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Final Report

Technical Analysis and Justification for Ground Water Ordinances on the Eastern Shore of Virginia

for

Virginia's Eastern Shore

Accomack-Northampton Planning District Commission

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EXECUTIVE SUMMARY

INTRODUCTION

The Eastern Shore of Virginia depends entirely on ground water as a source of drinking water. To protect this critical resource, the counties of Accomack and Northampton have enacted a number of protection measures by means of comprehensive planning, zoning ordinances, and the establishment of resource protection and management areas. Even with existing measures, however, some residential developments have a significant potential to reduce the quality or availability of ground water by overpumpage or contamination from surface sources. This report documents the results of a modeling investigation into the potential effects of residential development on ground water availability and quality on the Eastern Shore of Virginia (hereafter Eastern Shore), and is intended to provide a technical basis for development of local water resource protection ordinances and implementation of effective management practices.

To evaluate potential contamination of the ground water from residential landuse activities, LEWASTE, a model developed by USEPA for delineating wellhead protection areas, was used. Specific types of contaminants modeled were nitrate-nitrogen and herbicide (2,4-D) from developments of varying lot density. Simulated sources of nitrogen included normal fertilizer application to lawns and septic system effluent. The USGS model SHARP was used to simulate the effects of development-related pumping on saltwater intrusion and ground water levels. Both LEWASTE and SHARP were applied to two hydrogeologic settings on the Eastern Shore: a central recharge spine setting and a near-shore setting.

FINDINGS

Results from the landuse modeling indicate that normal rates of fertilizer application to more than ten percent of the pervious area of a development can cause nitrate-nitrogen concentrations to exceed the drinking water standard of 10 mg/L in shallow ground water, regardless of the size and number of lots. Septic systems were predicted to cause exceedance of the nitrate drinking water standard in ground water beneath developments that are comprised of 0.5-acre (or smaller) lots unless subsurface conditions favored denitrification. However, normal rates of pesticide application were not predicted to cause exceedances of Virginia ground water standards.

Developments greater than 50 lots, or adjacent to other developments having an aggregated size greater than 50 lots, have a significant potential to adversely impact the ground water resource either through saltwater intrusion or loss of well yield from lowered ground water levels. For developments with small lot sizes (¼ acre) and a large number of lots (greater than 250), the potable water demand can result in significant saltwater intrusion and lower ground water levels, both for inland and coastal areas. For lot sizes one acre and larger, irrigation demand during the summer can result in both saltwater intrusion and excessively lowered ground water levels. The impacts for coastal areas are much greater than impacts for inland areas, such that most of the scenarios evaluated for a coastal area predict impacts from overpumping.

RECOMMENDATIONS

In order to protect the shallow aquifer system from high loading rates of nitrogen, it is recommended that homeowners apply the *minimum* fertilizer application rate for the soil and grass type on their lot. A centralized wastewater collection and treatment system (WCTS) should be constructed for any new developments with a minimum of 50 lots and an average lot size of 0.25 acre or less. Protective measures should also be implemented on new developments of 50 or more lots with an average lot size between 0.25 and 0.5 acres if soils are predominantly sand and if the seasonal water table is less than 10 feet deep.

Protection of the ground water resource from overpumping can be accomplished through alternate well design, conservation measures, or an appropriately designed central water supply. New developments which exceed 50 lots, or new developments located adjacent to existing ground water users which exceed an aggregated 50 lot demand should either institute conservation measures or employ alternate well designs. Effective conservation measures include use of low flow plumbing fixtures, irrigation only in the evenings and metered irrigation, and the use of landscaping that requires minimal water use. The alternate well design resulting in the greatest reduction in impacts is a two-well system. With the two-well system, potable water would be pumped from a confined (preferably upper Yorktown aquifer) well and non-potable water from the water table aquifer. This would require separate plumbing to prevent cross connects between the two systems.

A centralized water system can also provide significant benefit for the larger residential areas (greater than 50 lot developments) by buffering the peak water demand. A centralized potable water system withdrawing from a confined aquifer with non-potable irrigation water supplied by individual residential wells pumping from the water table aquifer provides the greatest protection from saltwater intrusion and loss of yield due to over pumping.

For developments greater than 50 lots located in or near the spine recharge area, screening the potable water wells in the upper or middle Yorktown aquifer will reduce the potential for saltwater intrusion. Lot sizes of one acre or greater should pump non-potable irrigation water from the water table aquifer or implement conservation measures to reduce irrigation demand. Very large developments (greater than 250 lots) should consider <u>both</u> pumping non-potable water from the water table aquifer and implementing conservation measures to prevent adverse impacts. Many of the impacts can be reduced with a properly designed central supply system, where peak demands are buffered by the system.

Impacts to the ground water resource are more severe in the coastal area, and the recommendations extend to smaller developments with smaller lot sizes. All developments that are 50 lots or greater should obtain their potable water supply from the upper Yorktown aquifer. All developments greater than 50 lots should also obtain their non-potable (irrigation) water from the water table aquifer. Residential developments that are greater than 250 lots should implement conservation measures to reduce demand or develop a centralized water supply system to prevent adverse impacts to the ground water resource.

1.0 INTRODUCTION

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. Local ground water protection ordinances are one way to ensure protection and wise management of this supply for both existing uses and future growth in Accomack and Northampton Counties. This report documents the results of a modeling investigation into the potential effects of residential development on ground water availability and quality. The modeling results are intended to assist local governments in developing water resource protection ordinances for the Eastern Shore.

1.1 BACKGROUND

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 (Figure 1-1). Depression of the hydraulic head occurs around every pumping well, but if pumping rates are too high or if wells are to 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).

The ground water table is generally found within 20 feet of the surface near the central spine of the Eastern Shore, and is less than 6 feet from the surface near most coastal areas. The material comprising the water table aquifer is typically sandy, and infiltration of water into this aquifer is relatively rapid. Because the water table aquifer is productive, it is used by a significant number of private residences as a source of drinking water. However, its shallow depth and lack of overlying confining unit make this aquifer highly vulnerable to contamination from a variety of sources. Major potential sources of ground water contamination on the Eastern Shore include fertilizer, pesticides, and septic system effluent (Figure 1-2).

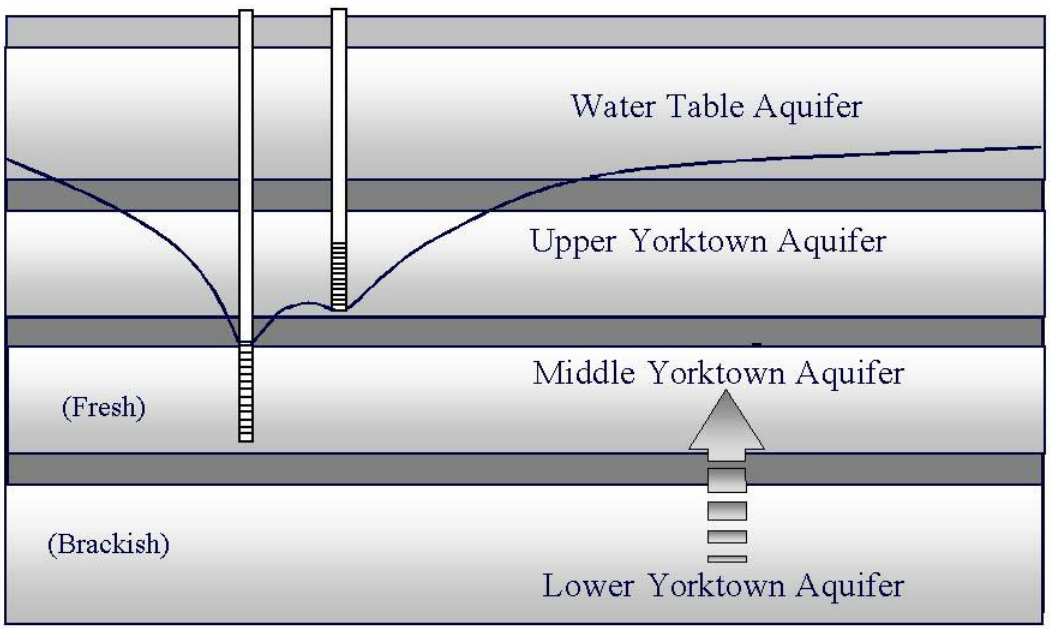

Figure 1-1: Schematic of saltwater intrusion and drawdown in response to pumping.

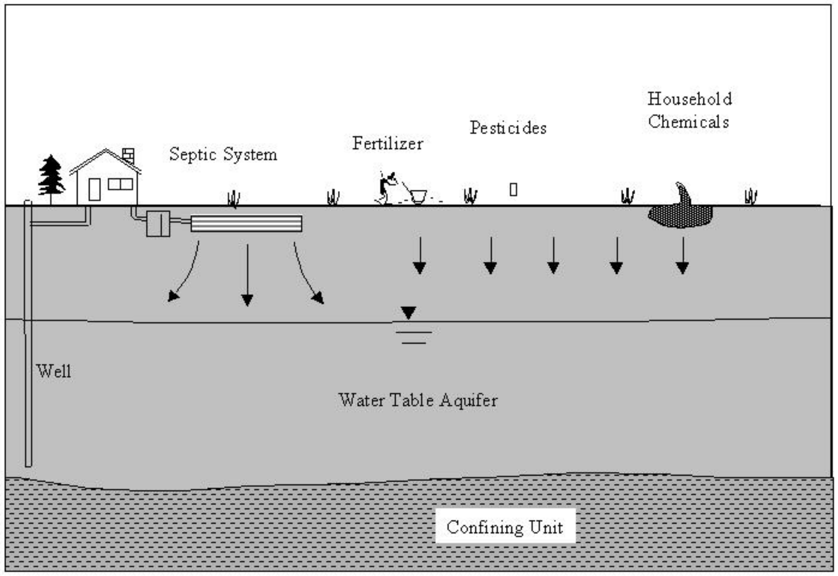

Figure 1-2: Common ground water contaminant sources in residential developments.

Individual ground water users that pump more than 10,000 gallons per day (gpd) are regulated by the Virginia Department of Environmental Quality. However, a large number of smaller demands (such as residential developments served by individual private wells) can also have adverse effects on ground water levels and quality. Many localities in Virginia have enacted ground water protection ordinances to ensure that development does not result in overpumpage or ground water contamination. Such ordinances typically specify minimum lot size, lot number, maximum impermeable areas, and minimum standards for the construction and operation of wells and septic systems. The purpose of this report is to provide technical information that can be used by Accomack and Northampton Counties to design effective ground water protection plans or ordinances relating to residential or commercial development.

