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E. Laurence Libelo
William & Mary

William G. MacIntyre
Virginia Institute of Marine Science

Gerald H. Johnson
William & Mary

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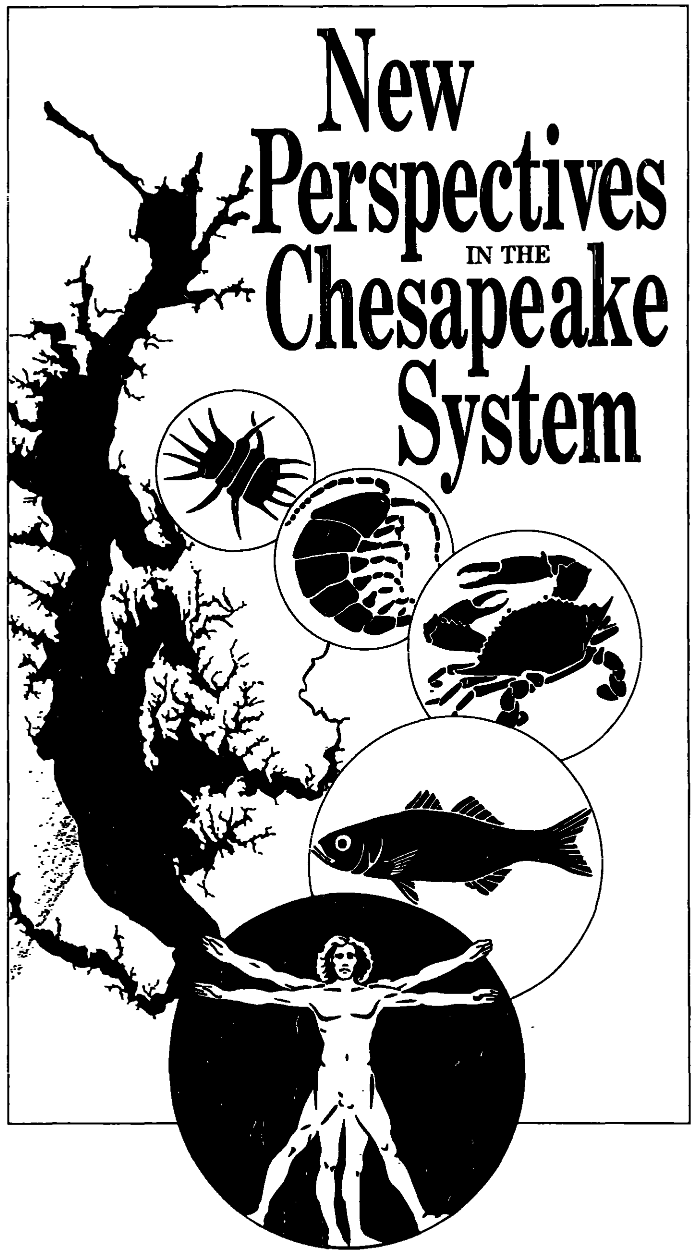

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Chesapeake Research Consortium
P.O. Box 1280
Solomons, MD 20688
Telephone: (301) 326-6700
Fax: (301) 326-6773

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Groundwater Nutrient Discharge to the Chesapeake Bay: Effects of Near-Shore Land Use Practices

E. Laurence Libelo, William G. MacIntyre, Gerald H. Johnson
College of William and Mary

ABSTRACT

Groundwater discharge supplies a significant portion of the inorganic nutrients entering the Chesapeake Bay. This discharge increases nutrient concentration in surface waters, which may result in increased macrophyte growth, reductions in submerged aquatic vegetation and alteration of habitat. Human activities adjacent to the shoreline greatly increase nutrient concentration in the underlying groundwater, and so affect the overall nutrient input by groundwater seepage. In order to quantify the effect of land use on groundwater nutrient loading in the Virginia coastal plain we have installed monitoring wells in a variety of near shore environments adjacent to the James and York Rivers. Since the Spring of 1988, groundwater nitrogen species concentrations have been monitored beneath agricultural fields planted with corn and soy beans, woodlands, vineyards, and suburban development with septic drain fields.

Nitrogen loading in groundwater is strongly increased in areas with high human activity. Below pristine woodlands, groundwater NO_2^-, NO_3^- and NH_4^+ concentrations were always below 1 mg/L and generally below 0.1 mg/L. Areas near septic discharge showed high nutrient loading up to 25 mg/L NO_3^-. Beneath planted fields loadings ranged up to 0.1 mg/L NO_2, 20 mg/L NO_3^- and 0.1 mg/L NH_4^+. Groundwater beneath forested areas adjacent to planted fields showed similar loadings but decreased with distance from the field. Vineyard loading ranged as high as 0.2 mg/L NO_2^-, 13 mg/L NO_3^- and 0.2 mg/L NH_4^+. Groundwater Nitrogen loading showed spatial and temporal variations.

