Using a New Groundwater-Regression Model to Forecast Nitrogen Loading from the Delmarva Peninsula

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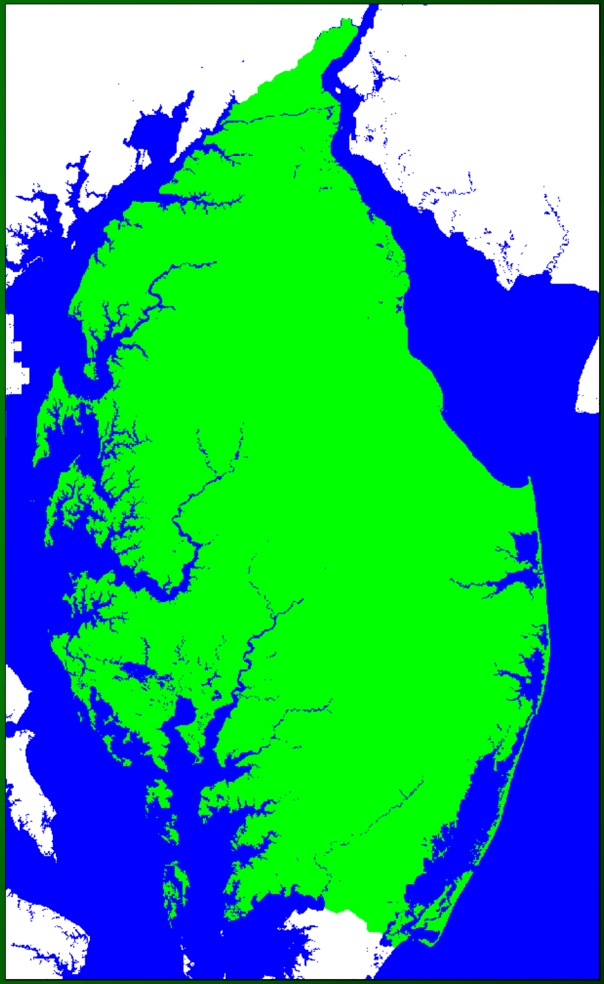
Objectives:

- To develop a groundwater flow model that can simulate return-times to streams (base-flow ages) on the Delmarva Peninsula
- To explain the spatial and temporal trends in nitrate on the Delmarva Peninsula using a mass-balance regression equation that includes the base-flow age distributions obtained from the flow model
- To use the calibrated equation to forecast total nitrogen loading to the Bay from the Eastern Shore
- To forecast changes in future loadings to the bay given different loading application rates at the land surface
- To develop maps that will help resource managers target areas that will respond most efficiently to better management practices

USGS

Groundwater Model—Delmarva Peninsula

- MODFLOW 2005
- 500 ft cell resolution
- 7 Model Layers
- 4+ million active cells
- 30-m DEM, LIDAR
- 300 ft deep
- Steady State Flow
- MODPATH travel times
- Sanford and others (2012) USGS Open File Report 2012-1140 (in press).