Section 1.0 of this report describes the hydrogeologic setting of the Eastern Shore and provides a review of ground water protection laws at the federal, state, and local level. Section 2.0 describes the modeling approach that was used to simulate the potential impacts of various development scenarios on a mid-peninsula site and a near-shore site on the Eastern Shore. Section 3.0 describes the results of the modeling scenarios, including the sensitivity of ground water quality and level to variables that might be regulated by ordinance. Finally, section 4.0 provides a summary of the findings and recommendations relating to the need and form of ground water protection ordinances and plans on the Eastern Shore.

1.2 HYDROGEOLOGY OF THE EASTERN SHORE

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 principal regional studies on the hydrogeology of the Eastern Shore and adjacent portions of Maryland are Fennema and Newton (1982), Richardson, D. (1992), Hulme (1955), and Cushing et al (1973). Other sources providing information presented in this section are Bachman and Wilson (1984), Hansen (1969), Weigle (1974), and Werkheiser (1990).

Most of the developable area of the Eastern Shore is underlain by moderately well-drained to excessively well-drained sandy and loamy soils. However, poorly-drained soils are also common along the central spine of the peninsula and in the western portion of Accomack County. The most prevalent soil association is the Bojac-Munden-Molena association, which underlies almost half the total land area of the Eastern Shore and has a permeability of 2-6 inches/hour in most locations. Septic system suitability of this soil type is considered moderate and limited more by drainage than by water table height considerations (HWH 1992). Much of the central part of Northampton County and the western portion of Accomack County are underlain by the Nimmo-Munden-Dragston association, which has a permeability of 1.2-2 inches/hour in most locations. This soil association is not well suited for septic systems due to poor drainage and seasonal high water table conditions.

The uppermost aquifers on the Eastern Shore consist of sediments from the Columbia Group and Chesapeake Group (Figure 1-3). All of the Chesapeake Group sediments and the lower members of the Columbia Group sediments were deposited under marine near shore to shelf conditions. As such, they can be generally characterized as a thickening wedge of sediments dipping seaward, to the east. These sediments range in thickness from approximately 200 feet in the western areas to 500 feet to the east. Slopes at the formational contacts increase with depth, from approximately 2 to 6 feet per mile at the base of the Chesapeake Group to 10 to 11 feet per mile at the base of the Columbia Group.

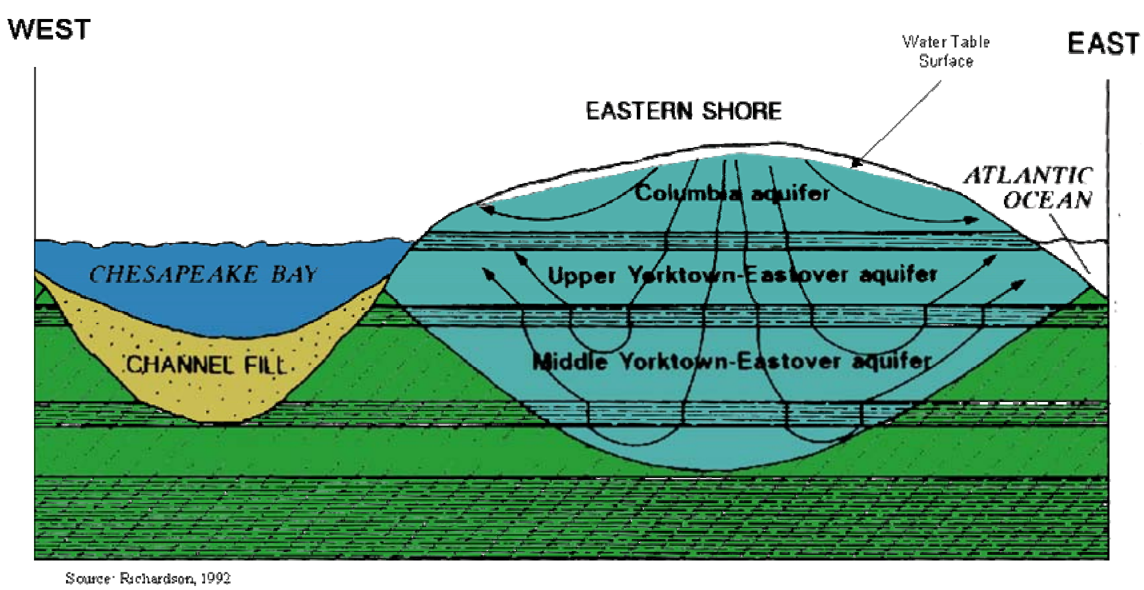

Figure 1-3: Hydrogeologic cross-section of the Eastern Shore.

The uppermost unit is generally designated the Columbia aquifer, and represents the water table aquifer in most areas of the Eastern Shore. The Columbia aquifer overlies the Yorktown aquifer, which has been subdivided into three hydrologic units (upper, middle, and lower). The upper and middle Yorktown aquifers are fresh throughout most of the Eastern Shore, while the lower Yorktown aquifer is typically brackish near the coast and fresh inland. Underlying the Yorktown aquifer is the Choptank aquifer, which is also comprised of sediments belonging the Chesapeake Group. Ground water in the Choptank aquifer is brackish to saline in this area. Because the Choptank and other deeper brackish ground water aquifers cannot provide acceptable water quality, they will not be described in greater detail.

The Columbia and Yorktown aquifers each consist of a sequence of sandy units separated by fine-grained facies, which are predominately fine sandy silts and clayey fine sands. The confining units separating the aquifers are leaky, and there is significant ground water flow through these layers. Flow through the confining units is the dominant source of recharge for the Yorktown aquifer on the Eastern Shore of Virginia. Within the individual aquifers there commonly are discontinuous silty and clayey layers which locally serve to restrict vertical flow.

1.2.1 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. 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 greatest thickness for the Columbia aquifer occurs near Salisbury, Maryland. On the Eastern Shore of Virginia, thickness generally ranges from 20 feet near the coast to 60 feet inland.

Transmissivities reported for the Columbia aquifer range from 100 to 50,000 ft^2/day. In Maryland, transmissivities are between 2,000 and 10,000 ft^2/day with a median of approximately 3,500 ft^2/day. The highest transmissivities for the Columbia aquifer are found near Salisbury, Maryland, where values has as high as 50,000 ft^2/day have been reported. 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.

Ground water levels in the Columbia aquifer on the Eastern Shore and adjacent portion of Maryland mimic surface topography. The highest elevations on the Eastern Shore are along the ridge deposits, with maximum elevations of +30 to +45 feet MSL in the central portion of the peninsula decreasing toward the coastline to approximately +10 feet MSL near the tidal marshes. Overall, it appears that depth to ground water is between

10 and 20 feet below ground surface for the upland areas and 5 to 10 feet below ground surface beneath the terrace deposits. Ground water from the Columbia aquifer is not used for any single large withdrawals on the Eastern Shore, therefore there are not any mappable cones of depression in this aquifer.

1.2.2 Upper Yorktown Confining Unit

The upper Yorktown confining unit consists of marine fine sandy silt with some clay and averages 15 to 30 feet thick. Maximum thickness of this confining unit exceeds 100 feet beneath Assateague Island and Chincoteague Island. These sediments are, for the most part, reworked sediments from the upper Yorktown Formation and may locally include 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. It is not uncommon for sandy channel deposits to incise through the confining unit into the underlying upper Yorktown aquifer. Channels penetrating through the confining unit into the Yorktown sediments are located near Salisbury and Pocomoke City (Maryland) and Exmore and Eastville (Virginia). While this unit is areally extensive, and only locally absent, it merely serves to restrict, not preclude, vertical movement of ground water. As evidence of this, the principal source of freshwater recharge and discharge for the Yorktown aquifers on the Eastern Shore is through the confining units.

The top of the upper Yorktown confining unit on the Eastern Shore is approximately -20 feet MSL along the western margin (Chesapeake Bay) to -60 feet MSL along the eastern margin (ocean side). Dip of this unit is 2 to 3 feet per mile and strike is northeast, parallel with the orientation of the peninsula. The Columbia aquifer on the Eastern Shore subcrops into the Chesapeake Bay to the west and the Atlantic Ocean to the east. Where it subcrops, freshwater flows directly from the aquifer into the ocean and estuarine water.

1.2.3 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. Sediments deposited in channels incised into the Yorktown Formation have also been identified as the upper Yorktown aquifer, even though it is not clear whether there is a good hydraulic connection between the channel fill sediments and the Yorktown Formation sediments. These channel fill deposits have been identified on the Virginia portion of the Eastern Shore near Exmore and Eastville. In Maryland, the upper Yorktown aquifer is generally referred to as the Pocomoke aquifer. 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.

Surficial recharge to the upper Yorktown aquifer occurs along a northeast striking belt approximately 1.5 to 4 miles wide. This recharge area is present near Chrisfield, Maryland and extends to the northeast, just east of Salisbury, Maryland. Recharge for the Eastern Shore of Virginia occurs through the overlying confining unit.

The top of the Yorktown aquifer on the Eastern Shore is approximately -75 feet MSL along the western edge to -125 feet MSL to the east. Dip of the upper Yorktown is approximately 3 feet per mile and strike is northeast, parallel to the peninsula. In Maryland, the top of the aquifer in the recharge area is near sea level, increasing to a depth of approximately -150 feet MSL to the east. The upper Yorktown aquifer is typically thinner to the west, where more of the sediments were eroded, and thickens to the east. In Maryland, the upper Yorktown aquifer (Pocomoke aquifer) pinches out in the recharge area and increases in thickness to the southeast, toward Snow Hill. On the Eastern Shore, the thickness of the upper Yorktown aquifer ranges from 15 feet, in southwest Northampton County, to greater than 100 feet near Assateague Island and is typically between 30 and 60 feet thick.

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 and has been reported as high as 8,000 ft^2/day near Pocomoke City, Maryland. The high transmissivity near Pocomoke City was reported for a well field lying southeast of the city. A much lower transmissivity (1,200 ft^2/day) was reported for a well field lying northwest of the city. This location is near the surficial recharge area for the upper Yorktown aquifer, and the confining layer separating the upper Yorktown aquifer from the Columbia aquifer may have been eroded by a stream channel at or near the well field, and is, thus, receiving recharge directly from the overlying Columbia aquifer or from the adjacent Pocomoke River.