These groundwater concentration measurements, estimates of the percent of shoreline represented by each land use, and total groundwater discharge permit calculation of the nutrient load delivered to the system by submarine groundwater discharge. Groundwater delivers 6.6 million kilograms of nitrogen per year to James River. This suggest that groundwater provides about 30 % of the total input to the Chesapeake Bay.

INTRODUCTION

Recent recognition of the fact that submarine groundwater discharge (SGWD) contributes water and nutrients to the Chesapeake Bay system has resulted in a realization of how little we understand this phenomenon. Only recently have researchers begun studying the extent and effects of SGWD in the Bay (Simmons, 1989). While the Chesapeake Bay is one of the most studied estuaries in the world, scientists and managers have lagged behind those in other regions in recognizing and examining groundwater seepage effects on the Bay system.

Groundwater has been shown to be of major significance in controlling near-shore ecologic processes (Johannes, 1980), and SGWD may provide a large portion of nutrient inputs into surface water bodies. In the Chesapeake Bay, the contribution of groundwater seepage to the water and nutrient budgets of the system are very poorly understood. In 1987, we studied the Chesapeake Bay model (Hydroqual, 1987), and noticed that the then current version of the model did not include groundwater as a source of water or nutrients to the bay, a deficiency which is still not addressed in the current versions. At that time, research efforts aimed toward characterizing the groundwater seeping into the bay and quantifying the total input of water and nutrients into the system by groundwater were initiated. Initial results were presented by MacIntyre *et al.* (1989). This paper provides further results of this ongoing effort to estimate the importance of groundwater seepage in the nutrient balance of the Chesapeake Bay system.

To determine the amount of nutrient input to the bay by SGWD, groundwater monitoring wells have been installed along the shores of the James and York Rivers, in areas representative of the different land uses in the region. These include pristine woodlands, suburban septic, conventional and no-till agricultural fields, woodlands adjacent to agricultural field and vineyards. Samples from these wells were collected monthly, providing time series data used to determine nutrient loading in groundwater associated with each land use. Wells are currently being installed in other sites to increase our data base. It is anticipated that this study will continue for the foreseeable future, and that estimates of loadings and fluxes will be further refined.

Water samples collected from the wells have been analyzed for nitrogen in the form of nitrite, nitrate, and ammonium ions. Phosphate was not determined since the lower portion of the bay is believed to be nitrogen limited and because phosphorous is fairly immobile in groundwater.

The James River subestuary is used as an example to demonstrate how groundwater nutrient characteristics below each type of land use can be combined with information about the amount of shoreline devoted to each land use and the total groundwater volume flux to yield an estimate of the total amount of nitrogen discharged to the system by SGWD.

$$\text{Mass Flux} = (C_A L_A + C_F L_F + C_R L_R) \times (Q) \quad (1)$$

where

C_A = Concentration below agricultural areas
C_F = Concentration below forested areas
C_R = Concentration below suburban septic areas
L_A = Length percent of total shoreline in agriculture
L_F = Length percent of total shoreline forested
L_R = Length percent of total shoreline urban septic
Q = Total groundwater discharge

METHODS AND MATERIALS

Sampling Sites

Ringfield

To get an idea of background nutrients in groundwater in the region, wells were installed at Ringfield in the Colonial Parkway National Park on the shore of Kings Creek, a tributary of the York River. This site was farmed until it was taken over by the National Park Service approximately 60 years ago. Since then it has been undisturbed. The drainage area supplying groundwater to the site is covered by woodland and natural grassland. The surficial geologic formation at the site consists of thin basal medium to coarse sands grading up to fine sand, silt and clay of the Pleistocene Shirley formation. This is underlain by iron oxide rich clayey silts and fossiliferous quartzose sand, clayey and silty fine sand and carbonate rich sediments of the Miocene Yorktown formation (Johnson and Hobbs, 1990). Wells were installed through the Shirley and completed in the upper Yorktown (figure 1).

VIMS

To measure the effect of septic drain fields on groundwater nutrient loading, wells were installed at the campus of the Virginia Institute of Marine Science near the mouth of the York River. The

Institute consists of about 30 buildings at Gloucester Point. Sewage waste is collected from the buildings and pumped to a central drainfield (figure 2). The geology at this site is similar to the Ringfield site except that the surficial unit is the Tabb formation. Wells 1 and 2 are completed in the Yorktown formation about 200 m down gradient from the drainfield. Well 3 is in Holocene beach deposits 500 m down gradient from the drainfield with several buildings in between. Well 4 is also in Holocene beach deposits but is hydraulicly isolated for the drainfield by an intervening marsh.