USGS

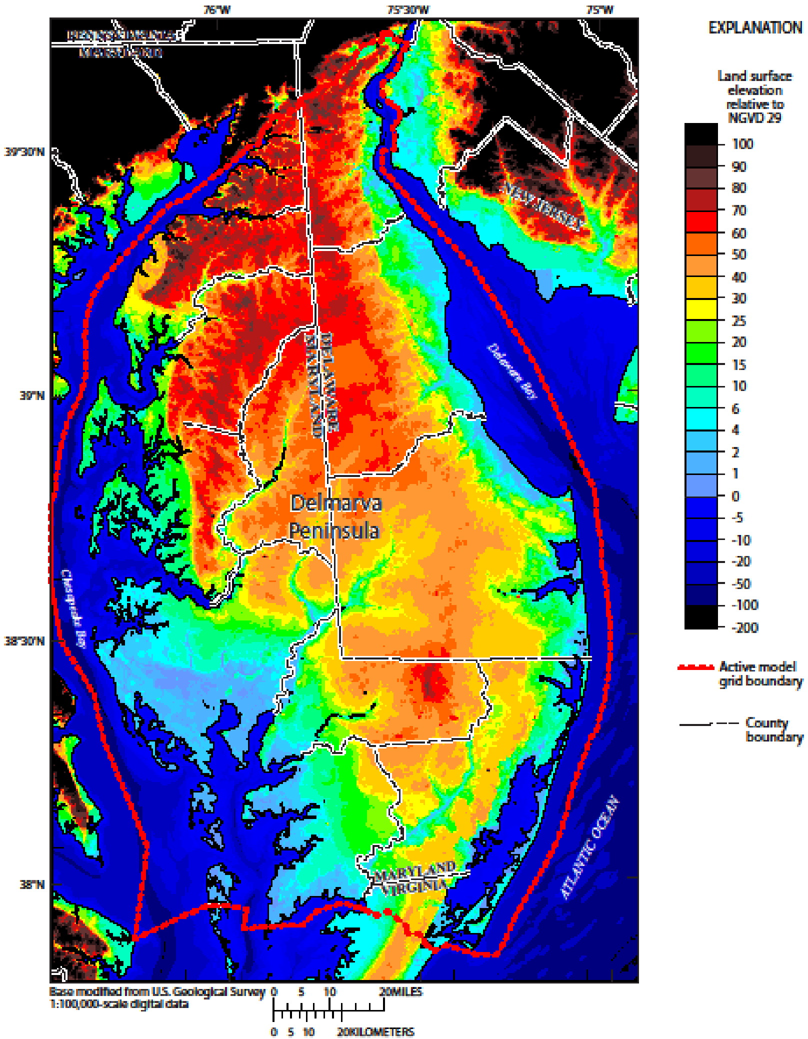


Figure 5. Elevation of land surface on the Delmarva Peninsula derived from LIDAR (unpublished data from Roger Barlow, U.S. Geological Survey), and bathymetry from National Oceanic and Atmospheric Administartion, National Geophysical Data Center, U.S. Coastal Relief Model, Retrieved July, 2007 from http://www.ngdc.noaa.gov/mgg/coastal/crm.html.

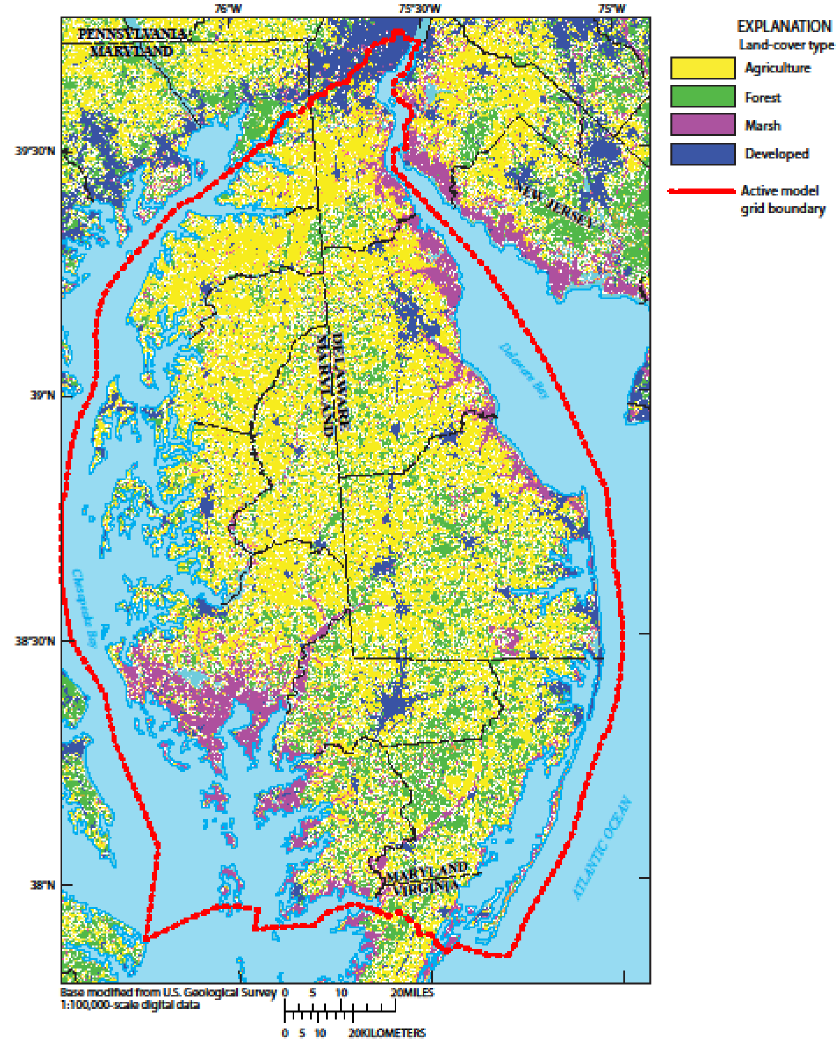


Figure 6. General land-cover types based on the USGS 2001 National Land-Cover Dataset. Data retrieved August 2007 from http://landcover.usgs.gov/natllandcover.php.

