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:

<u>Fertilizer application</u>: 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 <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. 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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