% of total water use) is withdrawn directly from fresh streams for agricultural use.

While groundwater is the sole source of drinking water on the Eastern Shore of Virginia, surface water is used extensively for agricultural irrigation and some limited industrial use. Over the most recent five-year period, approximately 93% of water used for irrigation is from farm ponds. Historically, most farm ponds were created through dams or impoundments on existing creeks and streams. In part as a result of wetland regulations, most new farm ponds are dug ponds located in upland areas. The majority of farm ponds on the Shore whether impoundments or dug ponds, extend into the Columbia aquifer. As water is pumped from the irrigation ponds, groundwater replenishes the pond. It is not unusual for farms to supplement the farm ponds with groundwater pumped directly from wells. Most often groundwater from the wells is pumped directly to the farm pond.

3.2.2.2 Use by County

In the past five year period (2007-2012), water use in Accomack County (12.1 MGD) has averaged significantly higher than in Northampton County (3.3 mgd) (**Figure 3.2-3**). Water use in Accomack and Northampton counties is categorized by the source and end use described above in **Figure 3.2-4** and **Figure 3.2-5**, respectively.

Figure 3.2-3: Recent Water Use by County



Average water use in Accomack County, as categorized by the sources and end uses described above, is presented in **Figure 3.2-4** and consisted of:

Source	End Use	Average Withdrawal
Groundwater	Municipal	0.72
	Commercial/Industrial	2.32
	Agricultural	0.83
Ponds	Agricultural	8.24
Other Surface Water	Agricultural	0.02
	Total Water Use	12.12

Average water use in Northampton, as categorized by the sources and end uses described above, is presented in **Figure 3.2-5** and consisted of:

Source	End Use	Average Withdrawal
Groundwater	Municipal	0.41
	Commercial/Industrial	0.03
	Agricultural	0.94
Ponds	Agricultural	1.21
Other Surface Water	Agricultural	0.70
	Total Water Use	3.30

Figure 3.2-4: Recent Water Use in Accomack County by Source and End Use

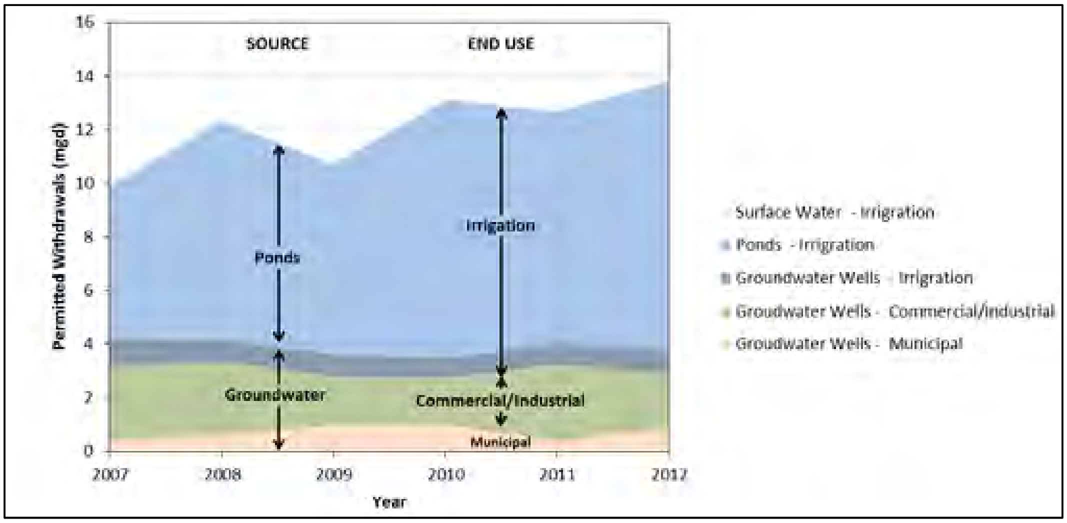
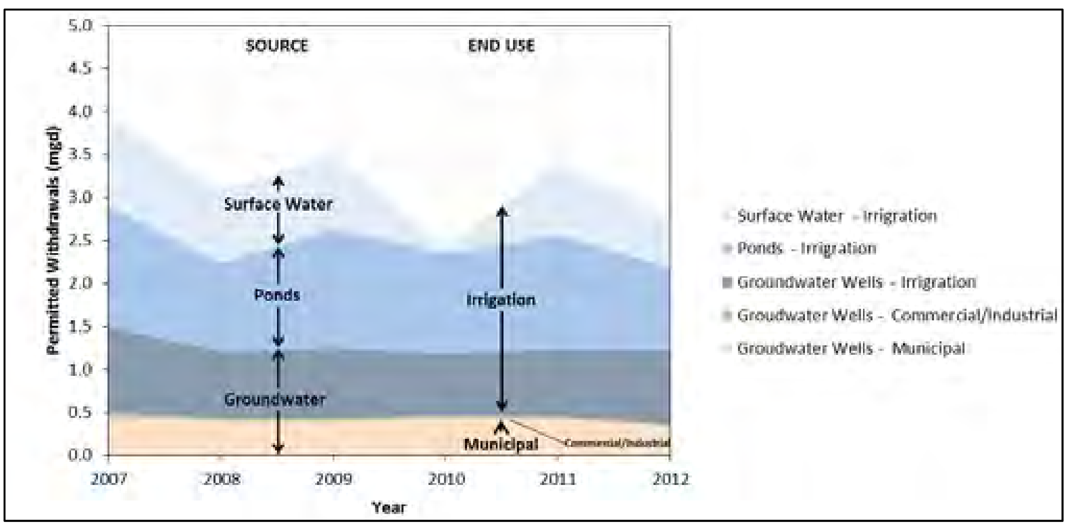


Figure 3.2-5: Recent Water Use in Northampton County by Source and End Use



3.2.3 Future Water Use Trends

3.2.3.1 Groundwater

A statistical trend in the groundwater usage data was not found; however, average annual groundwater usage over the past five year period (2007-2012) was approximately 5.25 MGD. Although linear interpolation provides a poor correlation to the data, recent groundwater usage has been steady to slightly declining (**Figure 3.2-6)**, groundwater usage is likely to remain consistent over the short term for reasons outlined below.

While the current comprehensive plans of both counties support residential and economic growth concentrated in areas already served by municipal supplies, groundwater demands have been declining due to reduced demands associated with conservation measures (**Figure 3.2-7**). Groundwater demands over the next five year period are likely to continue at current levels for the same reason – total demand is flat because growth in consumption is being exceeded by reductions in per capita consumption. As incremental steps in water conservation become more difficult or expensive to implement, demand for fresh potable groundwater will begin to grow again unless alternative sources are developed (see **Section 5.4**).

Figure 3.2-6: Recent and Projected Withdrawals

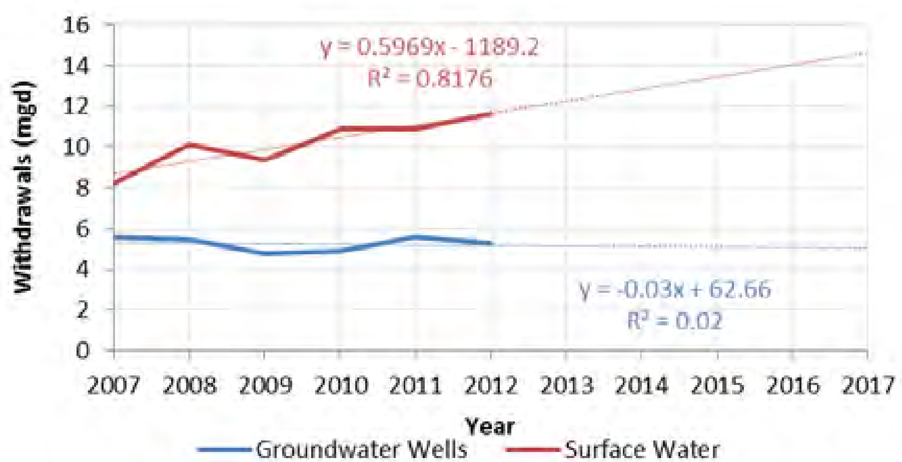
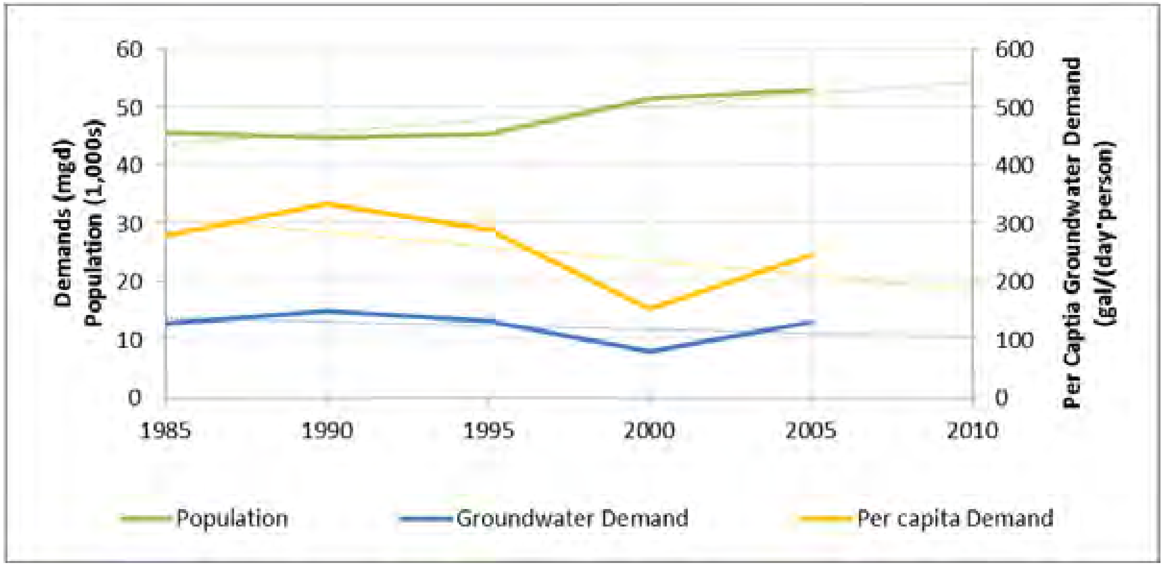