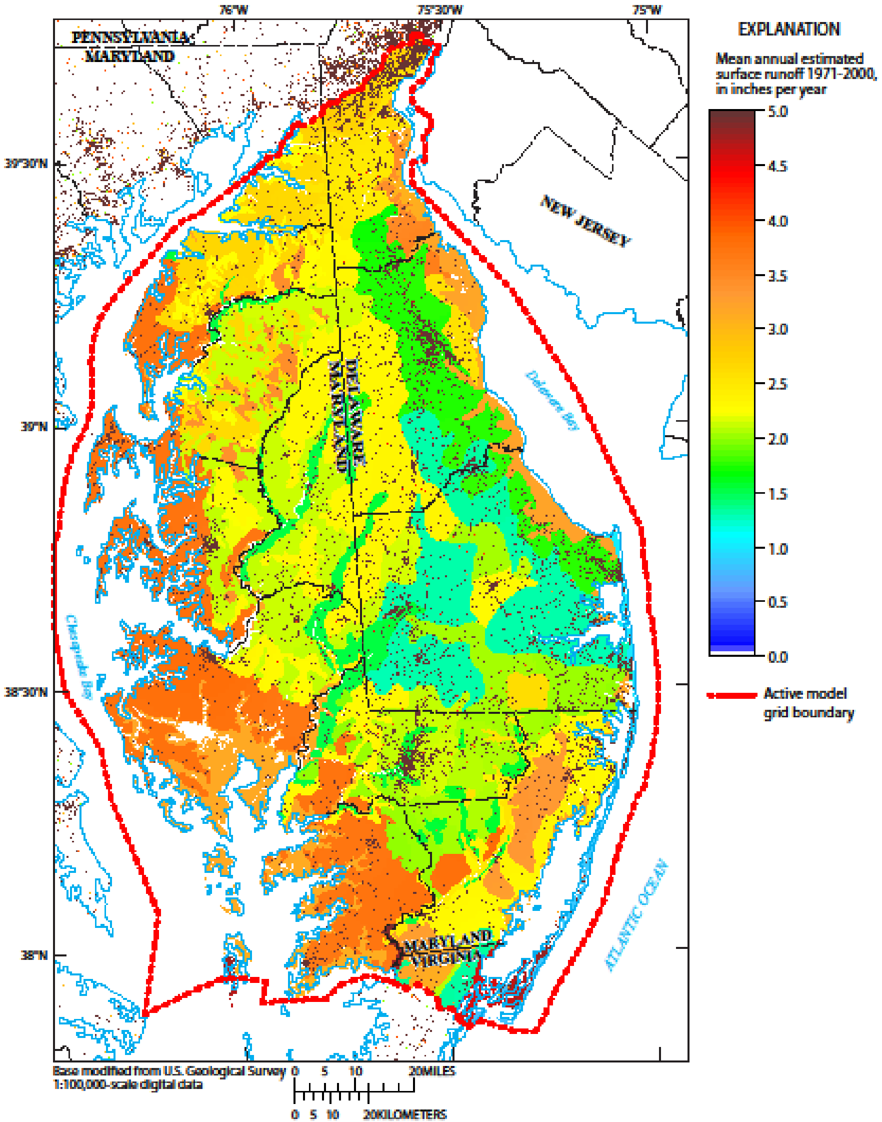


Figure 16. Mean annual estimated surface runoff on the Delmarva Peninsula from 1971 to 2000 based on the regression equations of Sanford and others (2011) for the Coastal Plain Province and the clay content of the soils. Regions outside the active model area only show runoff for impervious surfaces.