Ground water levels on the Eastern Shore follow the same general pattern as the overlying Columbia aquifer because recharge to this aquifer is from the Columbia aquifer. Because the confining unit separating the two aquifers is consistently present over most of the area, there is significant head loss between the two aquifers. A maximum ground water level of +25 feet MSL occurs in south central Accomack County, decreasing radially from this point. In Northampton County, ground water level is between +5 and +15 feet MSL and in central Accomack County, ground water level is +15 to +20 feet MSL, decreasing to +8 to +12 feet MSL near the state boundary with Maryland. Along the eastern and western coastline, ground water level decreases to approximately +5 feet MSL. A short distance offshore, vertical ground water flow direction is expected to reverse, with fresh ground water flowing from the upper Yorktown aquifer into the overlying Columbia aquifer. There are several prominent cones of depression resulting from ground water withdrawals centered around Crisfield and Pocomoke City (Maryland), and Temperanceville (Tyson Food), Accomack (Perdue), Exmore, and Cape Charles (Virginia).

1.2.4 Middle Yorktown Confining Unit

The middle Yorktown confining unit is not as prominent as the upper Yorktown confining unit in this region, and has been described as allowing substantial leakage between the upper and middle Yorktown aquifers. In some areas this confining unit is absent, and over most of the area, 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 feet, and tends to be thinner to the west and south.

1.2.5 Middle Yorktown Aquifer

The middle Yorktown aquifer is an areally extensive hydrogeologic unit of the Yorktown-Eastover aquifer system. The middle Yorktown aquifer, over most of its extent on 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 peninsula, 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 and 60 feet, although locally it can be absent or up to 100 feet thick. The top of the aquifer on the Eastern Shore is between -125 feet and 150 feet MSL along the western coast increasing to -225 to -250 feet MSL to the west. Dip of the Middle Yorktown is approximately 6 feet per mile, or roughly twice the dip of the overlying upper Yorktown aquifer beds. As with the other units, strike is northeast, parallel with the peninsula. Transmissivities for the middle Yorktown aquifer on the Eastern Shore range between 1,000 and 3,000 ft^2/day where the aquifer is present.

Ground water levels for the middle Yorktown aquifer on the Eastern Shore are only slightly lower in the central portion than level for the upper Yorktown aquifer, with a maximum ground water elevation between +20 and +25 feet MLS near Accomac. At the coast and a short distance offshore, the ground water level in the middle Yorktown aquifer is expected to be slightly higher than the level for the upper Yorktown aquifer, with the vertical ground water flow reversed to an upward direction.

1.2.6 Lower Yorktown Confining Unit

The lower Yorktown confining unit has been described on the Eastern Shore of Virginia but has not been identified to the north in Maryland and is assumed to pinch out completely between Chincoteague and Snow Hill. The confining unit is thickest in central and northern Accomack County, thinning to the south and pinching out to the north in Maryland. On the Eastern Shore of Virginia, sediments comprising the 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.

1.2.7 Lower Yorktown Aquifer

The lower Yorktown aquifer on the Eastern Shore typically consists of a fining-upward sequence of gray fine sand to silty fine sand with shell fragments. In Maryland, the basal portion is generally coarser, consisting of coarse to medium sand with some gravel. On 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 aquifer ranges between -175 and -225 feet MSL along the western coast and -300 to -350 feet MSL along the eastern coast. 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.

The transmissivity of this aquifer on 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 have been only a few pumping tests conducted in the lower Yorktown aquifer 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 the lower Yorktown aquifer's transmissivity.

1.3 GROUND WATER PROTECTION REGULATIONS AND PROGRAMS

Numerous federal, state, and local laws and programs with ground water protection components exist. Many are designed to protect ground water from chemical, waste, or petroleum hydrocarbon releases; e.g., the federal Resource Conservation and Recovery Act (RCRA) and Virginia's Undergound Storage Tank Program. This section provides a brief description of the major regulatory and non-regulatory programs aimed at protecting potable ground water supplies from over-pumpage and over-development, rather than from unintentional releases of hazardous substances.

1.3.1 Federal

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.

1.3.2 Commonwealth of Virginia

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.

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.

1.3.3 Eastern Shore of Virginia Ground Water Committee

Accomack and Northampton Counties formed a Ground Water Committee in 1990 to oversee the development of the *Ground Water Supply Protection and Management Plan for the Eastern Shore of Virginia* (HWH, Inc. 1992). The plan identified five major pumping centers that needed protection and delineated three protection zones. Zone 1 consists of a 200-foot radius around each wellhead and was delineated to protect wells in the case of poorly constructed or faulty wellheads. Zone 2 encompasses the central recharge spine of the Eastern Shore peninsula, a strip about 5,000 feet wide. Zone 2 was delineated to protect the major source of recharge water to the confined aquifers. Zone 3 includes virtually the entire Eastern Shore, and was delineated to emphasize the importance of protecting the entire ground water resource. Ground water protection measures recommended in the plan include:

- Creation of an overlay zoning district in the spine recharge area.
- Restriction on the siting of mass drainfields in the spine recharge area.
- Revision of county and subdivision zoning ordinances to incorporate ground water protection measures.
- Development of a private well ordinance to control the siting and construction of new wells.

The Ground Water Committee is currently implementing the ground water protection program and, as part of this implementation, is supporting the quantitative evaluation of various protection measures such as ordinances.

1.3.4 Northampton County

Northampton County revised their comprehensive plan in 1993 to support the findings of the Ground water Plan. Northampton County has designated the entire county as a Chesapeake Bay Preservation Area, forming the Chesapeake/Atlantic Preservation (CAP) District. The intent of the CAP as it relates to the ground water resource includes protecting existing high quality state waters, restoring all other state waters to a condition or quality that will permit all reasonable public uses, safeguarding the clean waters of the Commonwealth from pollution, preventing any increase in pollution, reducing existing pollution, and promoting water resource conservation. With the exception of some parts of incorporated towns, the CAP Overlay District applies to all of Northampton County, and the ground water protection provisions under the CAP are extended to both coastal and inland (spine recharge) areas.

There are two areas defined under the CAP: Resource Protection Areas (RPAs) and Resource Management Areas (RMAs). The RPAs include coastal areas such as tidal wetlands, non-tidal wetlands connected by surface flow to and contiguous with tidal wetlands or tributary streams, and shorelines or tidal shores. RMAs include floodplains, highly erodible soils, highly permeable soils, non-tidal wetlands not included in the RPA, and other lands that protect the quality of state waters. Northampton County's zoning ordinances have been revised to include the following ground water protection measures:

- Construction footprints will not exceed 60% of a site;
- Land development will minimize impervious cover;
- All septic systems must be pumped out at least once every five years; and
- A reserve septic system with a capacity at least equal to that of the primary system must be provided on all newly developed parcels.

There are also several common performance standards required over the entire CAP, including both RPAs and RMAs. Some of these performance standards are intended to achieve specific goals such as preventing a net increase in non-point source pollution from new development, achieving a 10-percent reduction in non-point source pollution from redevelopment, and achieving a 40-percent reduction in non-point source pollution from agricultural uses. If these goals are met for the county, there will be significant protection of the water table aquifer, which is most affected by the non-point source pollutants. Goals of the CAP performance standards also provide for increasing recharge of the ground water by minimizing impervious cover, thereby reducing storm water runoff. Maintaining recharge to the water table aquifer is the only way to insure ground water remains a renewable resource.

Northampton County has drafted (but not approved) an ordinance aimed at providing additional protection for groundwater resources. There are few direct measures that act to preserve the ground water supply in the proposed ordinance. The most significant measures include encouraging connections to central water and sewerage systems, limiting the amount and locations where industries can withdraw ground water, and restricting the amount of water used for irrigation in sensitive areas. The proposed ordinance requires that, when central water and/or sewerage systems with adequate capacity either exist or are proposed within a reasonable distance of the development, provisions will be made to connect to the system. Industrial uses are restricted to using less than 50,000 gallons/day (less than 300,000 gallons/month) in all Districts. A special use permit may be issued for industrial withdrawals exceeding these amounts only in Community Development Districts types “CG” and “M1”. Irrigation wells using more than 300,000 gallons/month are not allowed in Conservation Districts. In all other districts (except for agricultural districts), such irrigation well require special use permits. There are also significant restrictions on lot sizes within various Zoning Districts, such as Rural Villages and Conservation Districts. These restrictions prevent high density residential developments over much of the county.

The Northampton County zoning ordinance does not address a number of ground water protection issues. Primary among these are construction standards and performance standards for potable water and irrigation wells. Such performance standards, for instance, would require use of the water table aquifer for irrigation and the usage of the confined Yorktown aquifers for potable water supplies, unless a special exception is granted. Performance standards might also include other water quality parameters (the Health Department requires testing only for coliform bacteria), such as nitrates from agricultural activities and chlorides from saltwater intrusion. Addition of some of these requirements to the appropriate Primary or Secondary Zoning Districts (such as Community Development Districts) would provide significant measures to preserve the existing ground water resource.

1.3.5 Accomack County

In compliance with the Chesapeake Bay Preservation Act, Accomack County delineated the western portion of the county as a Resource Management Area in 1992. The protection measures provided in the Accomack County ordinance are generally the same for Northampton County, except they do not apply to the eastern (seaside) portion of the county nor does it apply to much of the spine recharge area. The limited area covered by the Chesapeake Bay Preservation Act reduces the impact of the ground water protection in Accomack County.

In November 1998, Accomack County passed an ordinance that requires the development of a Resource Quality Protection Plan (RQPP) for any commercial or industrial development that creates 5 acres or more of impervious surface, or any new proposed subdivision with 50 or more lots. If such a subdivision is expected to use 10,000 gallons (or more) of ground water per day, the RQPP must contain a ground water use analysis that addresses:

- An analysis of daily and average demands;
- Well screen depths;
- Analysis of ground water chloride levels;
- Number, location, and capacity of wells;
- An evaluation of potential ground water quality and quantity effects, including a map showing the area in which 1 foot or more drawdown will occur; and

- Any supplemental information required by the county administrator, such as additional water quality analyses or saltwater intrusion modeling.

Moreover, the ordinance states that "Ground water withdrawal shall cause no reduction in ground water levels or changes in ground water quality that limit the ability of ground water use…" This ordinance provides the most protection of ground water resources from potential threats imposed by non-permitted users on the Eastern Shore. However, the ordinance does not address specific protection measures or provide general guidance on acceptable development plans.