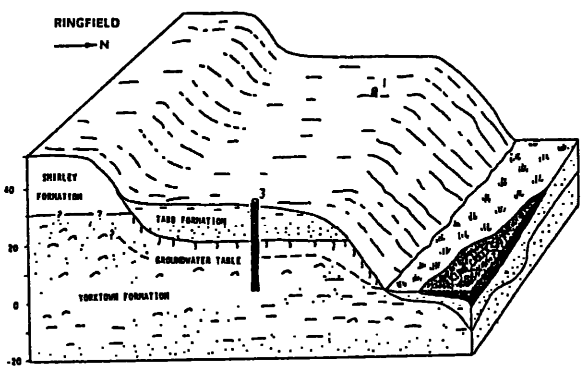

Figure 1. *Location of wells at Ringfield site.*

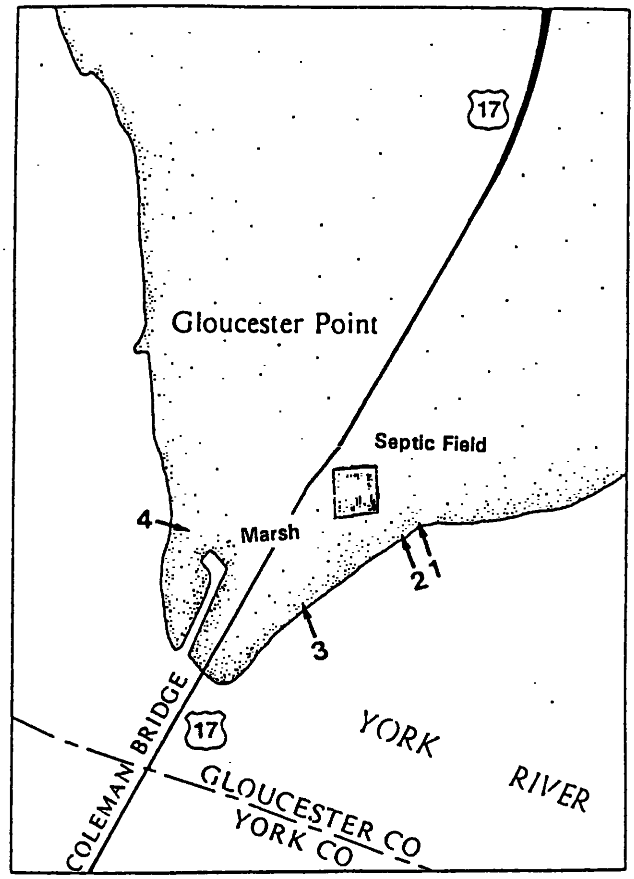

Figure 2. *Location of wells at VIMS site.*

Renwood

This site is along the northern shore of the James River. Wells were installed in the center and around the edge of a field which has been in conventional till production for at least 7 years (figure 3). The surficial unit at this site is the Tabb formation. This is underlain by the Shirley formation. The contact between these units in this area is a low permeability clay layer. Well 8 is completed below the clay layer in the Shirley formation. All other wells at this site are completed in the Tabb formation.

Hula Woods

This site is just upstream from the Renwood site. Wells were installed parallel to the shoreline about 75, 150 and 225 m for the edge of the field. The nearest up gradient agricultural field is approximately 500 meters away.

Hula Field

The Hula site is several hundred meters downstream from the Renwood site. This site consists of a field in no-till production with irrigation. Wells were installed along a road which bisects the field, in a small gully in the center of the field and along the edge of the field adjacent to the James River (figure 4). Wells 3,5,4,9 and 10 are completed in the Tabb formation. Well 11 is completed in the underlying Shirley formation.

Williamsburg Winery

This site is 2 km inland but was included in this study to evaluate the effect of agricultural practices other then corn, soy bean and small grain production on groundwater. Wells at this site were installed at the base of a scarp down slope from the vineyards (figure 5). The wells penetrate the Shirley Formation and are screened in the Yorktown Formation. Well 7 was installed up gradient from vineyards as a control well, but subsequent planting and fertilization around the well have made it unreliable as a control.

Well Installation and Sampling

Wells were installed by hand auger or truck mounted auger, and were constructed out of 2 inch Polyvinyl chloride (PVC) pipe and screen. Screening was from the water table down about 1.5 m. Samples were collected approximately monthly. All wells were purged prior to sampling. Samples were collected with a Watera inertial pump system and packed on ice for transport to the laboratory for analysis.