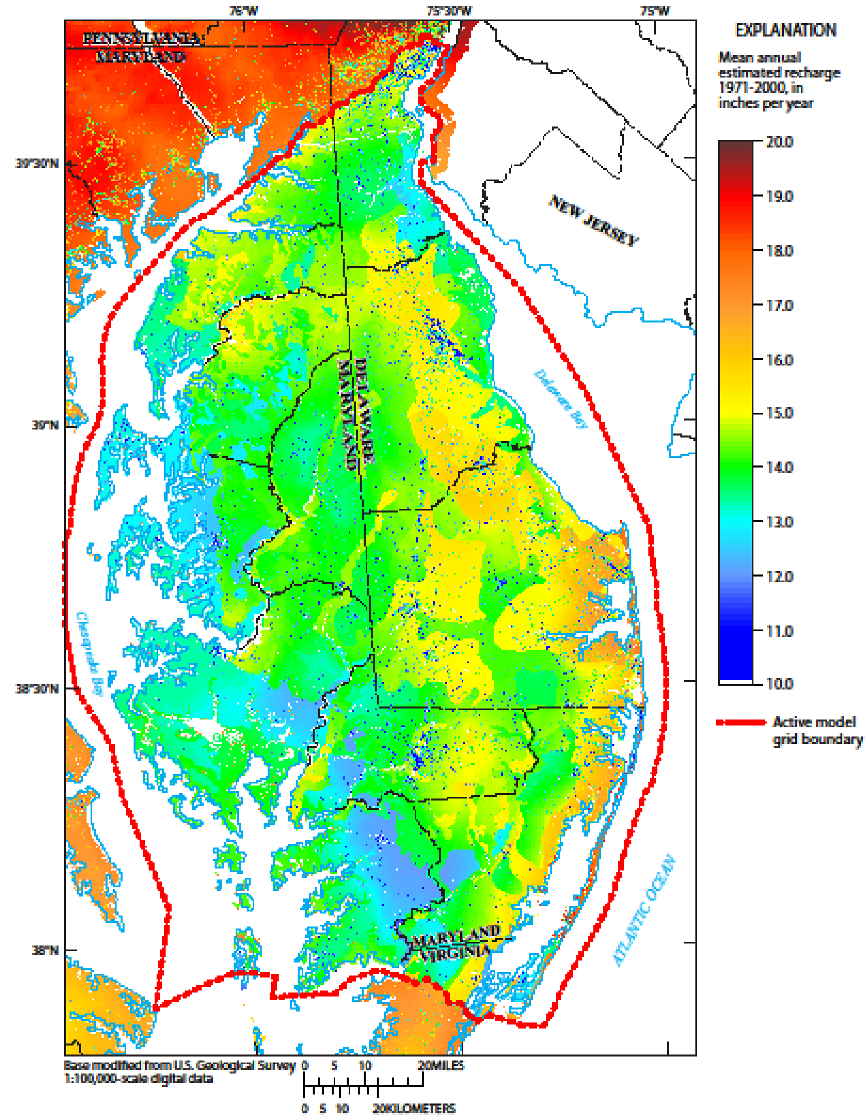


Figure 18. Mean annual estimated recharge on the Delmarva Peninsula from 1971 to 2000 based on the precipitation from the PRISM climate database and the climate and runoff regression equations of Sanford and others (2011). Values outside the active model area (fig. 3) represent total runoff rather than recharge.