2.0 METHODS

The basic approach taken for this investigation was to design ground water flow and contaminant transport models for two locations on the Eastern Shore—one on the recharge spine and the other near the shore—to simulate the effects of various development scenarios on the availability and quality of ground water. The scenario results were then used to develop specific recommendations for protecting ground water from potential risks associated with new residential or commercial development. Two different numerical models were utilized—FEMWATER/LEWASTE to simulate the transport of contaminants from surface sources and SHARP was used to examine the potential for saltwater intrusion and excessive drawdown.

2.1 FEMWATER/LEWASTE

LEWASTE is a finite-element model that USEPA developed for delineating wellhead protection areas. The model simulates transient or steady-state three-dimensional transport of contaminants through unsaturated and saturated media, including adsorption and first-order decay. The hydrologic fluxes simulated by FEMWATER can be used as input to LEWASTE, which can consider multiple aquifers and confining units, spatially variable hydraulic properties, pumping wells, distributed sources/sinks, and various types of boundary conditions. LEWASTE is documented by Yeh and others (1992).

2.1.1 Model Grid

In order to simulate the effects of development on ground water on the Eastern Shore, a two-dimensional LEWASTE model grid was developed that was two elements long, one element wide, and ten elements deep, for a total of twenty elements (Figure 2-1). All elements were rectangular and had horizontal dimensions of about 740 feet (225 m) and a vertical dimension of about 14 feet (4.3 m). Therefore, each element had a top surface area of about 12.5 acres (50,625 m^2) and the entire grid had a thickness of about 140 feet (43 m). The uppermost five elements in each column represented the Columbia aquifer, giving this unit a modeled thickness of about 70 feet. The bottommost four elements in each column represented the upper Yorktown aquifer, with a modeled thickness of about 53 feet. The single element between these units represented the upper Yorktown confining unit with a thickness of about 14 feet. Hydrogeologic properties assigned to these units were selected to represent average conditions on the Eastern Shore. Based on a vertical hydraulic gradient of 0.001, a vertical hydraulic conductivity of 8 m/day, and a porosity of 30%, the vertical ground water flow velocity was calculated as 2.7 m/day.

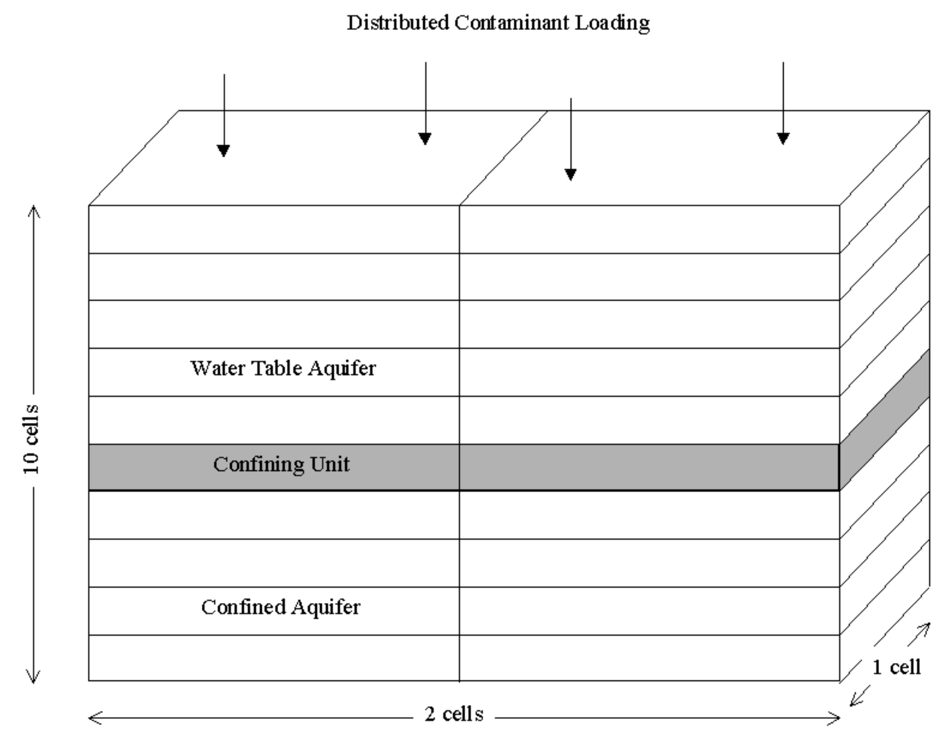

Figure 2-1: Schematic of LEWASTE grid.

For the recharge spine setting, the simulated water tables lay about 20 feet (8.5 m) beneath the land surface. Soil properties were selected to represent a moderately well-drained sandy loam. The horizontal ground water velocities were selected to represent a low hydraulic gradient (0.001) and a porosity of about 30%. Identical ground water flow velocities were simulated for the near-shore setting, but in this scenario the water table was modeled as six feet beneath the land surface and soil properties were selected to represent a sandy soil.

2.1.2 Contaminant Transport

LEWASTE was used to simulate the infiltration and subsurface transport of *nitrogen* and a *herbicide* from developed areas. The two modeled sources of nitrogen were septic systems and fertilizer application. Moderately conservative assumptions regarding contaminant loading rates were made so that the scenarios would accurately represent developed conditions (Table 2-1). Where possible, assumptions were made consistent with those used in the *Ground Water Supply Protection and Management Plan for the Eastern Shore of Virginia* (HRH, Inc. 1992) for nitrogen under buildout conditions.

The herbicide 2,4-dichlorophenoxyacetic acid (abbreviated 2,4-D) was selected as the herbicide to model because it is the most commonly-used chemical herbicide for controlling broadleaf weeds on grass, is relatively water soluble (when applied as a dimethylamine salt, as is common), is relatively mobile in the subsurface, and has a Virginia water quality standard (0.1 mg/L). The soil adsorption and degradation rates used in the model for 2,4-D (Table 2-1) were selected from the lower range presented in the literature as tabulated by Balogh and Walker (1992). The modeled application rate was the maximum application rate specified by the major commercial formulation (Trimec®). It was further assumed that 20-percent of the herbicide applied was lost due to volatilization and aerosol drift. The remaining 80-percent would be available for downward leaching.

Contaminant loading to the ground water system was modeled by simulating the uppermost elements of the model grid as distributed source elements. The moisture flux from these source elements was calculated as the natural recharge (9 in/year on pervious surface, 2 in/year on impervious) plus septic system fluxes (about 165 gal/day per household). Average contaminant concentrations of the moisture entering the ground water system were calculated by dividing the estimated contaminant load by the moisture flux. The north and south vertical horizontal boundaries were defined as no-flow boundaries because the dominant regional ground water flow directions on the Eastern

TABLE 2-1

FACTORS USED TO COMPUTE GROUNDWATER DEMANDS, RECHARGE, AND CHEMICAL LOADINGS

Factor	Units	Value
Potable water demand per lot	gal/day	170
Pavement area per lot	ft^2	500
Roof area per lot	ft^2	1500
Percentage of lot that is lawn	%	50
Road area per acre development	ft^2	1000
Irrigation rate for lawns	in/year	13
Percentage of lot that is irrigated	%	50
Percentage of homeowners that irrigate	%	50
Recharge rate for pervious area	in/year	9
Recharge rate for impervious area	in/year	2
Septic system factors		
Septic system effluent--flow per lot	gal/day	165
Septic system effluent--nitrogen concentration	mg/L	40
Percentage of septic system effluent recharged to Columbia aquifer	%	100
Fertilizer factors		
Fertilizer nitrogen loading rate per unit area lawn	lbs/year/acre	150
Percentage of fertilizer nitrogen available for leaching	%	80
Percentage of homeowners that fertilize	%	50
Herbicide factors		
Percentage of irrigation water recharged to Columbia aquifer	%	20
2,4-D application rate to lawns	lbs/acre/year	2
Percentage of homeowners that apply 2,4-D	%	50
Percentage 2,4-D lost to volatilization/drift	%	20
2,4-D degradation rate	day^{-1}	0.05
2,4-D soil adsorption coefficient	--	20

Shore are east-west rather than north-south. Similarly, the bottom boundary was defined as a no-flow boundary.

2.2 SHARP MODEL

The SHARP model (Essaid 1990) is a quasi-three-dimensional, finite-difference model that simulates freshwater and saltwater flow separated by a sharp interface in layered coastal aquifer-confining unit systems. SHARP can consider multiple aquifers and confining units, spatially variable hydraulic properties, pumping wells, distributed sources/sinks, and various types of boundary conditions. The USGS developed a ground water model of the Eastern Shore of Virginia using the SHARP model to simulate flow and predict the position of the saltwater/freshwater interface for the Yorktown aquifers (Richardson 1991).

Malcolm Pirnie used the USGS model as the basis for the SHARP model used on this project, although several significant modifications to the original model were made. The following sections describe the setup and calibration of the Eastern Shore SHARP model, followed by a description of local modifications used to examine the effects of development on the recharge spine and near-shore settings.

2.2.1 USGS Eastern Shore SHARP Model

The USGS Eastern Shore model area, developed by Richardson (1991), included all of the Eastern Shore peninsula and portions of the surrounding Chesapeake Bay and Atlantic Ocean. The northern limit of the model area extended only a very short distance north of the Virginia-Maryland State line. The model grid used to represent aerial distribution of aquifer characteristics and ground water elevations consisted of 106 rows and 59 columns, ranging in area from a minimum of 0.24 mi^2 to a maximum of 10.82 mi^2.

The USGS Eastern Shore model simulated flow in the Yorktown aquifer system (upper, middle, and lower Yorktown aquifers). The overlying Columbia aquifer (water table aquifer) is represented as a constant head boundary and the underlying St. Mary's confining unit as a no-flow boundary. The confining units separating the Yorktown aquifers were represented by leakance values, allowing vertical flow between the aquifers.

The western and southern boundaries for the Eastern Shore peninsula is the Chesapeake Bay and the eastern boundary is the Atlantic Ocean. The edges of these boundaries were represented as no-flow boundaries in the model. Near shore saltwater-flow characteristics were handled by extending the offshore boundaries well away from the coastline. The northern boundary of the model was an artificial boundary located immediately north of the Virginia-Maryland State line and was simulated as both a no-flow boundary and a constant head boundary in the model simulations.

Pre-pumping heads were estimated in the model based on surface topography and previous ground water level estimates by Bal (1977). Ground water elevations prior to 1940 were assumed to represent pre-pumping conditions. The first ground water withdrawal in the model began in 1940 and continued through 1988. Changes in the ground water withdrawal rates were simulated as 12 pumping periods over this time. The Eastern Shore model was calibrated to 1988 ground water levels and verified against 12 ground water observation wells with historical water level information.