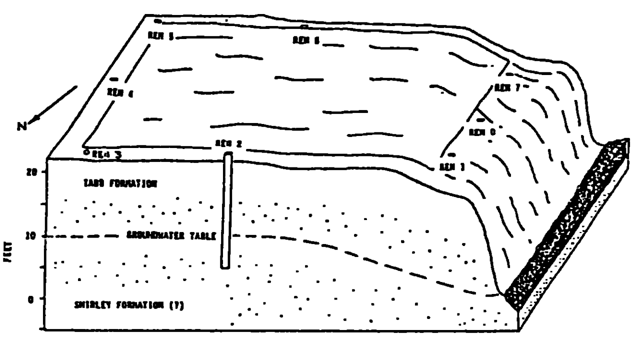

Figure 3. *Well locations at Renwood site.*

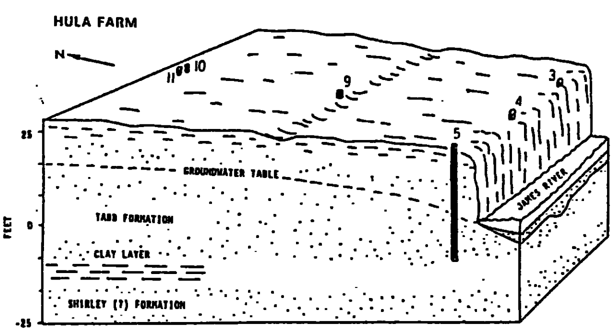

Figure 4. *Location of wells at Hula site.*

Sample Analysis

Samples were filtered through 0.45 um fiber filters within 24 hours of collection, and stored frozen until analyzed. Analysis for nitrogen species was by EPA approved methods. Ammonium was determined by indolphenol dye formation (EPA STD. Method 419). Nitrate plus nitrite was determined by cadmium reduction

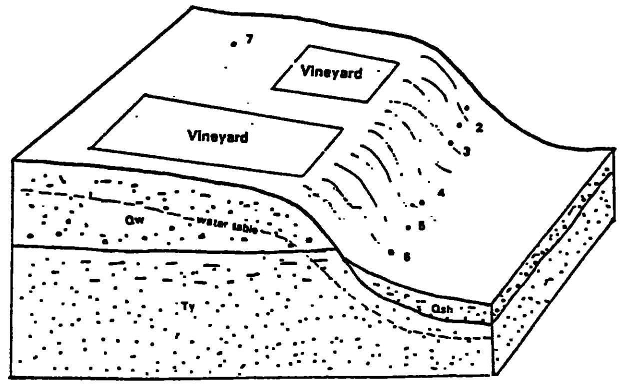

Figure 5. *Location of wells at Williamsburg Winery.*

and diazo dye formation (EPA STD. Method 418). Nitrite was determined by diazo dye formation (EPA STD. Method 419) and nitrate calculated by difference.

Shoreline Land Use Determination

The length of shoreline along the James River representing agricultural, woodland, and suburban septic was determined from Shoreline Situation Reports (Hobbs *et al*, 1974, 1975; Owen *et al.*, 1975a, 1975b, 1976a, 1976b; and 1976). The measured reach length in each county was calculated and the total percentage for each land use was calculated (table 1).

RESULTS AND CONCLUSIONS

Land use effect on groundwater nutrient loading

Figure 6 shows the concentration of nitrogen species in well samples from the pristine Ringwood site. The concentration for nitrate, nitrite and ammonium were always below 1.0 mg/L and generally below 0.1 mg/L. This suggests that background nutrient concentration in areas not affected by human activity are very low. In these wells and in all other wells except VIMS 4 nitrate was the predominant species as would be expected for oxygenated groundwater.

Figure 7 shows nitrate levels in the wells at the VIMS campus. Nitrate concentrations in these wells was always several orders of magnitude greater then nitrite and ammonium. Wells 1, 2 and 3 down gradient from the drainfield show elevated nitrate concentrations significantly above

County	Shoreline (Kilometers)	% Agricultural	% Residential	% Forested
Suffolk	270	60	23	17
Charles City	137	32	4	64
Henrico	51	59	13	28
Chesterfield	80	34	22	44
Isle of Wight	209	52	19	29
Prince George	179	23	20	57
Surry	138	13	9	78
James City	243	9	20	71
Newport News	76	0	70	30
Total	1466			
Agriculture	481 (33%)			
Residential	285 (19%)			
Forested	700 (48%)			