Figure 3.2-7: Trends in Groundwater Use



3.2.3.2 Surface Water

Surface water withdrawals (including a significant majority from the agricultural ponds) have increased over the past five years (2007-2012) from approximately 8 mgd to almost 12 mgd. If a similar trend continues over the next five years, demand would increase to approximately 15 mgd (**Figure 3.2-6**). A further uncertainty to predicting future surface water demands is that surface water is largely used for irrigation and demand is largely tied to weather and climate, which are inherently unpredictable (recent and predicted climate trends are discussed in **Section 4.4**). Periods where average evapotranspiration exceeds precipitation (including droughts) require more irrigation waters and will put further pressure on demands.

References

[1] USGS, 2013. *Water Use in the United States*. National Water-Use Information Program website: http://water.usgs.gov/watuse/. Last Accessed: September 24, 2013.

4.0 RESOURCE VULNERABILITY

This section of the Groundwater Management Plan identifies and discusses existing and potential vulnerabilities to water resources on the Eastern Shore of Virginia.

There are two major concerns regarding groundwater on the Eastern Shore:

1. quantity and
2. quality.

Groundwater quantity is limited by the nature of the aquifers and must be carefully managed to prevent overuse that can result in saltwater intrusion (**Section 4.1**) and water level declines (**Section 4.2**).

Groundwater quality depends on proper management of land use activities that can contaminate aquifers (**Section 4.3**). In recognition of the limited groundwater supply and the potential for contamination, the U.S. Environmental Protection Agency designated the Eastern Shore of Virginia a Sole Source Aquifer in 1997. The designation provides protection to the Shore's water supply by requiring the EPA to review proposed projects on the Shore that are receiving federal financial assistance to ensure they do not endanger the water supply.

Climate change and sea level rise (**Section 4.4**) may result in impacts to ground water quantity and quality due to changes in recharge patterns and increased potential for saltwater intrusion, respectively.

4.1 SALTWATER INTRUSION

Saltwater intrusion occurs when fresh groundwater is withdrawn at a rate faster than it is replenished. Because the sole source of fresh groundwater on the Eastern Shore of Virginia is from direct precipitation, the Shore is susceptible to saltwater intrusion. Saltwater intrusion typically occurs in two forms: 1) lateral movement and 2) upconing.

Lateral movement of saltwater generally occurs near the edge of the freshwater / saltwater interface from the aquifer where the withdrawal is occurring. The lateral movement is a response to a smaller freshwater lens, with saltwater replacing freshwater in these areas. On the Eastern Shore of Virginia, although there are no well documented cases of lateral intrusion, it is likely at least a portion of the saltwater intrusion observed in Bayshore Concrete wells near the Town of Cape Charles is due to lateral intrusion. One reason lateral saltwater intrusion has not been readily observed on the Shore is that the location of the freshwater/saltwater lens is generally off-shore. The current rate of withdrawals is not sufficient to result in significant landward movement of the freshwater/lens.

The Eastern Shore Model has been used to further evaluate conditions where lateral saltwater intrusion could occur. One example of saltwater encroachment in areas generally off-shore is a hypothetical 1-mgd withdrawal located halfway between the two major groundwater users on the Shore (Perdue and Tyson Farms) (**Figure 4.1-1**). Like these two major users, the hypothetical withdrawal was located near the center of the freshwater lens. The model predicted increases in chloride levels that exceed the Drinking Water secondary Maximum Contaminant Level of 250 mg/L over a relatively small area long the Seaside and secondarily the Bay. It is unlikely this saltwater intrusion would be observed in wells currently used on the Shore.

Upconing is the more commonly observed form of saltwater intrusion occurring on the Shore, and occurs when groundwater pumped from a confined aquifer induces localized upward move movement of underlying saltwater as a result of the lowered freshwater levels (**Figure 4.1-2**). Unlike lateral intrusion, which commonly occurs some distance from the pumping well, upconing typically occurs in the immediate vicinity of the well.

Figure 4.1-1: Model Predicted Saltwater Intrusion from Hypothetical 1-MGD Withdrawal

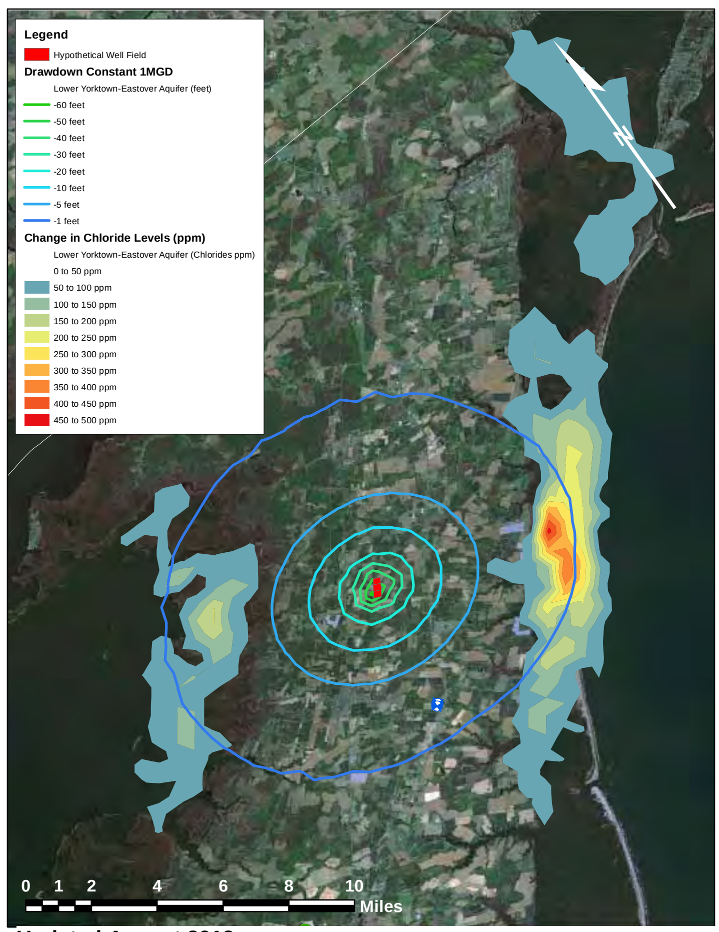


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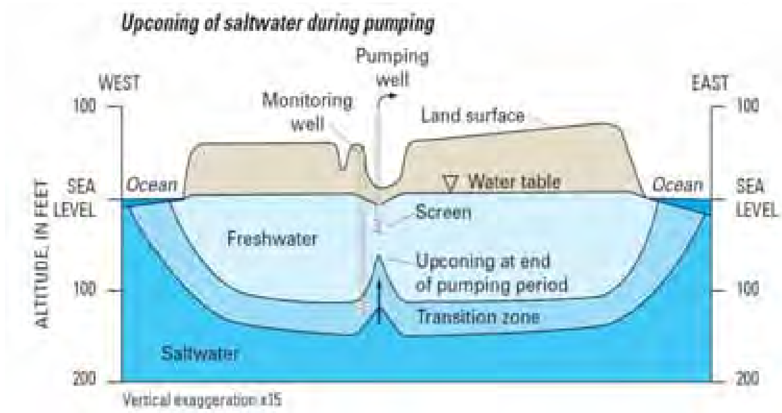
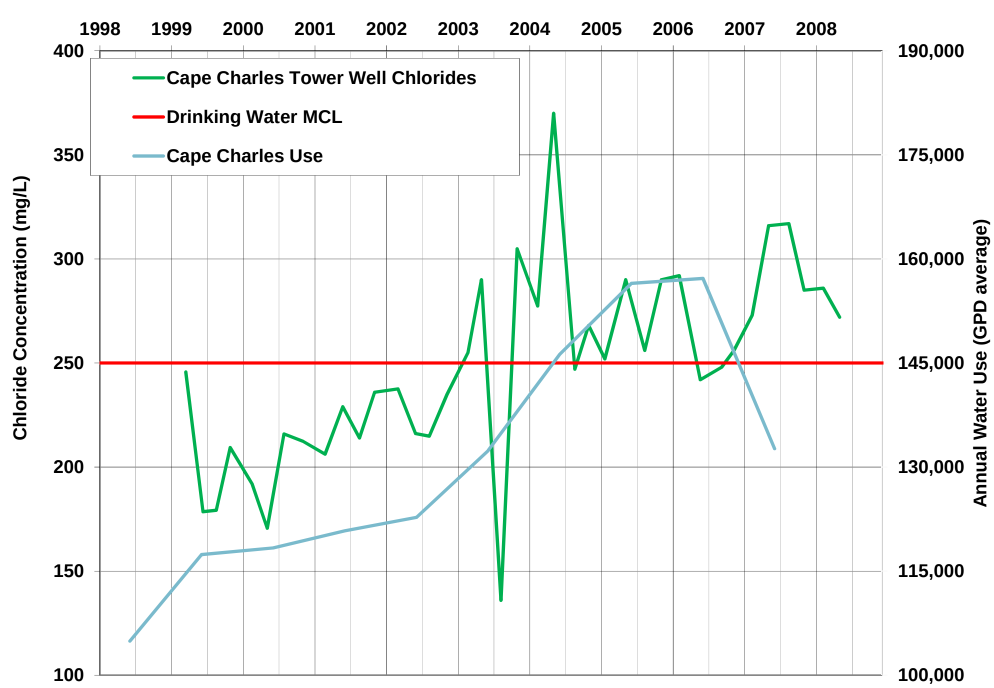
Figure 4.1-2: Example of Upconing