The saltwater-freshwater interface was represented in the model as a sharp interface. There are no offshore data for the Eastern Shore; therefore, the actual position of the saltwater-freshwater interface and the width of the transition zone are unknown. Initial position of the saltwater interface was simulated by the model based on the Ghyben-Herzberg approximation (incorporated in the SHARP model).

Leakage between the saltwater and the freshwater zone was restricted by the model. Saltwater was not allowed to leak into the freshwater zone. The leakage of freshwater was distributed between the saltwater and the freshwater zones based on the amounts of each type of water in the node receiving the leakage. The approach was designed to reproduce the general response of the interface and did not provide information concerning the nature of the transition zone between saltwater and freshwater.

Vertical leakage of saltwater into freshwater was not directly simulated; evidence of vertical saltwater intrusion from overlying saline surface-water bodies was provided by examination of the water level gradients and areas of reversed ground-water flow.

The model was not able to simulate upconing of saltwater through a confining unit as a result of pumpage. Because of the density gradient between fresh and brackish ground water and the restricted flow through the confining unit, upconing through a confining unit would generally occur only when there was a very large gradient between the two aquifers or the confining unit was effectively absent. Within an aquifer, upconing was represented by a change in the interface position for mixed cell areas.

2.2.2 Modified Eastern Shore SHARP Model

In recreating the USGS Eastern Shore SHARP model, Malcolm Pirnie made two principal changes. First, the northern boundary of the original model extended only a short distance beyond the Virginia-Maryland border. The northern model boundary was extended to include the Maryland counties of Somerset, Wicomico, and Worcester, and this boundary was set as a no-flow boundary. Secondly, the uppermost aquifer (Columbia aquifer) was defined in the USGS model as a constant head boundary. This was changed to an unconfined aquifer to predict drawdown in the Columbia aquifer as a result of regional ground water withdrawals in the Yorktown aquifer.

Because the upper model layer was defined as the water table aquifer, two additional conditions were incorporated into the model. Recharge, representing the amount of precipitation reaching the saturated zone minus loss through evapotranspiration, was added as a constant rate. The initial value for recharge was 12 inches/year and the final recharge value after calibration was 9 inches/year. The second addition was a leaky head-dependent boundary to simulate recharge/discharge of ground water to surface water. This head-dependent boundary was defined only for model cells with major rivers or creeks. The head for these cells was set equal to pre-pumping ground water levels presented in Richardson (1991) and ground water levels presented in Cushing et al (1973). Leakance through this boundary was set to a constant $1x10^{-3}$ day^{-1}. The leakance represented streambed leakance. Because no streambed leakance values were available for this area, a constant vertical hydraulic conductivity of $1x10^{-6}$ cm/sec and a uniform streambed thickness of 3 feet was assumed.

For the modified SHARP model, the pre-pumping interface was assumed to be roughly equal to the interface predicted by the USGS Eastern Shore model. The initial interface position was calculated based on the Ghyben-Herzberg solution. Some minor modifications to the model during calibration were necessary to provide an interface position closely matching the USGS Eastern Shore model.

<u>*Setup and Calibration*</u>: Model setup involved assigning initial aquifer characteristics, boundary conditions, and ground water elevations to the model. Information on the aquifer distribution used in developing the model was obtained principally from published data for the USGS Eastern Shore model (Richardson 1991) and the USGS Water Resources of the Delmarva Peninsula (Cushing et al 1973). The top of the aquifers and confining layers, ground water elevations, and aquifer and confining layer thicknesses were obtained from these sources.

To "discretize" the information presented on the maps for the model, a grid 3 mi^2 (1.75 mile on a side) was overlain on the Eastern Shore model maps and Delmarva Peninsula maps and representative values were assigned to each grid location. The discretized data was then smoothed using an inverse distance algorithm, and individual values assigned to each model cell location using the nearest neighbor approach. Hydraulic conductivity values were initially set at the values presented in the USGS model and adjusted to closely match measured transmissivities. Leakance was initially set as an assumed vertical hydraulic conductivity of 1×10^{-6} cm/sec for the upper Yorktown confining unit and 5×10^{-5} cm/sec for the middle and lower Yorktown confining units divided by the calculated thickness of the confining unit.

The calibration step included optimizing the matrix solution parameters (SIP parameters), adjusting aquifer characteristics to match pre-pumping and existing ground water elevations, and the initial saltwater interface position (based on the USGS Eastern Shore model). A total of 146 model runs were used to calibrate the model. The initial model runs were used to select the most efficient SIP parameters. The following SIP and related parameters were used in the final model:

- Number of Iteration Parameters (NITP) = 10
- Convergence Closure Criteria (ERR) = 1×10^{-3}
- Steady State Criteria (STST) = 1×10^{-3}
- Relaxation Factor (RFAC) = 0.4

- Weighting Factor (WFAC) = 0.5
- Factor Used in Calculating Iteration Parameters (WITER) = 10000

Once the iteration parameters were set, the next step in calibration was to reproduce pre-pumping ground water elevations predicted by the USGS Eastern Shore model and current ground water elevations as measured at 77 ground water observation wells. Ground water elevations were first matched against pre-pumping levels. To obtain pre-pumping levels, the model was run with the initial parameters until steady state conditions were achieved (as defined by the steady state criteria). To accelerate convergence to steady state, pre-pumping storage was set to zero. Concurrent with the pre-pumping ground water elevation calibration, position and distribution of the saltwater interface was checked against the USGS predicted positions and adjustments were made to correct for major discrepancies.

Parameter Estimation: Local transmissivities were calculated for each model grid block using a method similar to the procedure Richardson (1991) used in calibrating the USGS Eastern Shore model and were not varied during calibration. The vertical leakance for each confining unit was calculated based on well logs describing the physical characteristics of the section. Leakance values were set constant across each confining unit. Initial values were set at $1x10^{-6}$ cm/sec for the upper Yorktown confining unit and $5x10^{-5}$ cm/sec for the middle and lower Yorktown confining units. During calibration runs these values were adjusted by as much as five times the initial value in order to obtain adequate matching between predicted and observed water levels. The storage coefficient for each model grid location was set at a constant value: 0.05 for the Columbia aquifer, and 1×10^{-4} for the confined aquifers. Porosity of all aquifers was set at 0.25, which is the value used in the USGS Eastern Shore Model.

2.2.3 Recharge Spine Setting

The SHARP model described above was developed for the entire Eastern Shore of Virginia. In order to examine the more localized effects of development, it was necessary to modify the grid to provide greater resolution in localized areas. For the recharge spine setting, the model cell size was reduced from the minimum USGS cell size of 0.24 mi^2 to

30 acres in the vicinity of a hypothetical development in central Accomack County (Figure 2-2).

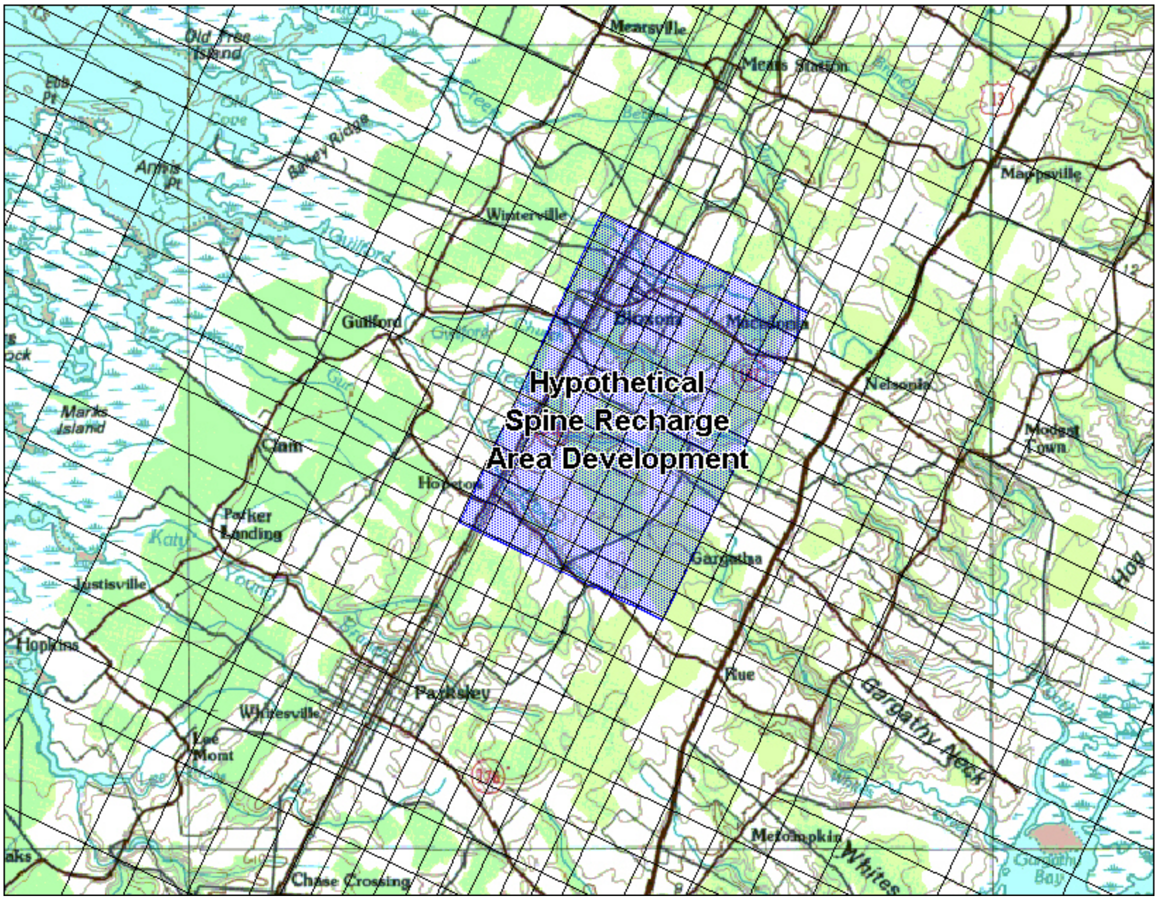

Figure 2-2 Spine Recharge Model Area

The cell size increased to a maximum of 12.25 mi^2 with distance from the developed area. To accommodate the smaller cell size and increased area to the north, 81 rows and 61 columns were used to cover the entire model area.