Table 1. *Shoreline land use along the James River.*

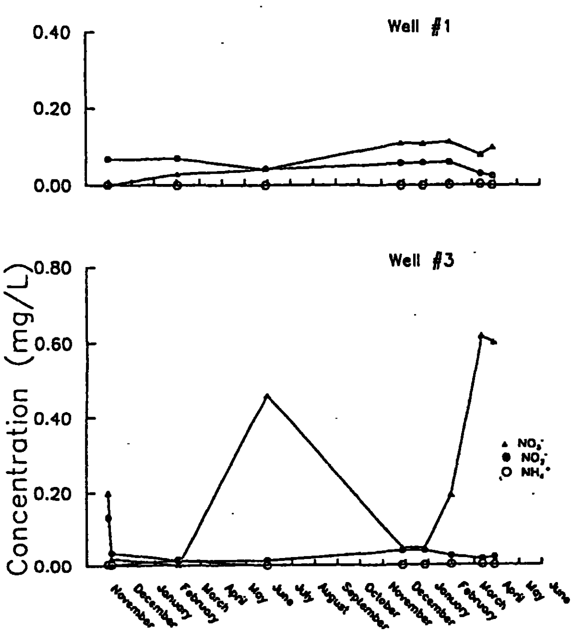

Figure 6. *Nitrogen species concentrations in samples from Ringfield site.*

background. They typically range between 2 and 5 mg/L. Well 4, isolated from the drainfield, had nitrate concentrations approaching background levels. The only sample from well 4 with concentration above 0.2 mg/L was unreliable due to contamination when the cap was left off the well. The elevated concentrations in wells

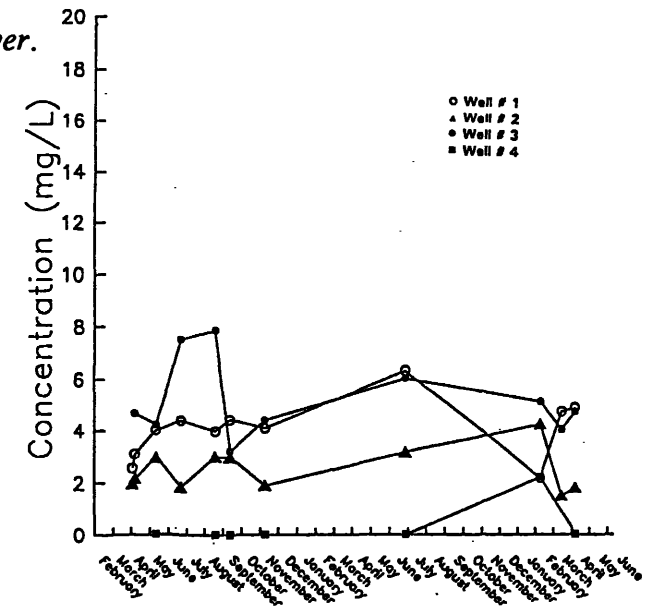

Figure 7. *Nitrate concentrations in VIMS wells.*

down gradient from the drainfield suggest that septic systems contribute a large amount of nitrate to groundwater in the Chesapeake Region. Septic systems are generally the most common point sources for groundwater contamination (Tabb, 1980).

Nutrient concentrations in water samples from wells at the Hula site which were completed in the Tabb formation and sampled the unconfined aquifer showed nutrient concentrations greatly above background (figure 8). Nitrate concentrations ranged from about 1 mg/L to greater then 20 mg/L and were usually between 10-14 mg/L.

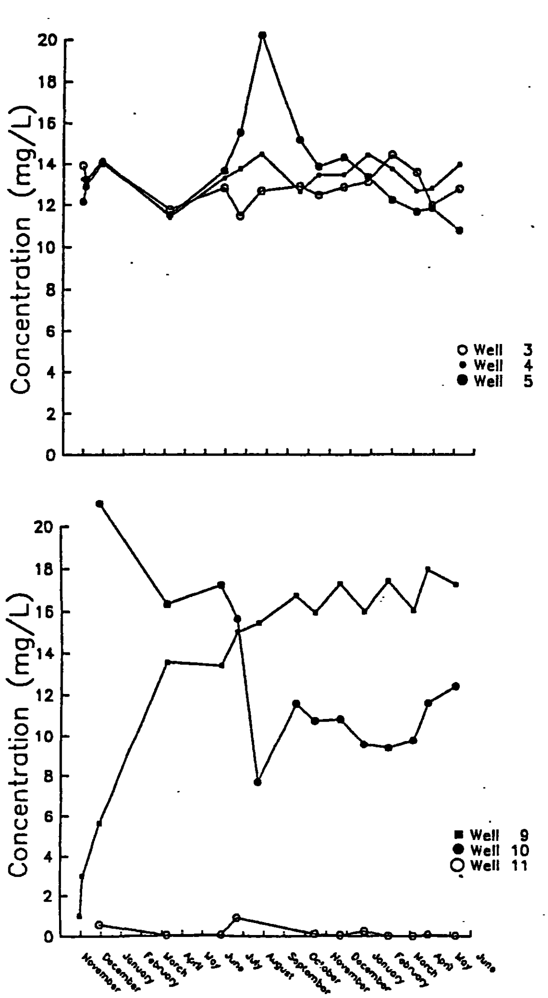

Figure 8. *Nitrate concentrations from Hula wells.*

Wells located away from the river showed the greatest variation in nitrate concentration. Wells near the river showed much less variation and were between 10 and 14 mg/L. Well 10 showed an unusually high level of nitrate when the well was installed. This is interpreted as a parcel of water with very high concentration moving through the aquifer. This parcel was apparent in well 9 about 4 months into the study and in 5 at about 10 months. Well 11, completed below the clay layer at the contact between Tabb and Shirley formations had nitrate concentrations near background. This suggests that the confined aquifer is not greatly affected by contamination in the overlying unconfined aquifer.