Source: USGS Circular 1262 (2003)

Upconing has been observed in the Town of Cape Charles production wells, with brackish groundwater in the lower Yorktown-Eastover aquifer moving up into the middle Yorktown-Eastover aquifer. Chloride levels in the Town's production wells increased by almost 100 mg/L over a 10-year period as a direct result of increases in the Town's groundwater use (**Figure 4.1.3**).

Figure 4.1.3: Saltwater Intrusion in the Town of Caper Charles Production Wells



4.2 WATER LEVEL DECLINES

A consequence of groundwater withdrawals are lower groundwater levels in the aquifer being pumped as well as, in some cases, overlying and underlying aquifers. The amount the water level declines and the area that is impacted by the water level declines is a function of the rate the water is withdrawn and certain characteristics of the aquifer, such as the transmissivity, storage, and rate of aquifer recharge. Consequences of water level declines include:

- Reduced well capacity
- Potential well failure
- Potential groundwater mining
- Potential land subsidence
- Increased potential for saltwater intrusion
- Increased potential for transport of contaminants from land use activities

Useful Definitions:

Well yield: the maximum groundwater withdrawal rate. Yield is a function of aquifer characteristics and well construction/maintenance.

Drawdown: the decrease in groundwater levels relative to existing or baseline condition groundwater levels due to changes in groundwater flow, usually pumping.

Most often reduced well capacity does not result in a total loss of well yield, rather it typically results in lower withdrawal rate leading to longer pumping time in order to maintain the desired yield. However, in some cases the water levels will fall below a pump intake with the resulting well failure. The following measures will commonly correct well failure: 1) lowering pump intake; 2) increasing pump capacity; or 3) if the preceding measures cannot be implemented, replacing the well.

Groundwater mining occurs when the water level is lowered below the top of the aquifer. In addition to loss of well capacity, mining results in some land subsidence and a permanent reduction in the aquifer capacity where the water is drained from the aquifer matrix. To prevent this from occurring, the Virginia Department of Environmental Quality (VDEQ) regulates all withdrawals greater than or equal to 300,000 gallons/month. Under these regulations, the VDEQ:

- Requires that all pump intakes are above the top of the aquifer and
- Groundwater levels are not lowered below the 80% criterion

Anytime the water level is lowered in the freshwater aquifer, the size of the freshwater lens is reduced and saltwater intrusion occurs. Often the change is not measureable or does not affect any users. However, some localized saltwater intrusion that has resulted in measurable increases of sodium and chloride concentrations in the groundwater has been documented on the Shore. The lowered water levels also correspond to an increase in the groundwater flow velocity. Movement of any contaminants that may be present in the groundwater can occur or increase.

Water level declines on the Shore are evaluated through two approaches:

- Collecting and comparing empirical water level measurements over time from State Observation Wells maintained by the USGS (**Figures 4.1-1** through **4.1-3**) and
- Predicting groundwater levels based on simulations of various groundwater withdrawal scenarios using the Eastern Shore Model (**Figure 4.1-4**).