2.2.4 Near-Shore Setting

As for the recharge spine setting, the grid spacing of the Eastern Shore SHARP model was modified to provide adequate resolution of a hypothetical development on the Chesapeake Bay side of Accomack County (Figure 2-3).

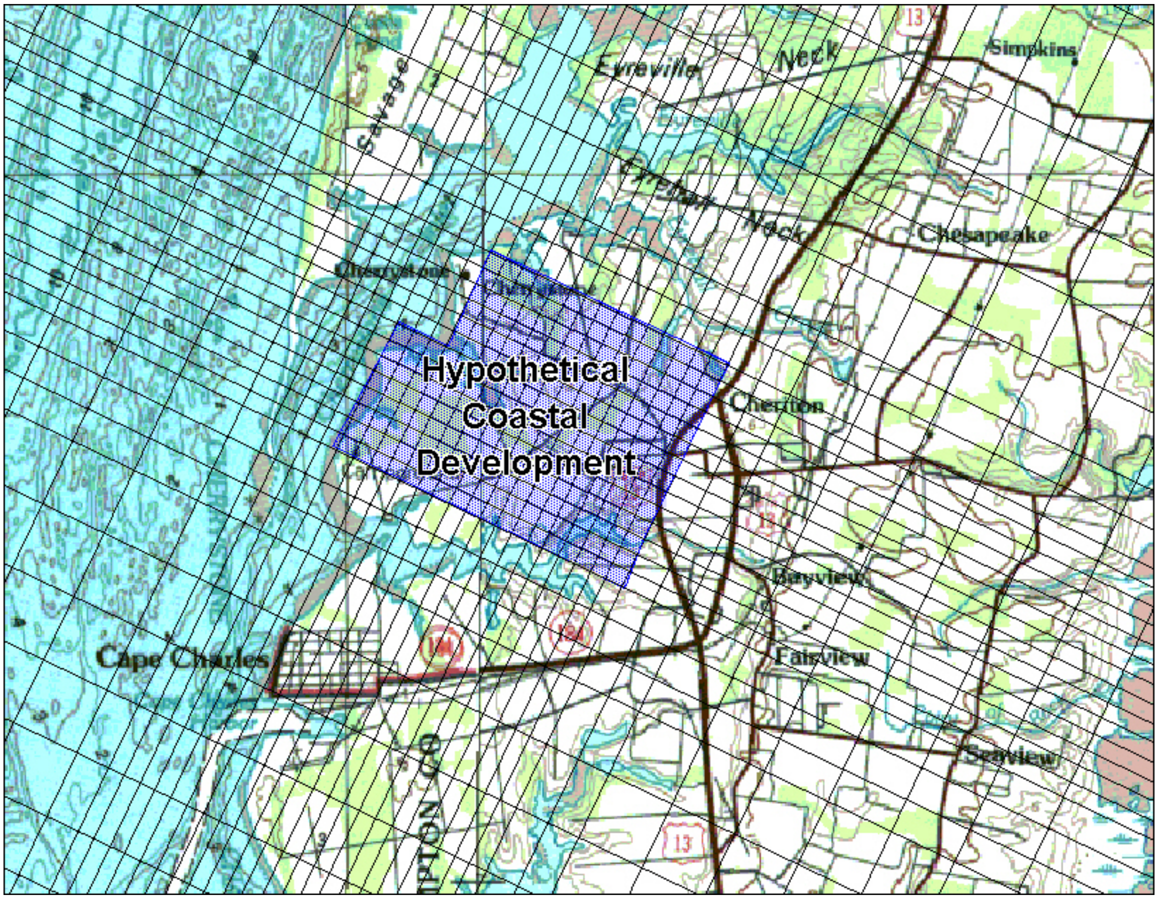

Figure 2-3 Coastal Development Model Area

The model cell size was reduced to 7.6 acres in the area of simulated development and increased to a maximum cell size of 12.25 mi^2 with distance from the well field. To accommodate the smaller cell size and increased area to the north, 76 rows and 75 columns were used to cover the model area.

2.3 MODEL SCENARIOS

Virginia's zoning law was amended in 1988 to allow localities to adopt zoning ordinances that "include reasonable provisions…to protect surface water and ground water." In the publication *Wellhead Protection: A Handbook for Local Governments in Virginia* (VGPSC, 1991), the Virginia Ground water Protection Steering Committee endorses the following regulatory methods for protecting ground water:

- Prohibition of certain uses
- Reduced densities
- Limits on impervious surface
- Special requirements for septic systems
- Strict control of hazardous and toxic materials storage and management
- Special stormwater and waste disposal restrictions

For the purposes of this modeling investigation, the most important of these potential ordinance restrictions are reduced densities and limits on impervious surface. High lot density (and associated high impervious area) has the potential to impact ground water in several ways. Ground water pumping rates, septic system loads, fertilizer application rates, and pesticide application rates increase with lot density, whereas ground water recharge rates decrease. Lot density is a function of the individual lot size and the total number of lots on a developed parcel. On the Eastern Shore of Virginia, the vertical placement of well screens may be as important as the aerial density in protection of the aquifers. For example, wells that are screened too deep might cause upconing of saltwater. Similarly, overpumpage of the confined aquifers might cause saltwater intrusion or unacceptable amounts of drawdown.

2.3.1 Contaminant Transport

LEWASTE model scenarios were developed to examine the effects of lot density on ground water quality. Modeled lot densities were 4, 2, 1, 0.5, and 0.33 lots/acre, corresponding to individual lot sizes of 0.25, 0.5, 1, 2, and 3 acres. Scenarios were run to predict the ground water nitrogen concentrations from septic systems alone, fertilizer application alone, and both septic systems and fertilizer application. The model result of interest was the maximum concentration of nitrogen/herbicide in the Columbia aquifer, which occurred directly beneath and immediately downgradient of the development.

2.3.2 Saltwater Intrusion and Drawdown

SHARP model scenarios were developed to examine the effect of lot number, lot size, and ground water development pattern on the position of the saltwater interface and the potentiometric surface (Table 2-2). The model was used to simulate development sizes of 50, 250, and 500 lots and lot sizes of 0.25, 1, and 3 acres. For a particular lot number and size, three ground water development scenarios were simulated: (1) all wells pumping from the upper Yorktown-Eastover aquifer; (2) all wells pumping from the deepest fresh water aquifer; and (3) potable water wells pumping from the deepest fresh water aquifer and irrigation wells pumping from the water table (Columbia) aquifer. For the spine scenarios, the deepest fresh water aquifer was the lower Yorktown-Eastover aquifer. For the coastal area, the middle Yorktown-Eastover was assumed to be the deepest fresh water aquifer. The potable water demand was assumed to be 170 gpd per household, and the irrigation demand was estimated by assuming a 13 in/year irrigation rate for 50% of the lawn area (Table 2-1). It was further assumed that 20-percent of this irrigation water would recharge the Columbia aquifer.

TABLE 2-2

SHARP MODEL SCENARIOS

Model Scenario[1]	Lot Size (acres)	Number of Lots	Screened Aquifer:[2] Primary Wells	Screened Aquifer: Separate Wells for Non-Potable Uses
1	NA	0	NA	NA
2	0.25	50	Upper Yorktown	NA
3	0.25	50	Lowest Confined	NA
4	0.25	50	Lowest Confined	Columbia
5	0.25	250	Upper Yorktown	NA
6	0.25	250	Lowest Confined	NA
7	0.25	250	Lowest Confined	Columbia
8	0.25	500	Upper Yorktown	NA
9	0.25	500	Lowest Confined	NA
10	0.25	500	Lowest Confined	Columbia
11	1	50	Upper Yorktown	NA
12	1	50	Lowest Confined	NA
13	1	50	Lowest Confined	Columbia
14	1	250	Upper Yorktown	NA
15	1	250	Lowest Confined	NA
16	1	250	Lowest Confined	Columbia
17	1	500	Upper Yorktown	NA
18	1	500	Lowest Confined	NA
19	1	500	Lowest Confined	Columbia
20	3	50	Upper Yorktown	NA
21	3	50	Lowest Confined	NA
22	3	50	Lowest Confined	Columbia
23	3	250	Upper Yorktown	NA
24	3	250	Lowest Confined	NA
25	3	250	Lowest Confined	Columbia
26	3	500	Upper Yorktown	NA
27	3	500	Lowest Confined	NA
28	3	500	Lowest Confined	Columbia

[1]Model scenarios for the recharge spine and near shore settings are deisgnated with the letters RS and NS, respectively; e.g scenarios 8-RS and 8-NS.

[2]The lowest confined aquifers for the recharge spine and near shore scenarios are the lower Yorktown and middle Yorktown aquifers, respectively.

3.0 RESULTS

This section presents the results of the LEWASTE and SHARP modeling scenarios described in section 2.0.

3.1 CONTAMINANT TRANSPORT

The combined effects of fertilizer application and septic systems were predicted to result in ground water nitrate-nitrogen concentrations that ranged from about 18 mg/L beneath developments comprised of 3-acre lots, to over 30 mg/L beneath developments comprised of 0.25-acre lots (Table 3-1). Due to the conservative nature of the model (e.g., no denitrification), these values represent the high end of the range of anticipated ground water concentrations. However, LEWASTE results clearly demonstrate the potential for nitrate-nitrogen concentrations to exceed the MCL of 10 mg/L in shallow ground water beneath developments.

TABLE 3-1: LEWASTE PREDICTIONS OF MAXIMUM NITRATE CONCENTRATIONS IN SHALLOW GROUND WATER

Lot Size (acres)	**Lot Density** (#/acre)	**Septic Flow** (m^3/day/acre)	**Percent Pervious** (%)	**Recharge** (m^3/day/acre)	**Maximum Nitrate Concentration In Ground water** (mg/L as N)
Fertilizer Only					
0.25	4	0.0	75	2.04	18.3
0.5	2	0.0	84	2.22	16.8
1	1	0.0	89	2.31	16.2
2	0.5	0.0	91	2.35	15.9
3	0.33	0.0	92	2.37	15.8
Septic System Effluent Only					
0.25	4	2.5	75	2.04	22.0
0.5	2	1.2	84	2.22	14.4
1	1	0.6	89	2.31	8.5
2	0.5	0.3	91	2.35	4.7
3	0.33	0.2	92	2.37	3.2
Fertilizer Application and Septic System Effluent					
0.25	4	2.5	75	2.04	30.3
0.5	2	1.2	84	2.22	25.2
1	1	0.6	89	2.31	21.3
2	0.5	0.3	91	2.35	18.7
3	0.33	0.2	92	2.37	17.7

3.1.1 Nitrogen from Fertilizer

Fertilizer application alone was predicted to result in ground water nitrate-nitrogen concentrations of over 15 mg/L even for the low-density (3-acre lot) development, and almost 20 mg/L for the highest density (0.25-acre lot) development. Lot density had relatively little effect on the predicted value of nitrate-nitrogen concentrations because the modeled fertilizer application rate of 150 lbs of nitrogen per acre of fertilized lawn was the same for large and small lots. Some benefit of larger lot size was provided by the larger pervious area relative to the smaller lot developments, which caused more ground water recharge and therefore more dilution of the fertilizer-derived nitrogen.