Nutrient concentrations in samples from the Renwood wells were similar to those at the Hula site (figure 9). Concentrations in wells farthest away from the river showed the greatest variation in concentrations, from about 3 up to 18 mg/L, and were generally above 8 mg/L. Wells 3, 4 and 5 showed a general upward trend in nitrate concentration of about 0.01 mg/L/day. Extrapolation of this rate of increase back to background concentration suggests that the beginning of the increase in nitrogen concentration began about the time the field was put into production by the current tenant. Wells 2 and 6 in the center of the field showed similar concentrations with a smaller rate of increase. Wells 1 and 7 at the edge of the field near the river had similar concentrations, between 8 and 10 mg/l, but showed much less variation. Well 8, completed in the Shirley formation, had concentrations approaching background, again suggesting that the underlying confined aquifer is not affected by contamination in the shallow unconfined aquifer.

Wells at the Hula wood were expected to have nitrate concentrations similar to background levels since they are in woods 75 m from the nearest agricultural field. Instead, they were found to have concentrations well above background in the well closest to the field and slightly above background in the farthest well (figure 10). This suggests that trees may not be as effective at removing nutrients as expected and that thick buffer strips would be needed if uptake by trees is to prevent nutrients in groundwater from reaching the bay.

Figure 11 shows nitrate concentration in well samples from the winery site. These concentrations ranged from 4 to 14 mg/L, and depended on the position of the well. The concentrations in each increased over time, as anticipated since the vineyard has only been operational for about five years.

Shoreline land use

Table 1 shows shoreline use by percent in each county along the James river. The total percent of the shore devoted to agriculture, residential and forest were determined to be 33%, 19% and 48% respectively.