Figure 4.2-1: Measured Groundwater Levels - Assawoman

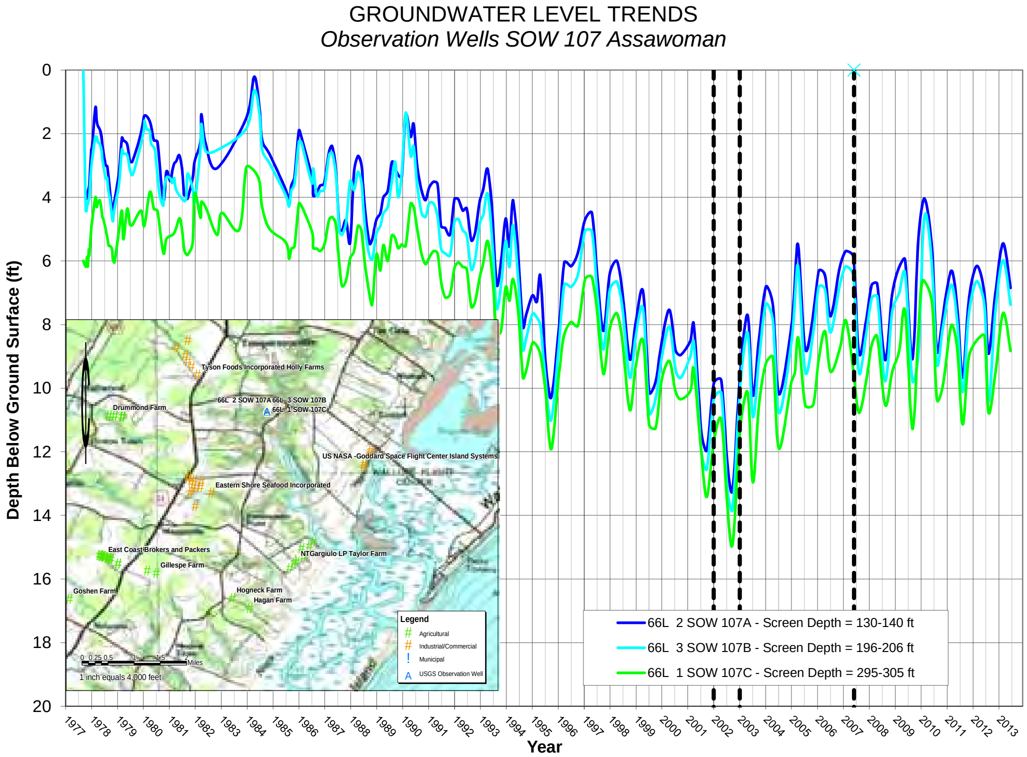


Figure 4.2-2: Measured Groundwater Levels – NW of Melfa

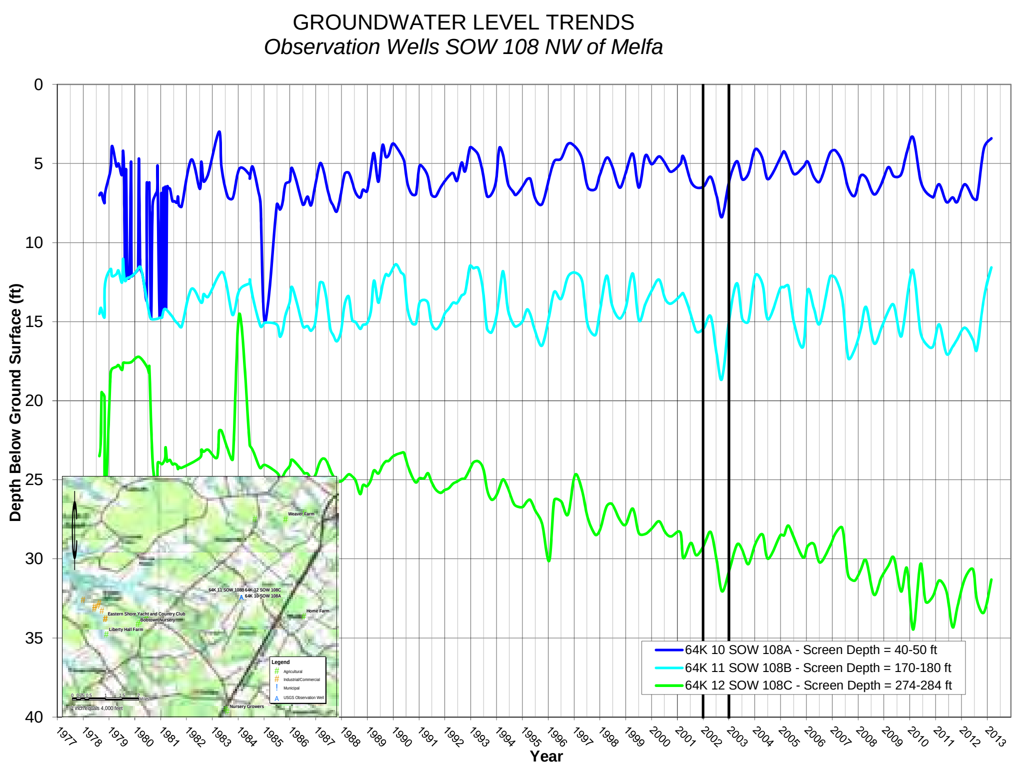
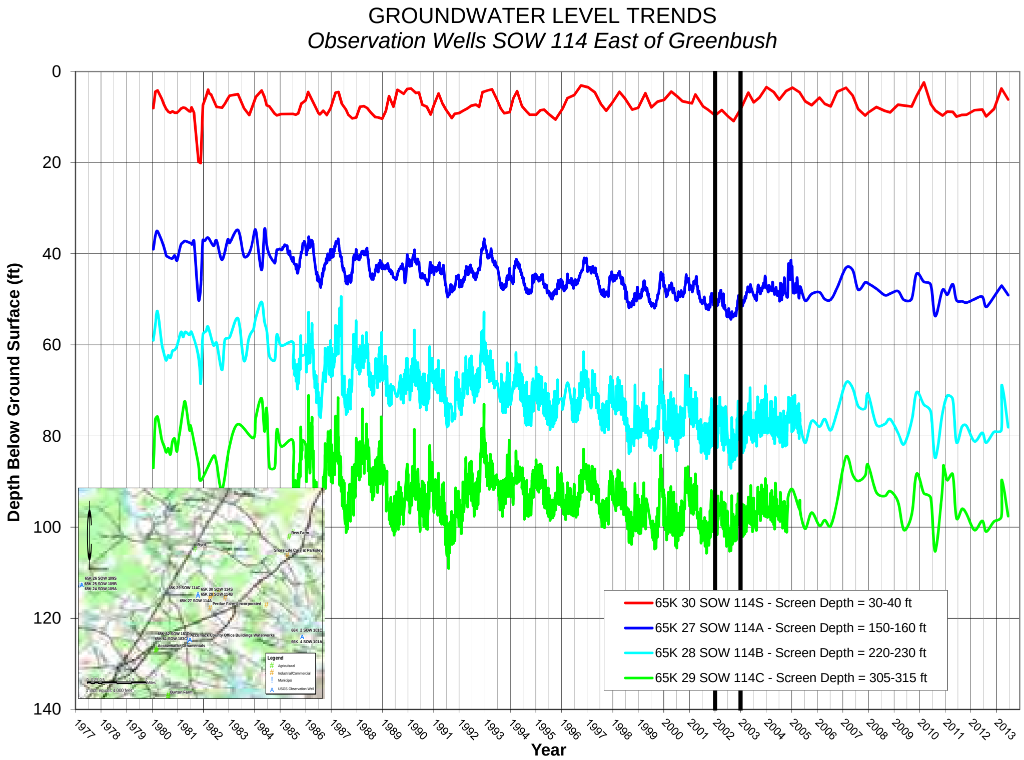


Figure 4.2-3: Measured Groundwater Levels – E of Greenbush



Water level measurements collected from wells on the Eastern Shore during the period between 1997 and 2013 demonstrate that water levels have declined in some areas by averages of up to 20 feet, particularly in the deeper portions of the Yorktown aquifer (i.e. the deeper screened intervals at SOW 108 northwest of Melfa and at SOW 114 eat of Greenbush). Measured water levels in the shallower aquifers (i.e. the Columbia and Upper Yorktown aquifers) have remained consistent or declined much less over the same period. This is largely due to the higher recharge associated with the shallower aquifers.

Simulations groundwater levels from the Eastern Shore Model resulting from withdrawing at the maximum annual average rate for each permitted user (as of 2013) conservatively predict water level declines (i.e. drawdown) based on current usage. The scenario is conservative because, it is unlikely that all users will withdraw at the maximum rate, particularly since recent groundwater withdrawals have been relatively stable or even declining slightly over the past ten years (as of 2010). As shown in **Figure 4.2-4**, the most significant area of potential drawdown (and therefore potential water level decline) is located in the central portion of Accomack County.

Figure 4.2-4: Model Predicted Drawdown for All Permitted Withdrawals

Updated August 2013

4.3 LAND USE ACTIVITIES

Existing and potential vulnerabilities to water resources on the Eastern Shore of Virginia may be associated with various land use practices that can contaminate aquifers, typically in the following categories:

- Agricultural
- Industrial/Commercial
- Municipal/Residential
- Waste Management

Each of these land use activities and their potential impact on Eastern Shore groundwater resources are discussed below.

4.3.1 Agricultural

Cultivation of crops for food and feed and husbandry of livestock are important activities to the culture, character, and economy of the Eastern Shore. These practices provide obvious benefits in terms of food production and employment and are actively encouraged as part of the comprehensive plans of both Accomack and Northampton counties. Improper land management activities associated with agriculture can contribute to the degradation of water resources. Excessive application of fertilizers and pesticides can impact water quality and overuse of water for irrigation and other agricultural purposes can lead to declines in water levels (see Section 4.2) and concentrate minerals already present in the surficial aquifer. The most common groundwater quality impacts from agricultural activities are elevated nitrogen levels that, in some areas, exceed the USEPA Drinking Water Maximum Contaminant Level. Other impacts to groundwater that have been observed are low levels of pesticides that appear to be related more to past agricultural practices than current activities.

4.3.1.1 Nitrogen

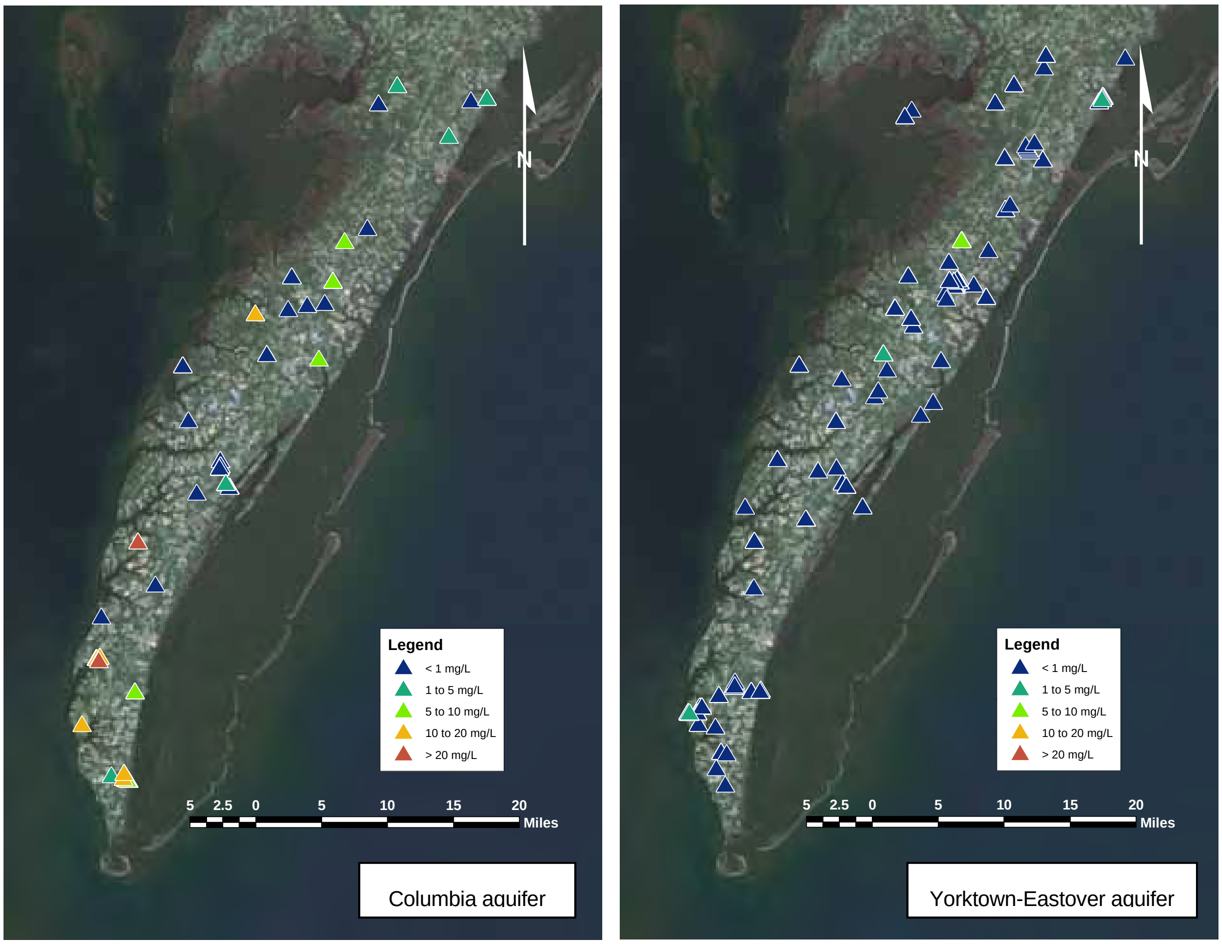
Nitrogen (often in the form of nitrate) is one of the most widespread groundwater contaminants in the United States. The primary and most common agricultural sources of nitrogen on the Eastern Shore include:

- Crop fertilization (natural/synthetic and organic/inorganic); and
- Land application of animal wastes, including from concentrated animal feed operations (CAFOs)

Studies have shown that the surficial aquifer on the Eastern Shore has been impacted by historical agricultural practices and other human sources of nitrogen with concentrations above natural background conditions and exceeding 10 mg/L as nitrate (the USEPA maximum contaminant level goal)[1,2,3] (Debrewer, et al, 2007; Miller, 1972; Speiran, 1996). The highest levels of nitrogen in the groundwater are associated with agricultural fields. Based on groundwater rage dating conducted by Speiran (1996), there has been a decrease in nitrate levels within 10-years of the groundwater samples collected in 1993 as part of the USGS study, indicating improved recent agricultural practices reducing the nitrogen load to the groundwater. However, the information provided in this study is now over 20-years old. More recent information on nitrogen concentration trends on the Shore are very limited (Debrewer, et al, 2007).