Other key assumptions that contributed to the high nitrate predictions were that 50-percent of homeowners fertilize their lawns and that 50-percent of each lot area was lawn. Under these assumptions, 25-percent of the developed area was assumed to receive fertilizer. When this proportion is reduced to 10-percent, LEWASTE does not predict that fertilizer alone would cause exceedance of the 10 mg/L MCL for any lot density. This result demonstrates that the potential of fertilizer to cause ground water to exceed the nitrate MCL will be highly dependent on the actual proportion of fertilized lawn area.

3.1.2 Nitrogen from Septic Systems

Lot density is predicted to have a larger relative effect on septic-derived nitrate concentrations than fertilizer-derived nitrate concentrations, because the nitrogen load from septic systems is a direct function of the number of lots. Septic systems alone were predicted to result in ground water nitrate-nitrogen concentrations less than the MCL of 10 mg/L beneath lots that are comprised of 1-acre or more (Table 3-1). However, nitrate-nitrogen concentrations were predicted to exceed 10 mg/L beneath developments comprised of 0.25 and 0.5-acre lots, with a maximum concentration of about 22 and 14 mg/L, respectably.

In many soils, denitrification is an important process in reducing nitrate concentrations in septic system effluent. The rate of denitrification depends upon many factors such as the concentration of nitrate, redox potential of the soil, the presence of denitrifying bacteria, and the availability of dissolved carbon. Rates of subsurface denitrification are generally highest in fine-grained, organic rich soils and sediments. Greater depths to the water table allow more time for denitrification to occur in the unsaturated zone. Denitrification in the fine-grained sediments of confining units is the major reason that elevated nitrate concentrations in the Columbia aquifer are not observed to impact nitrate concentrations in the underlying confined aquifers on the Eastern Shore.

If conditions are unfavorable for denitrification, septic-derived nitrate can reach the water table aquifer with little attenuation, and nitrate-nitrogen concentrations of over 20 mg/L have been observed in ground water impacted by septic systems (Shaw 1992). For the purposes of this modeling exercise, the conservative assumption was made that subsurface conditions were unfavorable for denitrification. If conditions were favorable, however, septic systems would be expected to have a greater impact in the near-shore setting than the recharge spine setting. This is because the recharge spine scenario includes a deeper water table and a loamy sand soil that would have a higher organic content than the sandy soil of the near-shore setting.

3.1.3 Herbicide Application

None of the LEWASTE scenarios predicted that 2,4-D concentrations in shallow ground water would exceed the Virginia standard of 0.1 mg/L, regardless of lot density (Table 3-2). In fact, the maximum predicted concentrations of 2,4-D in ground water were less than 1×10^{-6} mg/L for all near-shore scenarios, and less than 1×10^{-8} mg/L for all recharge spine scenarios. Although the average 2,4-D concentration of infiltration was estimated to be about 0.2 mg/L (twice the Virginia standard), the herbicide was rapidly degraded in the unsaturated zone. Concentrations of 2,4-D in ground water were lower for the recharge spine setting because of the greater water table depth and the higher organic content of the sandy loam soil, which encouraged adsorption.

Homeowners apply many pesticides other than 2,4-D, some of which are more persistent in the subsurface. However, the reported degradation rates of 2,4-D are on the same order of magnitude as many common pesticides (Balogh and Walker, 1992), and the mass loading rate of a turfgrass herbicide such as 2,4-D is likely to be higher than that of many other homeowner-used pesticides. The LEWASTE results suggest that pesticide contamination of ground water beneath residential developments will not be a major problem if the chemicals are applied at or below rates suggested by the manufacturer.

TABLE 3-2: LEWASTE PREDICTIONS OF MAXIMUM 2,4-D CONCENTRATIONS IN SHALLOW GROUND WATER

Lot Size (acres)	Lot Density (#/acre)	Recharge Spine Setting (mg/L)	Near-Shore Setting (mg/L)
0.25	4	1×10^{-9}	4×10^{-7}
0.5	2	9×10^{-10}	4×10^{-7}
1	1	9×10^{-10}	4×10^{-7}
2	0.5	9×10^{-10}	3×10^{-7}
3	0.33	9×10^{-10}	3×10^{-7}

3.2 GROUND WATER USE

Impacts to the ground water resource from withdrawals associated with residential development were evaluated using the USGS SHARP model. The types of impacts considered were excessive drawdown from over pumping resulting in a loss of well yield and saltwater intrusion resulting in a degradation of ground water quality. A total of 28 different scenarios were considered for both the spine area and coastal area evaluations. These scenarios varied residential lot size from a minimum of 0.25 to 3-acres and the number of lots varied from 50 to 500. Three different withdrawal scenarios were considered:

1. Pumping from the uppermost confined aquifer (upper Yorktown)
2. Pumping from the lowermost confined fresh aquifer (lower Yorktown in the spine area and middle Yorktown in the coastal area)
3. Potable withdrawals only from the lower most confined fresh aquifer with non-potable withdrawals (e.g., irrigation water) from the water table aquifer.

For each scenario, time trend plots were produced for model cells located near the center of and along the periphery of the pumping. Each trend plot recorded the change in ground water elevation and change in the position of the freshwater – saltwater interface. An impact was deemed significant if ground water levels were drawn down to the base of the water table aquifer or if saltwater intrusion occurred in any aquifer as a result of the withdrawal.

3.2.1 Withdrawals in the Spine Recharge Area

The area selected for simulating impacts from a development in a spine recharge area is between two major existing ground water users, Tyson Foods and Perdue Farms, in Accomack County. Results for the spine recharge area scenarios are summarized on Table 3-3. In the table, the notation "I" indicates that an impact from saltwater intrusion or excessive drawdown occurred and the notation "N" represents no significant impacts. Potential impacts to ground water quality from saltwater intrusion occurred for scenarios with lot densities exceeding 50 lots. For the 50-lot scenario, no impacts from excessive drawdown or from saltwater intrusion were predicted regardless of lot size (e.g.; 0.25 acre, 1 acre, or 3 acres).

For the next lot size simulated, 250 lots, significant saltwater intrusion was predicted to occur when ground water was withdrawn only from the lower Yorktown aquifer. The saltwater intrusion was restricted to the lower Yorktown aquifer, where the withdrawals occurred, and did not extend to the overlying aquifer. Drawdown in this scenario also was significant, exceeding 50 feet over a portion of the area. While 50 feet of drawdown does not extend the ground water level below the top of a confined aquifer, it is sufficient to prevent pumping from shallow, single pipe ejector jet pumps and would reduce the yield for deep, dual pipe ejector pumps. No significant impact was predicted for ground water withdrawals from the upper Yorktown aquifer or from potable withdrawals from the lower Yorktown aquifer and non-potable withdrawals from the Columbia aquifer for 0.25-acre lots. When the lot size was increased above 0.25 acres, saltwater intrusion was predicted to occur in the lower Yorktown aquifer if all ground water demand was supplied by the upper Yorktown aquifer (potable water plus irrigation water). This impact was the result of decreased recharge to the middle and lower Yorktown aquifer from the overlying upper Yorktown aquifer. Because the 1 and 3-acre lots are larger, and the same per-acre irrigation demand is used, there was significantly

TABLE 3-3

SHARP MODEL
SPINE RECHARGE AREA DEVELOPMENT SCENARIOS

Model Scenario[1]	Lot Size (acres)	Number of Lots	Screened Aquifer:[2] Primary Wells	Screened Aquifer: Separate Wells for Non-Potable Uses	Model Results
1	NA	0	NA	NA	
2	0.25	50	Upper Yorktown	NA	N[3]
3	0.25	50	Lowest Confined	NA	N
4	0.25	50	Lowest Confined	Columbia	N
5	0.25	250	Upper Yorktown	NA	N
6	0.25	250	Lowest Confined	NA	**I**[4]
7	0.25	250	Lowest Confined	Columbia	N
8	0.25	500	Upper Yorktown	NA	**I**
9	0.25	500	Lowest Confined	NA	**I**
10	0.25	500	Lowest Confined	Columbia	N
11	1	50	Upper Yorktown	NA	N
12	1	50	Lowest Confined	NA	N
13	1	50	Lowest Confined	Columbia	N
14	1	250	Upper Yorktown	NA	**I**
15	1	250	Lowest Confined	NA	**I**
16	1	250	Lowest Confined	Columbia	N
17	1	500	Upper Yorktown	NA	**I**
18	1	500	Lowest Confined	NA	**I**
19	1	500	Lowest Confined	Columbia	N
20	3	50	Upper Yorktown	NA	N
21	3	50	Lowest Confined	NA	N
22	3	50	Lowest Confined	Columbia	N
23	3	250	Upper Yorktown	NA	**I**
24	3	250	Lowest Confined	NA	**I**
25	3	250	Lowest Confined	Columbia	N
26	3	500	Upper Yorktown	NA	**I**
27	3	500	Lowest Confined	NA	**I**
28	3	500	Lowest Confined	Columbia	**I**

[1]Model scenarios for the recharge spine and near shore settings are deisgnated with the letters RS and NS, respectively; e.g scenarios 8-RS and 8-NS.

[2]The lowest confined aquifers for the recharge spine and near shore scenarios are the lower Yorktown and middle Yorktown aquifers, respectively.

[3]N = No model predected impact

[4]I= Model predicted saltwater intrusion would occur or saltwater intrusion and excessive drawdown

less recharge reaching the lower Yorktown aquifer than with the 0.25-acre scenario. When irrigation water was withdrawn from the water table aquifer, no significant impacts were predicted.