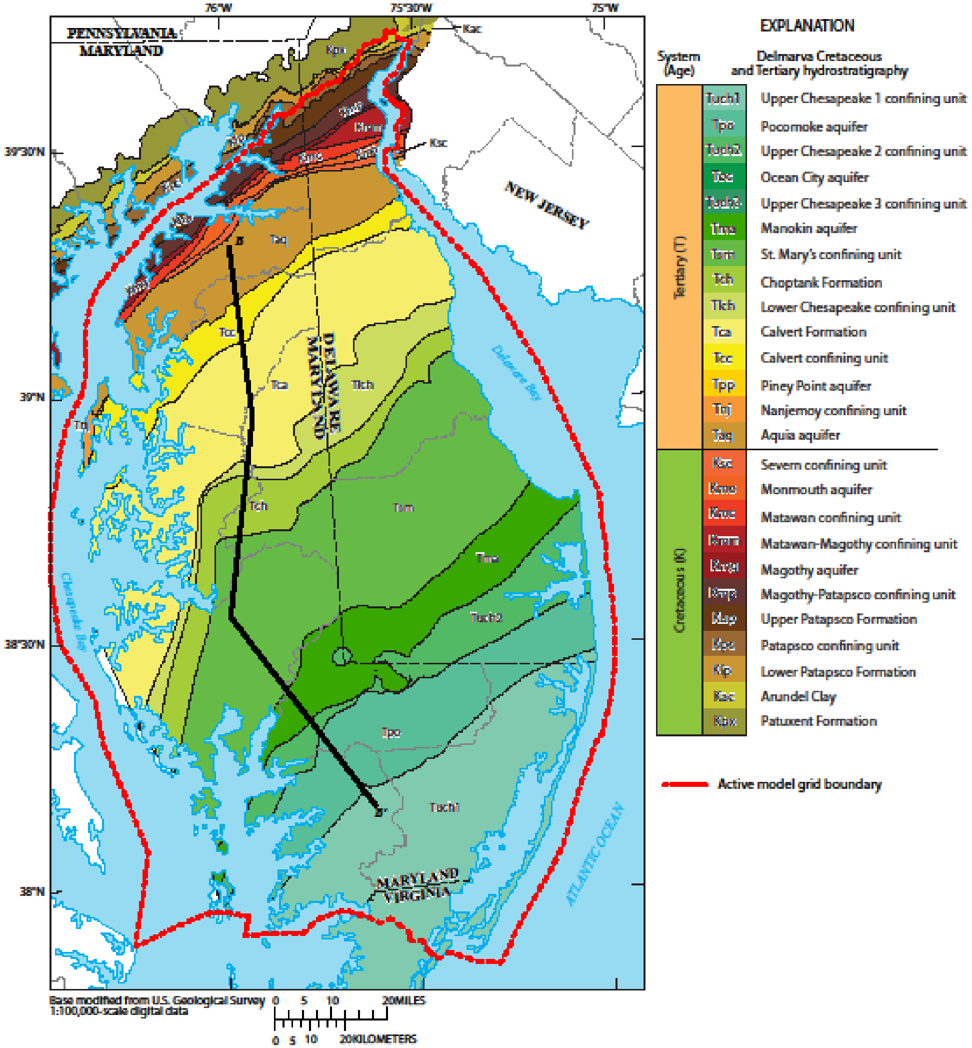


Figure 20. Locations where various Cretaceous (K) and Tertiary (T) deposits outcrop at the land surface or subcrop beneath Quaternary deposits on the Delmarva Peninsula. Section along line B-B' is shown in figure 23. Data files from Andreasen and others (2007).