Elevated nitrate concentrations are, for the most part, restricted to the shallow Columbia aquifer and do not exceed the USEPA Drinking Water MCL in the confined Yorktown-Eastover aquifer (**Figure 4.3-1**).

Figure 4.3-1 Nitrate Concentrations in Groundwater (2002)



Once nitrates have infiltrated to groundwater, it is difficult to reduce their concentration, so it is important to minimize nitrate loading for land activities. Agricultural sources of nitrates can be controlled using best management practices (BMPs) such as:

- (enhanced) nutrient management planning,
- animal waste management,
- conservation tillage, and
- riparian and wetland buffer creation/restoration.

Such practices are already widely used on the Eastern Shore and are supported by numerous government agencies through regulations, support programs, and funding/grant initiatives

4.3.1.2 Pesticides

Pesticide residues and degradation products (including metolachlor, alachlor, and atrazine) have been detected at low concentrations throughout the surficial aquifer on the Eastern Shore (Debrewer et al, 2007), almost always below drinking water standards. In addition to the publication by the USGS, the Virginia Polytechnic Institute (VPI)[4] conducted a pilot study in Northampton County in 1992-1993 to evaluate potential pesticide and nitrate contamination in groundwater. The VPI study included 359 private wells, with approximately 1/3 screened in the Columbia aquifer and the remainder screened in the Yorktown-Eastover aquifer. The VPI study found 10% of the wells sampled had detectable levels of herbicides and 4% of the wells in the Columbia aquifer had herbicide levels exceeding an EPA risk level. While pesticides do not appear to be as persistent or widespread issue as nitrate in groundwater, it is important to continue to track occurrence of these compounds and to encourage the same appropriate agricultural practices that would limit its impact on groundwater.

4.3.1.3 Water Use

Agricultural water use, in total, is the greater than any other use type on the Shore, totaling over 12 million gallons per day on average in 2010 through 2012. Approximately 85 percent of this water is withdrawn from Farm Ponds with the remainder from groundwater wells. The contribution from groundwater wells (approximately 1.9 million gallons per day on average) is less than the industrial groundwater use (2.35 million gallons per day on average), making agricultural irrigation the second greatest use of groundwater from the confined Yorktown-Eastover aquifer. Because agricultural use is both seasonal and episodic (droughts), net impacts of the groundwater resource is poorly understood. Specifically, the impact of a high rate of withdrawal over a period of several months when demand is greatest followed by months and sometimes years with a low rate of withdrawal.

Use of the water table aquifer for irrigation, from Farm Ponds or from wells, has much less impact on the water resources. With the ability of the Columbia to quickly recharge from precipitation use of this aquifer as a source of irrigation supply is currently sustainable.

4.3.2 Industrial/Commercial

The major industries on the Eastern Shore are poultry processing and a growing seafood industry. Both industries have an impact on water resources from water use as well as waste disposal. Poultry processing and the seafood industries have disposed of wastes on land through land application systems that, if not properly operated, can adversely impact groundwater quality. In addition Concentrated Animal Feeding Operations (CAFOs) associated with the poultry industry has the potential to impact water quality. In addition to the conventional water quality constituents, such as nitrogen compounds, CAFOs have the potential to impact groundwater with a class of compounds referred to as emerging contaminants that include antibiotics and steroids.

4.3.2.1 Nitrogen

Similar to agricultural use, nitrogen is the constituent most likely to impact groundwater on the Shore for the current major industrial uses. Source of the nitrogen would be from waste management practices associated with the poultry processing, CAFOs, and seafood industries. Known impacts from industries do not match the extent or magnitude of agricultural use, and as long as land application systems and waste ponds are appropriately managed these systems are unlikely to have significant future impacts. From research conducted by the USGS on the Shore, nitrogen levels in and around CAFOs are elevated over background levels but below the Drinking Water Maximum Contaminant Level[4]. Likewise, nitrogen associated with land application system for poultry production does not exceed the Drinking Water Maximum Contaminant Level at the edge of the treatment fields. However, it is important to note that land treatment systems in other areas of Virginia have exceeded the nitrate Drinking Water Maximum Contaminant Level due to under sizing or poor operational practices.

4.3.2.2 Emerging Contaminants

Emerging contaminants include compounds associated with antibiotics and steroids and have the potential to be present in poultry processing, CAFOs, as well as municipal waste waters. While there is very limited information on presence of emerging contaminants in groundwater on the Shoe, initial indications are these compound are not currently present at detectable levels[4]. As research provides a better understating of the fate and transport as well as potential effects on human health and the environment, additional analysis of groundwater on the Shore may be warranted.

4.3.2.3 Water Use

Industrial use is the largest single category of groundwater use on the Shore, with the two poultry processing industries comprising over 90% of this use. Averaging over 2¼ million gallons per day, use by the two poultry processing industries exceeds the next highest use by agricultural irrigation, which averages approximately 1¾ million gallons per day. Unlike agricultural use which relies on both the unconfined Columbia aquifer and the confined Yorktown-Eastover aquifers, all of the groundwater withdrawals for poultry manufacturing are from the confined aquifer, where the long term sustainable supply is more limited. Additionally unlike irrigation use, these withdrawals do not vary significantly seasonally and there are no significant episodic withdrawals. As a consequence, while the average use is similar, impact from industrial use will be different and it is not clear based on current information if the impacts would are greater.

Based on empirical water level measurements and model simulations with the USGS Eastern Shore Model, most of the impacts from groundwater withdrawals by the two poultry industries have already occurred. These impacts are for the most part restricted to water level declines, which in the vicinity of the Perdue facility, approach 100-feet in the Yorktown-Eastover aquifer. While these water level declines reduce groundwater availability in these areas, they do not, at present limit use. Additionally, potential saltwater intrusion from these withdrawals is limited to the Bayside and Seaside areas for the Yorktown-Eastover aquifer and do not appear to have resulted in any significant saltwater intrusion landward.

While the groundwater use by the two primary industrial groundwater users appear to be sustainable at current levels, these withdrawals occur in the area of the Shore where groundwater in the Yorktown-Eastover aquifer is most plentiful: in the northern portion of the Shore near the “Spine Recharge Area”.

Availability of fresh groundwater in the Yorktown-Eastover aquifer further south or closer to the Bayside or Seaside is much more limited. There are historical empirical reports of saltwater intrusion resulting from groundwater withdrawals by the former KMC processing plant, located near the Spine Recharge Area in Northampton County. Additionally, saltwater intrusion has more recently been measured from groundwater withdrawals near the Bayside in the vicinity of Cape Charles in Northampton County.

4.3.3 Municipal/Residential

Municipal and residential land use has many of the same potential impacts to the water resources as agricultural and industrial use, although the magnitude of these impacts is typically less. Potential impacts to the groundwater resource from municipal and residential land use include:

- On-Site Disposal Systems:
  - Poorly maintained septic systems
  - Inadequately designed or maintained mass drain fields
- Inadequately sized or inadequately operated land application systems
- Nonconforming or improperly functioning waste disposal units (historical dumps and landfills)
- Improper use and disposal of household chemical
- Over application of fertilizers
- Reduced groundwater recharge resulting from high impervious areas
- Excessive groundwater use

4.3.3.1 Groundwater Contaminants

Land-based wastewater disposal systems, ranging from individual home septic systems to land applications have the potential to impact the Columbia aquifer if these systems are not property designed, constructed, and maintained. The principal concern for septic systems and mass drain fields is construction in proper soils conditions, periodic maintenance (pump-outs for septic systems), and disposal of chemical that disrupt the biological treatment in the septic system. Principal issue for most municipal land application systems is adequate pretreatment and maintaining sufficient land area and storage for final treatment of the wastewater in the soils before the treated water reaches the groundwater table. Similar to impacts from industrial use, excessive nitrate leaching to the groundwater is the most likely impact from improperly operating land disposal systems. Excess nitrate has been documented in residential areas with septic systems from previous studies[3,4]. Improved maintenance of septic systems is expected to reduce these impacts. Very few additional constituents impacting the groundwater quality have been documented for septic systems on the Shore.

Potential impacts from lawn fertilizer and pesticide application was evaluated for the Shore using the USEPA FEMWATER model[5]. Based on this model, normal pesticide application would not result exceedance of the Virginia groundwater standards or the Health Department Drinking Water Maximum Contaminant Levels. However, based on the model for sandy soils such as the Bojac series, normal fertilizer application rates to more than 10-percent of the pervious area of a residential development could cause nitrate levels to exceed the Drinking Water Maximum Contaminant Level. Additionally, for dense residential areas (1/2 acre or less lot size) with greater than 50-lots, wastewater from septic systems can likewise result in nitrate levels exceeding the Drinking Water Maximum Contaminant Level.