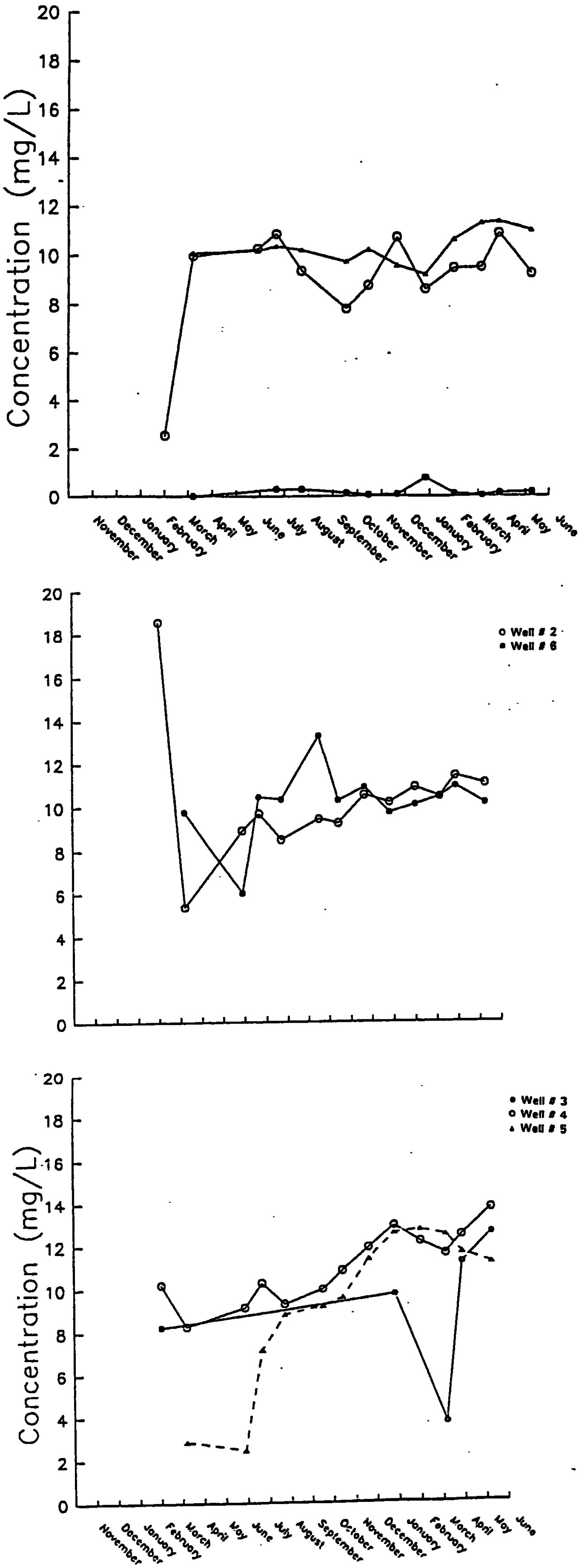

Figure 9. *Nitrate concentrations from Renwood wells.*

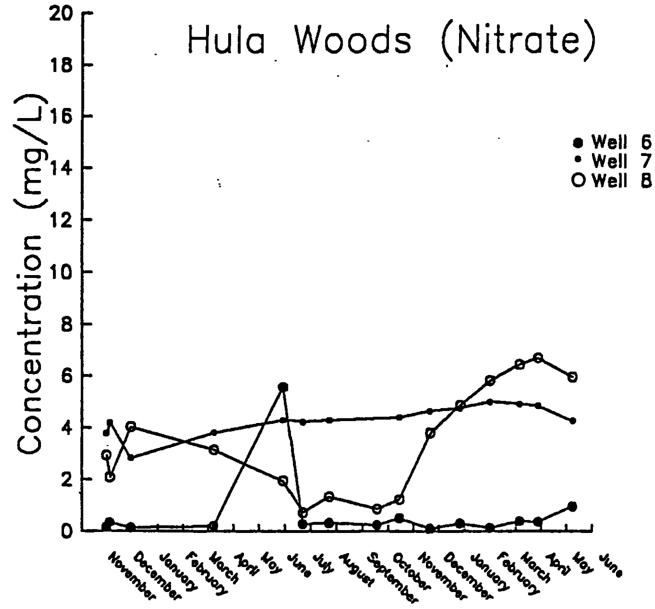

Figure 10. *Nitrate concentrations from Hula Woods wells.*

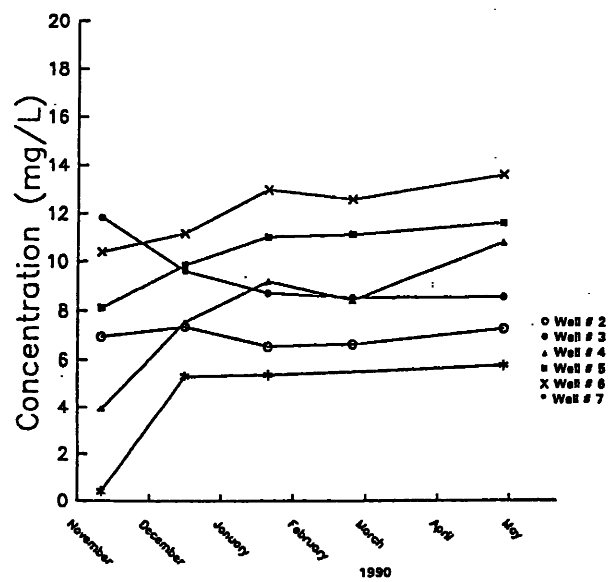

Figure 11. *Nitrate concentrations from Williamsburg Winery.*

Estimation of total groundwater discharge

Modelling of the James River has failed to explain the salinity distribution in the river, apparently due to underestimation of the total freshwater input to the system. Average fresh water input at the fall line, 212 cubic meters per second (m^3/sec) (Neilson and Ferry, 1978) accounts for only about 50 % of the total required to achieve the observed salinity values and to balance the salt budget (Cerco, Personal communication). In our calculations we used 50 m^3/sec, about 25% of the unaccounted fresh water input, as an estimate of the input from groundwater seepage. This value probably represents a low estimate. The drainage area for the James River below the fall line is about 10,7600 km^2. The Average rainfall in the basin is about 110 cm/year, so the total rainfall in the basin below the fall line is about 373m^3. Our estimate of 50 m^3/sec for groundwater below the fall line is 13 % of the rainfall. Variation in groundwater discharge rate along the shoreline is assumed to be minimal. This assumption may, upon further study, prove to be inadequate but it allows a first approximation of groundwater discharge. Further study is needed to evaluate the validity of this estimate.

Total nutrient input

Equation 1 gives a total mass of nitrogen into the James River subestuary of 6.6 million kilograms per year using typical values for nitrogen concentrations of 4 mg/L in residential areas, 0.2 in forested areas and 10 in agricultural areas, length percent of shoreline represented by each of 33, 48, and 19 respectively and an estimated total groundwater discharge 50 m^3/sec. By comparison, input by the river at the fall line is about 5 million kilograms per year. This estimate of groundwater nutrient flux is rough and will require a great deal of further research to verify. We believe that it represents a fairly good order of magnitude estimate.

SUMMARY

We have collected several years of data on the effect of land use on the concentration of nutrients in groundwater in the Chesapeake Bay region. Long term monitoring data, begun here, will be needed to understand how land use affects groundwater nutrient concentration and so impacts the Chesapeake Bay via submarine groundwater discharge.

Agricultural activities result in high levels of nitrate in the underlying groundwater, often exceeding the drinking water standard of 10 mg/L. Septic systems also result in significant elevations in groundwater nutrient concentrations, but generally less than those associated with agricultural activities.