When the number of lots increased to 500, the predicted impacts also increased. For lot sizes of 0.25 to 1-acre, pumping non-potable water from the water table aquifer was necessary to prevent saltwater intrusion or excessive drawdown in the confined aquifers. Saltwater intrusion was predicted to occur if all ground water demand (potable and non-potable) was supplied by a confined aquifer. Simulated drawdown in the aquifer pumped also exceeded 60 feet, which would be sufficient to prevent pumping from shallow, single pipe ejector jet pumps and would reduce the yield for deep, dual pipe ejector pumps. As the lot size was increased to 3 acres, saltwater intrusion impacts were predicted for all withdrawal scenarios, including irrigation water withdrawn from the water table aquifer. The more widespread impacts for the 3-acre lot scenario was due principally to the greater total volume of water used for irrigation purposes and the larger area from which the withdrawals occurred.

3.2.2 Withdrawals in Coastal Areas

The area selected to simulate impacts from withdrawals in coastal areas is south of the Town of Cape Charles, where significant coastal growth is already expected to occur. The impacts from long term pumping were already taken into account in the model, and the predicted increase in impacts is due solely to the additional hypothetical development south of the town. Results for the coastal area scenarios are summarized in Table 3-4. In this table, the notation "I" indicates that an impact from saltwater intrusion or excessive drawdown occurred and the notation "N" represents no significant impacts.

The predicted impacts in the coastal area were greater than predicted impacts in the spine recharge area, even though the deepest ground water withdrawal occurred in the middle Yorktown aquifer, instead of the lower Yorktown aquifer. In all cases, if an impact was predicted to occur in the spine area, an impact was also predicted for the corresponding scenario in the coastal area.

For 50 lots, impacts from saltwater intrusion in the lower Yorktown aquifer occurred when all ground water demand was supplied from the middle Yorktown aquifer.

TABLE 3-4

SHARP MODEL
COASTAL AREA DEVELOPMENT SCENARIOS

Model Scenario[1]	Lot Size (acres)	Number of Lots	Screened Aquifer:[2] Primary Wells	Screened Aquifer: Separate Wells for Non-Potable Uses	Model Results
1	NA	0	NA	NA	
2	0.25	50	Upper Yorktown	NA	N[3]
3	0.25	50	Lowest Confined	NA	**I**[4]
4	0.25	50	Lowest Confined	Columbia	N
5	0.25	250	Upper Yorktown	NA	**I**
6	0.25	250	Lowest Confined	NA	**I**
7	0.25	250	Lowest Confined	Columbia	N
8	0.25	500	Upper Yorktown	NA	**I**
9	0.25	500	Lowest Confined	NA	**I**
10	0.25	500	Lowest Confined	Columbia	I
11	1	50	Upper Yorktown	NA	N
12	1	50	Lowest Confined	NA	**I**
13	1	50	Lowest Confined	Columbia	N
14	1	250	Upper Yorktown	NA	**I**
15	1	250	Lowest Confined	NA	**I**
16	1	250	Lowest Confined	Columbia	N
17	1	500	Upper Yorktown	NA	**I**
18	1	500	Lowest Confined	NA	**I**
19	1	500	Lowest Confined	Columbia	**I**
20	3	50	Upper Yorktown	NA	**I**
21	3	50	Lowest Confined	NA	**I**
22	3	50	Lowest Confined	Columbia	N
23	3	250	Upper Yorktown	NA	**I**
24	3	250	Lowest Confined	NA	**I**
25	3	250	Lowest Confined	Columbia	**I**
26	3	500	Upper Yorktown	NA	**I**
27	3	500	Lowest Confined	NA	**I**
28	3	500	Lowest Confined	Columbia	**I**

[1]Model scenarios for the recharge spine and near shore settings are deisgnated with the letters RS and NS, respectively; e.g scenarios 8-RS and 8-NS.

[2]The lowest confined aquifers for the recharge spine and near shore scenarios are the lower Yorktown and middle Yorktown aquifers, respectively.

[3]N = No model predected impact

[4]I= Model predicted saltwater intrusion would occur or saltwater intrusion and excessive drawdown

No significant impacts were predicted for a 50-lot development if the water was supplied from the upper Yorktown aquifer or if non-potable demand was provided by the water table aquifer. No significant drawdown effects were predicted for a 50-lot development.

As the number of lots increased to 250, the predicted impacts increased. Regardless of lot size, saltwater intrusion was predicted to occur if all ground water was supplied from a confined (Yorktown) aquifer. The impacts for 1-acre or smaller lots were acceptable only when the non-potable demand was withdrawn from the water table aquifer. For 3-acre lots, a 250-lot development was predicted to impact ground water quality regardless of the aquifer from which the ground water was withdrawn.

Predicted impacts from the largest development evaluated, 500 lots, were significant, both in regard to saltwater intrusion and drawdown. All 500-lot scenarios predicted saltwater intrusion in the lower Yorktown aquifer. For 0.25 acre lots, where all ground water was withdrawn from the middle Yorktown aquifer, saltwater intrusion in the middle Yorktown aquifer was also predicted. The other scenarios where saltwater intrusion was predicted to occur into the middle Yorktown aquifer were 1 and 3-acre lots when all ground water was pumped from a confined (Yorktown) aquifer. Only the scenarios where non-potable water was pumped from the water table were the saltwater impacts restricted to the lower Yorktown aquifer. In addition to the high potential for saltwater intrusion, simulated drawdown exceeded 100 feet for all lot sizes when the total demand was provided by a confined aquifer. Where the lot size was 1-acre or more, drawdown was predicted to exceed 140 feet in some areas of the development. These drawdowns are sufficient to prevent pumping from shallow, single pipe ejector jet pumps as well as many deep, dual pipe ejector pumps, making submersible pumps the only feasible pump alternative.

4.0 CONCLUSIONS AND RECOMMENDATIONS

The modeling applications described in this report were designed to evaluate the effects of residential development on the aquifer system of the Eastern Shore in a conservative but realistic fashion. Although the actual effects would depend on site-specific hydrologic conditions, the LEWASTE and SHARP model scenario results provide a useful indication of whether certain development/ground water use patterns would impact ground water in the recharge spine or near-shore settings. Major conclusions of the modeling exercise are as follows:

1. Normal rates of fertilizer application to more than 10-percent of the pervious area of a development can cause nitrate-nitrogen concentrations to exceed the MCL of 10 mg/L in shallow ground water.

2. If soil conditions do not favor denitrification, septic systems can cause exceedance of the nitrate MCL in ground water beneath developments that are comprised of 0.5-acre (or smaller) lots.

3. Normal rates of pesticide application are not expected to cause exceedances of Virginia ground water standards.

4. In general, developments of 50 lots or less do not have a significant impact on drawdown or saltwater intrusion. Saltwater intrusion or excessive drawdown is much more likely to occur in developments of greater than 50 lots.

5. Pumping non-potable (e.g. irrigation) water from a confined aquifer greatly increases the chance for saltwater intrusion to occur, especially for lot sizes exceeding ¼ acre. This is due to a combination of increased irrigation demand for larger lots and a larger area affected by the withdrawal.

6. Pumping all non-potable water from the water table aquifer had the greatest effect in reducing the potential for saltwater intrusion and reducing the drawdown impact.

Based on these conclusions, the following ground water protection measures are recommended for the Eastern Shore:

Fertilizer application: As a general ground water protection practice, homeowners should apply the *minimum* fertilizer application rate for the soil and grass type on their lot. The Virginia Cooperative Extension can provide technical assistance in the determination of the minimum application rate.

Wastewater disposal: In order to protect the shallow aquifer system from high loading rates of nitrogen and other contaminants, a centralized wastewater collection and treatment system (WCTS) should be constructed for any new development with a minimum of 50 lots and an average lot size of ¼ acre or less. Protective measures should also be implemented on new developments of 50 or more lots with an average lot size between ¼ and ½ acres if soils are predominantly sand without significant amounts of clay and if the seasonal water table is less than 10 feet deep. Acceptable protective measures include (1) construction of a WCTS; (2) increasing the size of the septic drainfield; (3) use of an alternative on-site disposal systems (e.g., mounds); (4) any other method deemed acceptable by the zoning administrator. A cost-benefit analysis of these alternatives was beyond the scope of this study but should be performed prior to implementation of an ordinance with this provision.

The ground water resource would be further protected from failing septic systems by requirements that all systems be pumped out every five years, and that a reserve septic system with capacity at least equal to that of the primary system must be provided on all newly developed parcels.

General water quality protection: LEWASTE modeling results demonstrate that shallow ground water quality is better beneath developments with more pervious surface area because there is a greater amount of recharge that dilutes ground water contaminants. This result supports several ordinance provisions that are currently applied to RMAs and RPAs. Namely, construction footprints should not exceed 60% of a site, and land development should minimize impervious cover.

Ground water use: New developments that exceed 50 lots, or new developments located adjacent to existing ground water users which exceed an aggregated 50 lot demand should either institute conservation measures or employ alternate well designs. Some effective conservation measures include use of low flow plumbing fixtures, irrigation only in the evenings and metered irrigation, and the use of xerotopic landscaping. The alternate well design resulting in the greatest reduction in impacts is a two well system. With the two well system, potable water would be pumped from a confined (preferably upper Yorktown aquifer) well and non-potable water from the water table aquifer. This would require separate plumbing to prevent cross connects between the two systems.

A centralized water system can also provide significant benefit for the larger residential areas (greater than 50 lot developments) by buffering the peak water demand. A centralized potable water system withdrawing from a confined aquifer with non-potable irrigation water supplied by individual residential wells pumping from the water table aquifer provides the greatest protection from saltwater intrusion and loss of yield due to over pumping.

There are several recommendations specific to developments located in or near the spine recharge area. For all developments greater than 50 lots in size, screening the potable water wells in the upper or middle Yorktown aquifer will reduce the potential for saltwater intrusion. Lot sizes of 1 acre or greater should pump non-potable irrigation water from the water table aquifer or implement conservation measures to reduce irrigation demand. Very large developments (greater than 250 lots) should consider both pumping non-potable water from the water table aquifer and implementing conservation measures to prevent adverse impacts. Many of the impacts can be reduced with a properly designed central supply system, where peak demands are buffered by the system.

Impacts to the ground water resource are more severe in the coastal area, and the recommendations extend to smaller developments with smaller lot sizes. All developments that are 50 lots or greater should obtain their potable water supply from the upper Yorktown aquifer. All developments greater than 50 lots should also obtain their non-potable (irrigation) water from the water table aquifer. The residential developments that are greater than 250 lots should implement conservation measures to reduce demand or develop a centralized water supply system to prevent adverse impacts to the ground water resource.

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