4.3.3.2 Water Use

Municipal water use comprises about half the amount industry uses, and with municipal use distributed over a much larger area of the Shore, it is not expected to have as significant impact on the resource. However, unlike industrial use, municipal use occurs along the more vulnerable Bayside and Seaside. As a consequence, some minor localized saltwater intrusion associated with municipal withdrawals in both Accomack County and Northampton County has been documented. Estimated residential withdrawals from individual domestic wells on the Shore likely exceed both industrial and municipal use combined, at an estimated average 3¾ million gallons per day[6]. Unlike municipal and industrial use, residential withdrawals are widely distributed across the shore and the combined impacts from these withdrawals are currently sustainable. Only under certain conditions would individual domestic wells significant impact the groundwater resource and only when in aggregate with other domestic wells. Saltwater intrusion in the coastal areas are possible where domestic wells are located in large (greater than 250 lot) developments with likewise large lot sizes (1-acre or greater) where lawn irrigation is a common practice[5]. Use of the Columbia aquifer for lawn irrigation avoids the potential saltwater intrusion impacts under this restrictive condition.

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[2] Miller, J.C., 1972, Nitrate contamination of the water-table aquifer in Delaware: Delaware Geological Survey Report of Investigations No. 20.

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5.0 WATER RESOURCE SUSTAINABILITY PLAN

This section of the Groundwater Management Plan discusses the plan to sustain water resources on the Eastern Shore of Virginia.

5.1 INSTITUTIONAL MECHANISMS

There are abundant institutional measures available on the Federal, State, and local levels that server to protect and preserve the water resource. Many of these measures are in place already as regulations and ordinances. One of the principal goals of the 1992 Plan was to work toward improving and tracking effectiveness of regulations and ordinances. This important goal will be continued with this Resource Sustainability Plan.

5.1.1 Federal

There are numerous Federal Regulations to provide protection to the groundwater resource. The primary federal regulation for protection of potable ground water supplies is the Safe Drinking Water Act (SDWA), which requires that the U.S. Environmental Protection Agency (USEPA) specify maximum contaminant levels (MCLs) for public water supplies and directs States to develop programs to enforce the standards. Amendments to the SDWA that were passed in 1986 include the Wellhead Protection Program (WHPP) and the Sole Source Aquifer Demonstration Program. Under the 1986 amendments, each state was required to develop a WHPP that delineates wellhead protection areas (WHPAs) around public water supply wells, identifies contaminants within the WHPAs, and specifies ground water protection approaches for state agencies and local governments. Amendments to the SDWA in 1996 required States to develop Source Water Assessment Programs (SWAPs) that extend the WHPP concepts to public waterworks that use surface waters.

The Sole Source Aquifer Demonstration Program allows USEPA to designate aquifers that supply at least 50 percent of the drinking water consumed in an area as 'sole source aquifers.' The designation protects an aquifer by USEPA review of any proposed projects within the area that are receiving federal financial assistance. Such assistance may be denied if USEPA determines that the project does not meet federal, state, or local ground water protection measures. The aquifer system on the Eastern Shore of Virginia was designated a sole source aquifer in 1997.

5.1.2 State

Both the Virginia Department of Environmental Quality (DEQ) and Virginia Department of Health (VDH) enforce regulations relating to ground water protection. However, the Commonwealth's basic approach has been to allow local governments to take the lead in determining the need for and adoption of ground water protection measures. As such, there are no state laws that mandate ground water protection ordinance measures.

Wellhead Protection Efforts: In 1986, Virginia formed the interagency Ground Water Protection Steering Committee (GWPSC) to coordinate and promote ground water protection activities. With the aid of a federal grant the GWPSC drafted Virginia's approach to wellhead protection. This report is summarized in the publication Wellhead Protection: A Handbook for Local Governments in Virginia (VGWPSC 1991). The heart of Virginia's approach is to educate and encourage local governments to delineate WHPAs and implement protection measures such as comprehensive planning, zoning ordinances, septic tank requirements, acquisition of property development rights, and public education programs.

Chesapeake Bay Preservation Act: The Chesapeake Bay Preservation Act was passed in 1988 to create a means for state and local governments to cooperate in protecting water quality in the Chesapeake Bay watershed. The most important provision of the Act is the requirement that local governments designate Chesapeake Bay Preservation Areas. Within these areas, local governments are required to adopt comprehensive plans, zoning ordinances, and subdivision ordinances that include water quality protection measures. The act also created the Chesapeake Bay Local Assistance Department to aid local governments in accomplishing Bay Act goals.

Department of Environmental Quality: The most important ground water protection law enforced by DEQ is the Ground Water Management Act of 1992 (9 VAC 25-610) that specifies the procedure for designation of ground water management areas and the issuance of ground water withdrawal permits. The Eastern Shore of Virginia was designated a Ground Water Management Area in 1992 and any withdrawal of 300,000 gallons per month in this area requires a ground water withdrawal permit from DEQ. Before a permit can be issued, it must be demonstrated that the withdrawal will have no significant unmitigated impact on existing ground water users or the ground water resource. Specifically, it must be demonstrated that:

- The withdrawal will not cause saltwater intrusion into the aquifer.
- No other viable water sources exist.
- The withdrawal utilizes the lowest quality and least amount of water that supports the use.
- Confined aquifers will not be dewatered.
- The area of impact remains on the applicant's property; or adverse impacts beyond the applicant's property will be mitigated.
- The withdrawal will not lower water levels in a confined aquifer below 80% of the distance between the historical pre-pumping levels and the top of the aquifer.
- The applicant will implement a water conservation and management plan.

DEQ also enforces the Ground Water Rules and Standards for Water Wells, a set of standards for well construction, maintenance, and abandonment that ensures that wells will not become conduits of contamination to the subsurface. Virginia's Water Quality Standards (9VAC 25-260) include both enforceable ground water standards and non-enforceable ground water criteria as well as an anti-degradation policy that states that the natural quality of ground water will be maintained even it is below the ground water standards.

Water Supply Plan: In 2003, the Virginia General Assembly amended the Code of Virginia to require the development of a comprehensive statewide water supply planning process that would (1) ensure that adequate and safe drinking water is available to all citizens of the Commonwealth, (2) encourage, promote, and protect all other beneficial uses of the Commonwealth's water resources, (3) encourage, promote and develop incentives for alternative water sources. In addition, the General Assembly required that local or regional water supply plans would be prepared and submitted to the Virginia Department of Environmental Quality (DEQ) in accordance with criteria and guidelines developed by the State Water Control Board. The DEQ subsequently develop Local and Regional Water Supply Planning Regulations (9 VAC 25-780) to implement the mandates of the Code. In addition to administering the requirements of 9 VAC 25-780, DEQ has provided assistance for preparing local and regional water supply plans (WSPs) in the form of grants, workshops, and guidance documents.

Department of Health: VDH is the primary state agency that enforces provisions of the SDWA and related state laws such as the Waterworks Regulations (12 VAC 5-590). Other relevant VDH-enforced laws are the Private Well Regulations (12 VAC 5-630) and the Sewage Handling and Disposal Regulations (12 VAC 5-610). The Private Well Regulations specify minimum construction standards for private wells and minimum distances from potential sources of contamination such as septic systems, pipelines, and petroleum storage tanks. The Sewage Handling and Disposal Regulations specify construction standards, soil percolation rates, and separation distances to the seasonal water table for septic systems.

In response to the 1996 Amendments to the SDWA, VDH has released a draft SWAP document (VDH 1999). Under the proposed SWAP, source water protection areas for public ground water sources (analogous to WHPAs) would be delineated using the fixed radius approach, with two protection zones of 1,000 ft and 1 mile radii. The document also describes Virginia's strategic approach for identifying contamination sources and susceptibility for each water source.

5.1.3 Counties

5.1.3.1 Comprehensive Plan

Accomack County (2008)[1]: The Comprehensive Plan recommends the following comprehensive groundwater protection and supply management strategy in an effort to maintain an adequate supply of high quality water for the future needs of the region:

- Policies:
  - Encourage the wise use of Accomack County's groundwater resources.
  - Manage potentially polluting land uses so as to minimize contamination threats.
  - Seek additional information on the groundwater aquifers, the recharge process, and contamination threats.
- Recommended Actions:
  - Use the latest research to clarify the location of the groundwater recharge spine boundaries and consider creation of a groundwater protection overlay district within those boundaries.
  - Review the potential impact of new development on groundwater in the permit process.
  - Amend the subdivision ordinance to limit the allowable density of remotely located drainfields.
  - Amend the subdivision ordinance to require that the location of remotely located drainfields be recorded on the subdivision plat and that proper easements to those areas be provided.
  - Continue to conduct research on the geology of the aquifers, nature of recharge and contamination threats.
  - Amend the zoning and subdivision ordinances as necessary to adequately protect groundwater supplies and to balance the supply and demand for residential land.
  - Continually monitor available data for all key natural systems, particularly ground and surface water quality, so that warning signs of significant deterioration and risk to the well-being of the county can be identified as early as possible.