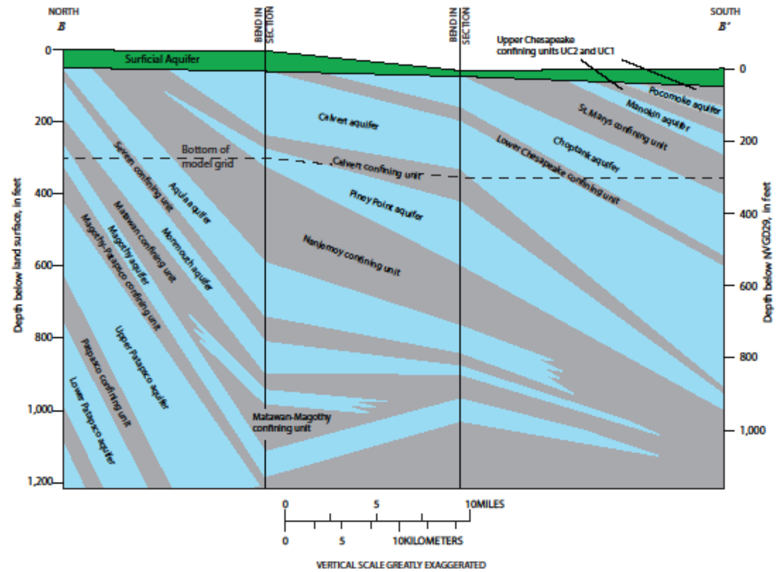
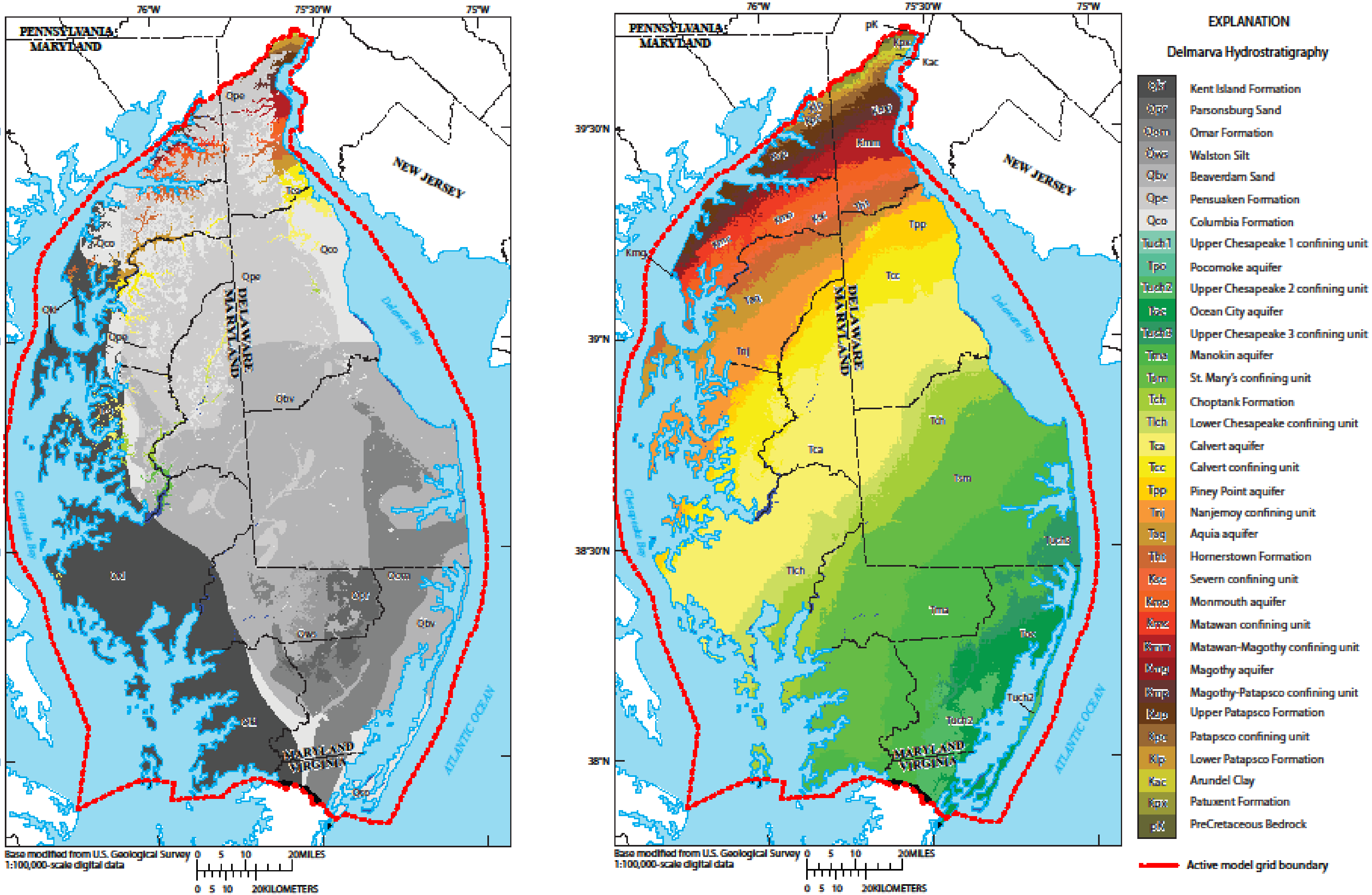


Figure 21. Cross-sectional view showing dipping of confined hydrogeologic units beneath the surficial aquifer along the line B-B'. See figure 22 for location of section line. Modified from Andreasen and others (2007).