From measurement of the concentration of nutrients in groundwater below different land uses, the percent of shoreline represented by each land use and estimates of the total flux of water into the system by groundwater seepage we calculate that the nitrogen flux into the James River subestuary from groundwater seepage is 6.6 x 10^6 kg/ year, or about as much as is brought in by the river at the fall line. This suggests that groundwater nutrient inputs in the Chesapeake Bay system may represent 30% of the total flux into the system.

This estimate indicates that any attempt to understand the Chesapeake Bay system without including the effects of groundwater discharge on the system is doomed to failure.

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REFERENCES

Hobbs, Carl H., Gary Anderson, William D. Athearn, Robert J. Byrne and John M. Zeigler. 1974. Shoreline Situation Report - Newport News, Virginia. Special Rept. in Appl. Marine Sci. and Ocean Engin. no. 54. VIMS. Gloucester Point, Virginia.

Hobbs, Carl H., Gary L. Anderson, Martha A. Patton, and Peter Rosen. 1975. Shoreline Situation Report - James City County, Virginia. Special Rept. in Appl. Marine Sci. and Ocean Engin. no. 15. VIMS. Gloucester Point, Virginia.

Hydroqual, Inc. 1987. A steady-state coupled hydrodynamic/water quality model of the eutrophication and anoxia process in the Chesapeake Bay. Work assignment No. 40, E.P.A. Contract No. 68-03-3319. Under contract to Battelle Ocean Sciences, 397 Washington Street, Duxbury, Mass.

Johannes, R. E. 1980. The ecological significance of the submarine discharge of groundwater. *Mar. Ecol. Prog. Ser.* **3**:365-373.

Johnson, G. H. and C. H. Hobbs. 1990. *Pliocene and Pleistocene depositional environments on the York-James peninsula, Virginia.* Field Guide Book for American Soc. of Limnology and Oceanography 1990 fieldtrip. American Soc. of Limnology and Oceanography. 39 pp.

MacIntyre, William G., Gerald H. Johnson, William G. Reay and George Simmons. 1989. Groundwater non-point sources of nutrients to the Southern Chesapeake Bay. Proc. *Ground Water Issues and Solutions in the Potomac River Basin/Chesapeake Bay Region.* Co-sponsored by the Association of Ground Water Scientists and Engineers... et al. March, 1989.

Neilson, Bruce J. and Penelope S. Ferry. 1987. A water quality study of the estuarine James River. Special Rept. in Appl. Marine Sci. and Ocean Engin. no. 131. VIMS. Gloucester Point, Virginia.

Owen, Dennis W., Margaret H. Peoples, and Gary L. Anderson. 1975. Shoreline Situation Report - Henrico, Chesterfield, and Richmond. Special Rept. in Appl. Marine Sci. and Ocean Engin. no. 98. VIMS. Gloucester Point, Virginia.

Owen, Dennis W., Lynn M Rogers, Margaret H. Peoples, and Gary L. Anderson. 1976. Shoreline Situation Report - Surry County, Virginia. Special Rept. in Appl. Marine Sci. and Ocean Engin. no. 50. VIMS. Gloucester Point, Virginia.

Owen, Dennis W., Lynn M. Rogers, and Margaret H. Peoples. 1976. Shoreline Situation Report - Charles City County, Virginia Special Rept. in Appl. Marine Sci. and Ocean Engin. no. 49. VIMS. Gloucester Point, Virginia.

Owen, Dennis W., Lynn M. Rogers, Margaret H. Peoples, and David Byrd. 1976. Shoreline Situation Report - Prince George County, Virginia Special Rept. in Appl. Marine Sci. and Ocean Engin. no. 47. VIMS. Gloucester Point, Virginia.

Owen, Dennis W., Gaynor B. Williams, Margaret H. Peoples, Carl H. Hobbs, and Gary L. Anderson. 1975. Shoreline Situation Report - Isle of Wight County, Virginia Special Rept. in Appl. Marine Sci. and Ocean Engin. no. 97. VIMS. Gloucester Point, Virginia.

Rogers, Lynn M., Dennis W. Owen and Margaret H. Peoples. 1976. Shoreline Situation Report - City of Suffolk, Virginia Special Rept. in Appl. Marine Sci. and Ocean Engin. no. 116. VIMS. Gloucester Point, Virginia.

Simmons, George M. 1989. The Chesapeake Bay's Hidden Tributary: Submarine Groundwater Discharge. Proc. *Ground Water Issues and Solutions in the Potomac River Basin/Chesapeake Bay Region.* Co-sponsored by the Association of Ground Water Scientists and Engineers... et al. March, 1989.

Todd, David Keith. 1980. *Groundwater Hydrology.* 2nd ed. New York, New York. John Wiley and Sons. 535 pp.