Northampton County Comprehensive Plan (2008)[2]: Ensure the protection and management of groundwater quality and quantity available to Northampton County through the following implementation Strategies:

- Support the efforts of the Eastern Shore of Virginia Groundwater Committee, such as continually reassessing the present demand and estimated future demand for groundwater and the establishment of a monitoring program as an early warning system for groundwater contamination.
- Support efforts by the Public Service Authority or Public Works Department to create public central water systems to serve development areas.
- Participate with the state in efforts and programs to prevent excessive water withdrawals for large users at single locations, and to set limits on amounts of groundwater to be withdrawn.
- Continue to implement the Chesapeake Bay Preservation Act on a County-wide basis.
- Study and implement zoning regulations to protect and manage selected recharge areas and other groundwater-sensitive areas.
- Establish regulations to promote a goal of zero runoff, especially in large-scale developments.
- Require central-water systems to be developed with uniform standards of operations and maintenance for all moderate and large-scale developments not served by a public water system.
- Establish restrictions regulating storage, treatment or disposal of waste containing hazardous substances in groundwater-sensitive areas.
- Develop standards for industrial development that will protect groundwater. j. Develop a groundwater-management plan for the County, including the designation of wellhead-protection areas and groundwater-protection overlay zones.
- Evaluate and implement a groundwater-management ordinance within five (5) years.
- Continue to work with the Department of Environmental Quality and other appropriate agencies in identifying and addressing any leaking underground storage tanks.
- Develop a comprehensive stormwater-management plan.
- Remain cognizant that a sole source-aquifer designation was made by the Environmental Protection Agency in 1997.

5.1.3.2 Ordinances

Accomack County has adopted an Ordinance, §106-235, which includes provisions to protect and preserve the water resource. This Ordinance provides for water resource protection for some developments that may use less than the 300,000 gallon per month requirement for a Groundwater Withdrawal Permit. Specifically, the Ordinance applies to “any commercial or industrial development which creates five acres or more impervious surface, or any subdivision which creates 50 or more lots”.

The objectives of the Ordinance includes the provision to “maintain water supply quality and quantity standards at a suitable level necessary to serve adequately and efficiently the public need, health, and welfare; and sustain the integrity of water resources and other sensitive natural resources.” The Ordinance requires preparation of a Resource Quality Protection Plan that includes the following components that directly address the water resources:

- Goals to:
    - Minimize or eliminate the transport of pollutants from development activities to surface and groundwater.

  - Prevent harm to the community by activities which adversely affect surface water, groundwater, and other sensitive natural resources.
  - Maintain or restore groundwater recharge areas and groundwater storage levels.
  - Prevent damage to tidal and non-tidal wetlands which aid in the maintenance of surface water and groundwater quality.
- An evaluation of potential groundwater quality and quantity effects that include the following information:
  - Average and daily proposed withdrawals
  - Number of wells, locations, capacity, and screen interval
  - Water quality analysis (chlorides)
  - An evaluation of potential groundwater quality and quantity effects.
- A provision that groundwater withdrawal will not limit the ability to use the water associated with the development or any existing groundwater use

[1] Accomack County (2008) *Accomack County Comprehensive Plan*, Accomack County Department of Planning.

[2] Northampton County (2008) *Northampton County Comprehensive Plan*, Northampton County Department of Planning.

5.2 EASTERN SHORE RESEARCH NEEDS

The Eastern Shore of Virginia has the benefit of significant past research on water resources. Summaries of this research, last updated **August 2013**, is provided in **Appendix A**. This research has identified a number of future research needs, or data gaps that are critical for our understanding of the sustainability of the water resource, these research needs are:

1. Form, hydraulic function, and distribution of paleochannels that bisect the Yorktown-Eastover confining unit.
2. Vertical and horizontal location, thickness, and movement of the freshwater / saltwater transition zone.
3. Hydraulic characteristics, variation in thickness, and leakance through the confining units
4. Occurrence, yield, and water quality for aquifers underlying the Yorktown-Eastover aquifer. In particular aquifers that are hydraulically connected to the mainland.
5. Occurrence, distribution, and age of existing conventional contaminants.
6. Occurrence and potential future impacts of emerging contaminants.
7. Impact of climate change on the Shore's water resources.

5.2.1 Paleochannels

Three paleochannels have been identified on the Eastern Shore of Virginia (see Section 2.2.1.3). All three cross the shore in an approximate northeast to southwest orientation. These paleochannels are believed to have eroded the fine grained sediments that comprise the upper Yorktown-Eastover confining unit, depositing coarser grained sediments in their place. There is relatively little known on the extent, composition, and hydraulic function of the features. The principal research needs regarding paleochannels are:

The confining unit that separates the water table aquifer (Columbia) from the confined Yorktown-Eastover aquifer is incised by a number of paleochannels. The locations of several of these paleochannels have been identified but a number of important questions remain:

1. What is the hydraulic function of these paleochannels:
    a. Do they "breach" the confining unit, allowing unrestricted vertical movement between the water table and Yorktown-Eastover aquifers?
    b. What is the flux across the paleochannels?
    c. Are they a potential "conduit" to the Yorktown-Eastover aquifer for contaminants in the water table aquifer?
    d. Do they provide a buffer to saltwater intrusion (upconing) from over use of the Yorktown-Eastover
2. How do the above impact groundwater quality, quantity, and use, both near the paleochannel(s) and regionally on the Shore? That is, what impact do the paleochannels have on the water resource management on the Shore?

3. Where are all of the paleochannels that incise the Yorktown-Eastover confining unit (including reconstruction of the morphology of the paleochannels)?

Comment: The hydrogeologic function of paleochannels that incise confining units is an issue that extends to most coastal plain areas (including the Potomac aquifers in the Coastal Plain of Virginia). As increasing use of the confined aquifers apply greater stress on these systems, understanding the function(s) of these features is becoming more important). The paleochannels on the Shore can be a good analogue (and relatively easy to study) for paleochannels in other areas.

5.2.2 Freshwater-Saltwater Transition

Relatively little information is known about the freshwater / saltwater interface for the Yorktown-Eastover aquifer, specifically:

1. Vertical and lateral distribution
2. Thickness / transition from brackish to fresh groundwater
3. Response of the above to stresses (pumping) including:
    a. Effect of constant pumping (common to industrial and public water supply)
    b. Effect of episodic pumping (common to agricultural use)
    c. Is the impact from an episodic withdrawal greater than a constant withdrawal (e.g.; is the impact from pumping an annual total of 109.5 MG over a 3-month period (1.2 MGD average) – with no pumping for the remaining 9 months greater than pumping a constant amount (0.3 MGD average) for 12 months.
4. Relate the above to changes in salinity that would be observed in production wells to assist in managing operation of a well field.
5. Relate the above to optimizing design and operation of a well field to minimize saltwater intrusion to the system.

5.2.3 Aquifer and Confining Unit Hydraulic Characteristics

Information on characteristics of the Columbia and Yorktown-Eastover aquifers have grown considerably over the past 10-years with the VDEQ requirement for aquifer tests as part of Groundwater Withdrawal Permit Program. Much of this information has been applied locally, only at the individual permit sites. It would be beneficial to compile the existing aquifer tests, along with new aquifer tests as they are completed in a comprehensive database. These aquifer tests would then provide one basis for significant re-calibration of the Eastern Shore Model. Revising the Eastern Shore Model based on these aquifer tests will increase the accuracy of the model predictions.

Unlike the aquifer characteristics, comparatively little information is available on the confining units. Because the confining units are a key component controlling recharge to the confined aquifers, hydraulic characteristics and spatial variability of the confining units is a critical component of understanding sustainability of the Yorktown-Eastover aquifers.

5.2.4 Deep Aquifers

While aquifers deeper than the Yorktown-Eastover are largely absent in Northampton County due to the bolide impact crater, the characteristic sequence of aquifers on the mainland are present in the northern portions of Accomack County. Information on the 1) hydraulic characteristics; 2) water quality; and 3) available groundwater for beneficial use is largely unknown.

While the fresh groundwater resources of the combined Columbia and Yorktown-Eastover aquifers are currently being use at a sustainable rate, potential use of these deep aquifers as a future water supply is an important consideration for maintaining a sustainable supply for the Shore.

5.2.5 Existing Contaminants

5.2.5.1 Agricultural Nutrients (Nitrogen):

Historically, fertilizer (nitrogen) was applied at amounts greater than needed by the crops, resulting in some areas where the water table aquifer has elevated levels of nitrogen (predominately nitrate). The fate and transport of nitrogen has already been investigated to some degree on the Shore by the USGS and others, but some additional work can build on what has been done:

1. It would be useful (and interesting) to document the impact of current agricultural practices on the groundwater relative to past practices. This can include looking into issues such as:
    a. Impact of plasticulture practices
    b. Increased irrigation
    c. Cycling between the vadose zone and the groundwater table, perhaps using (pressure-vacuum lysimeters).
    d. Age dating plumes – mass flux between the field, vadose zone, groundwater table, and ultimately receptor (marsh/surface water).
    e. Nutrient cycling – in marshes and other wetland areas to determine whether they acts as a source or sink of nitrogen

5.2.5.2 On-Site Systems

There have been and are numerous on-site waste disposal systems ranging from pit-privies, to conventional septic systems, to advanced systems (such as puraflow systems), to land application systems. There is also a great deal of interest in other technologies, such as rapid infiltration basins (RIBs). Potentially useful studies include:

1. Compare design criteria to actual performance (this is a significant and on-going issue; is the design criteria too stringent or not stringent enough?)
2. Evaluate suitability of long standing (decades old) criteria (such as 50-foot setback distances)
3. Optimal use of resources (land application of waste versus discharge to surface water):
   a. Inter-relationship (and compatibility) of various on-site wastewater systems with groundwater use (co-existence), including considering systems that use the soil for treatment (e.g.; septic fields, land application system) and systems that do not (RIBs);
   b. Effect of land application of wastewater relative to surface water discharge (for the Shore it is of particular importance where maintaining salinity of many of the tidal creeks is important – aquiculture).

5.2.6 Emerging Contaminants

Emerging contaminants (consider potential receptors as both groundwater users and surface water): are emerging contaminants less of an issue where the source is from on-site systems or from point-source discharges to surface waters?

5.2.7 Climate Change

Much of the climate change research has focused on sea level change. Based on preliminary analysis, it is unlikely that sea level change will have a significant impact on the fresh groundwater resources on the Shore. However, climate change is also expected to result in changes in precipitation pattern that may results in more variable conditions (more severe droughts) and or net increases or decreases in precipitation. More frequent or longer droughts have the potential to have significant adverse impacts on the freshwater resource through 1) lower recharge to the aquifer and more significantly 2) increased use, principally for irrigation, to compensate for the lower rainfall.

Both increased research on how precipitation patterns will change as well as developing an adaptive management strategy for groundwater use are important considerations for maintaining long term sustainable groundwater supply. Adaptive management strategies may include, but are not limited to: alternative low irrigation demand crops during drought periods; use of alternative water supplies; improved surface water; storm water; and irrigation management systems; and high water conservation irrigation systems.

5.3 MONITORING

Monitoring is a critical component of any water resource plan in order to: 1) track progress on trends for key metrics and 2) identify unforeseen conditions early enough that a proactive response can be implemented. The basic of any water resource monitoring program are:

- Tracking water use
- Measuring groundwater levels for trends and critical water surface levels
- Measuring water quality and tracking changes that are indicative of:
    - Saltwater intrusion,
    - Conventional pollutants such as nitrogen compounds from land use activities,
    - Existing and/or emerging contaminants that are persistent and/or difficult to treat, and
    - Age dating to estimate changes in recharge rates over time to the aquifers

5.3.1 Water Use

Surface water and groundwater use is tracked by DEQ under the Virginia Water Withdrawal Reporting Regulation (9 VAC 25-200) that requires reporting of water withdrawal greater than 10,000 gpd or 1 million gallons per month for agricultural use. This water withdrawal information is maintained in the Virginia Water Use Data System (VWUDS).

Groundwater use for all permitted withdrawals (groundwater withdrawals greater than or equal to 300,000 gallons per month; or 10,000 gpd on average) is also tracked under the Groundwater Management Regulations (9 VAC 25-610) and maintained in a separate Groundwater Withdrawal Permitting Program Data Management System.

These two water use databases are adequate for tracking critical groundwater use on the Shore. For the purpose of tracking water use and trends, the Groundwater Committee should request a copy of the two databases on an annual basis.

5.3.2 Groundwater Levels

Groundwater level trends are an important empirical measure for determining whether groundwater use is sustainable or unsustainable. Measured groundwater levels are also important when evaluating critical water surface levels, such as the DEQ 80-percent criterion. The USGS and DEQ maintain a series of observation wells on the Shore. The Groundwater Committee has periodically evaluated trends in 19-observation well clusters. Because groundwater level trends are an important indicator for sustainable use and can identify areas where unexpected changes occur, the groundwater level trends should be updated annually.

5.3.3 Water Quality

Historically, DEQ routinely monitored water quality in some of the observation wells that were also used for groundwater level measurements. However, this routine water quality monitoring program ceased in the late 1980's due to lack of funding. The majority of these observation wells are clustered (more than one well at a location, each screened in a different aquifer) and are in locations representative of water for that area. As such, these wells provided valuable information on water quality distribution, between and within the aquifers. It would be beneficial to reinstate water quality monitoring in these wells, or at least in a critical subset of these wells.

In addition to the former routine water quality monitoring from the State Observation Wells, DEQ as a special condition in some of the groundwater withdrawal permits requires quarterly water quality samples. These samples are typically from production wells or monitoring wells in close proximity to the production wells. While this information is valuable, in particular when monitoring for potential saltwater upconing, they are not as useful for measuring more regional groundwater quality as the State Observation Wells. Water quality results from these samples are maintained in the Groundwater Withdrawal Permitting Program Data Management System. Water quality trends for these wells should by tracked be the Groundwater Committee on an annual basis.

5.4 Alternate Source Development

The alternative source development focuses on alternatives to the aquifers that have the most limited fresh groundwater supply; the Yorktown-Eastover aquifers. While the Yorktown-Eastover aquifer currently is not overdrawn, the objective of the alternative source development is to identify viable sources that can be proactively used in a cost effective manner to ensure the Yorktown-Eastover aquifer does not reach a critical condition.

5.4.1 Columbia (Water Table) Aquifer

While the Columbia aquifer is a freshwater aquifer, historically it has been underused compared to the confined Yorktown-Eastover aquifer. Additionally, recharge to the Columbia aquifer is estimated to be over 100-times greater than the Yorktown-Eastover aquifer. As a consequence, water withdrawn from the Columbia is replenished at a far greater rate than the confined Yorktown-Eastover. Because the Columbia is unconfined, recovery from any overdrawn condition would be rapid. This makes the Columbia a prime, economical, alternate source of groundwater under current conditions. However, the per-well yield from Columbia is generally lower than wells screened in the Yorktown-Eastover aquifer, and greater susceptibility for potential contaminants from land use activities may limit use of this aquifer under certain circumstances.

Use of the Columbia aquifer should be encouraged over the Yorktown-Eastover aquifers in areas where the yield and quality meets the beneficial use. A number of groundwater users already use the Columbia aquifer as a source of water, either solely on in conjunction with the Yorktown-Eastover aquifer for potable drinking water, irrigation, and industrial uses.

5.4.2 Brackish water / Saltwater Treatment *(membrane and ultrafiltration)*

Membrane treatment of brackish groundwater began growing rapidly in the late 1980's, with the cost of membrane treatment decreasing approximately 10-fold over a period of 10-years. As the treatment technology continues to improve and cost of material decreases, brackish groundwater treatment is expected to increasingly become a viable alternative source of groundwater on the Shore. Both single residence and municipal systems are already in common use, and are most applicable for treating brackish groundwater from the lower Yorktown-Eastover aquifer or areas where brackish groundwater occurs at shallower depths near the Bay and Seaside. For the foreseeable future, membrane treatment technologies will be most appropriate in local areas, such as near the Bay or Seaside, where fresh groundwater is naturally limited.

5.4.3 Reuse

Reuse of wastewater as an alternate source is already being used on the Shore by some of the Nurseries. Reuse has the dual benefit of reducing demand on the water resource as well as reducing wastewater discharges to surface water or the land. As a consequence, reuse should be encouraged where practical, with nurseries as an example of compatible use. In other areas of the Commonwealth, reuse water has been successfully used for golf course irrigation. For example, the demand for reuse water in New Kent County for the irrigation of golf courses has exceeded the supply during the peak demand in the summer.

5.4.4 Enhanced Recharge and Aquifer Storage and Recovery

Enhanced recharge and aquifer storage and recovery (ASR), although employing very different methods and targeting different aquifers both serve to replenish or increase water storage in the aquifer system. Enhanced recharge includes many Low Impact Development (LID) storm water management methods that include:

- Bioretention basins
- Grass swales and vegetated filter strips
- Infiltration basins and sand filters
- Retention Basins (in particular Retention Basin Type III)
- Enhanced extended detention basins
- Porous pavers

These methods have the positive benefit of increasing recharge to the Columbia aquifer. However there is only minimal benefit to the Yorktown-Eastover aquifer. LID storm water management practices have been used for various developments on the Shore. Continued, and expanded LID use should be encouraged based on the dual recharge benefit to the Columbia aquifer and water quality benefit to surface water.

There are a number of on-site wastewater practices in addition to the storm water management methods that increase recharge to the Columbia aquifer, including land application systems and Rapid Infiltration Basins (RIBs). Land application systems have been used successfully on the Shore. While RIBs have not been used on the Shore, this technology has been used successfully in other areas on the Delmarva Peninsula. Because these methods involve enhanced recharge of wastewater, care must be taken in the design and operation of these systems to prevent contamination of the Columbia aquifer.

Aquifer Storage and Recovery requires injecting groundwater through wells into a confined aquifer, such as the Yorktown-Eastover aquifer. The City of Chesapeake currently (as of 2013) operates the only operating ASR system in the Commonwealth of Virginia. The Chesapeake system treats surface water to drinking water standards before injecting the water into the Potomac aquifer, using the Potomac aquifer as a water storage reservoir. Unlike the City of Chesapeake, fresh surface water is of limited supply on the Shore, and injecting treated wastewater in other areas of the United States is generally used in non-potable aquifers. This limits potential use of ASR on the Shore as a method of increasing freshwater recharge to the Yorktown-Eastover aquifer. One potential application would be injecting water from the Columbia aquifer into the confined Yorktown-Eastover aquifer. Currently, this type of application is not necessary.