PENNSYLVANIA
MARYLAND
NEW JERSEY
DELAWARE
MARYLAND
MARYLAND
VIRGINIA
Delaware Bay
Chesapeake Bay
ATLANTIC OCEAN
76°W
75°30'W
75°W
39°30'N
39°N
38°30'N
38°N
Base modified from U.S. Geological Survey 1:100,000-scale digital data
0 5 10 20 MILES
0 5 10 20 KILOMETERS
EXPLANATION
Delmarva Hydrostratigraphy
Qk Kent Island Formation
Qpr Parsonsburg Sand
Qom Omar Formation
Qws Walston Silt
Qbv Beaverdam Sand
Qpe Pensauken Formation
Qco Columbia Formation
Tuch1 Upper Chesapeake 1 confining unit
Tpo Pocomoke aquifer
Tuch2 Upper Chesapeake 2 confining unit
Toc Ocean City aquifer
Tuch3 Upper Chesapeake 3 confining unit
Tma Manokin aquifer
Tsm St. Mary's confining unit
Tch Choptank Formation
Tlch Lower Chesapeake confining unit
Tca Calvert aquifer
Tcc Calvert confining unit
Tpp Piney Point aquifer
Tnj Nanjemoy confining unit
Taq Aquia aquifer
Tht Hornerstown Formation
Ksc Severn confining unit
Kmo Monmouth aquifer
Kmc Matawan confining unit
Kmm Matawan-Magothy confining unit
Kmg Magothy aquifer
Kmp Magothy-Patapsco confining unit
Kup Upper Patapsco Formation
Kpc Patapsco confining unit
Klp Lower Patapsco Formation
Kac Arundel Clay
Kpx Patuxent Formation
pK PreCretaceous Bedrock
Active model grid boundary

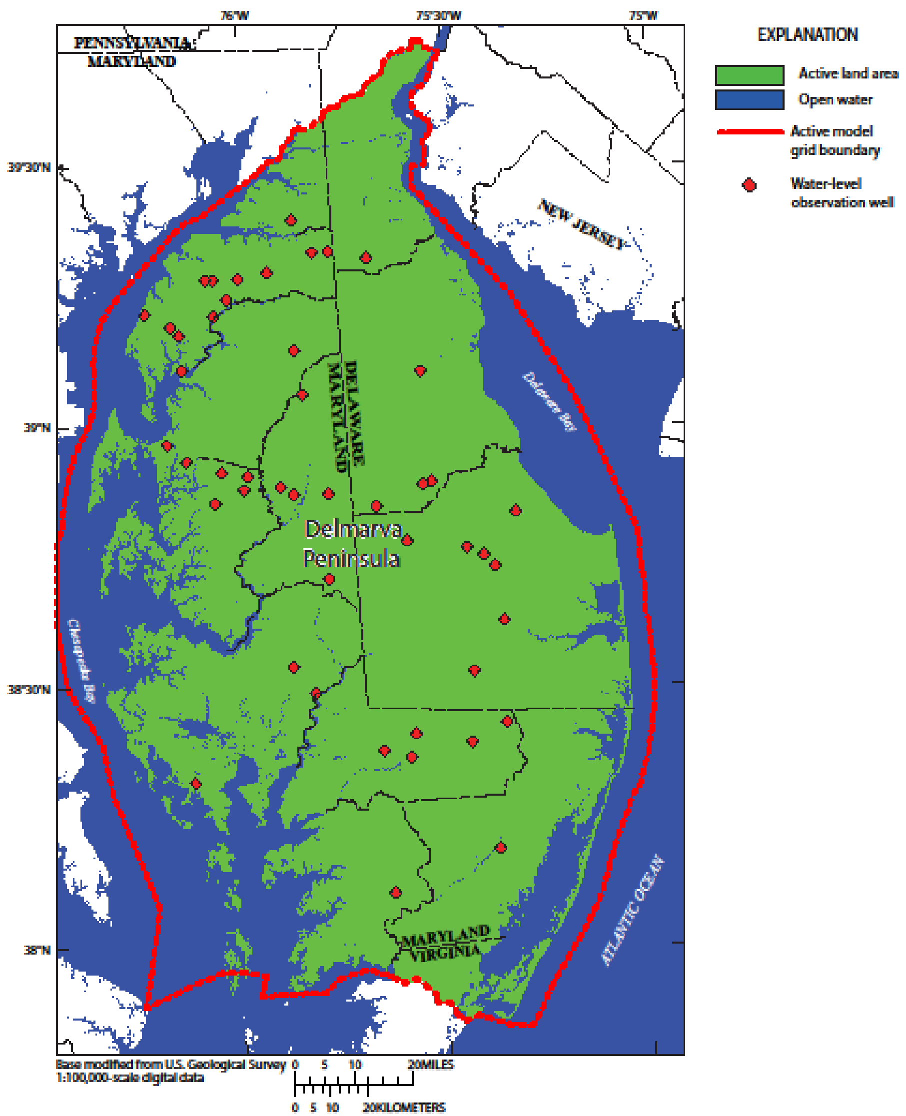


Figure 30. Locations of the 48 wells used for water-level observations.

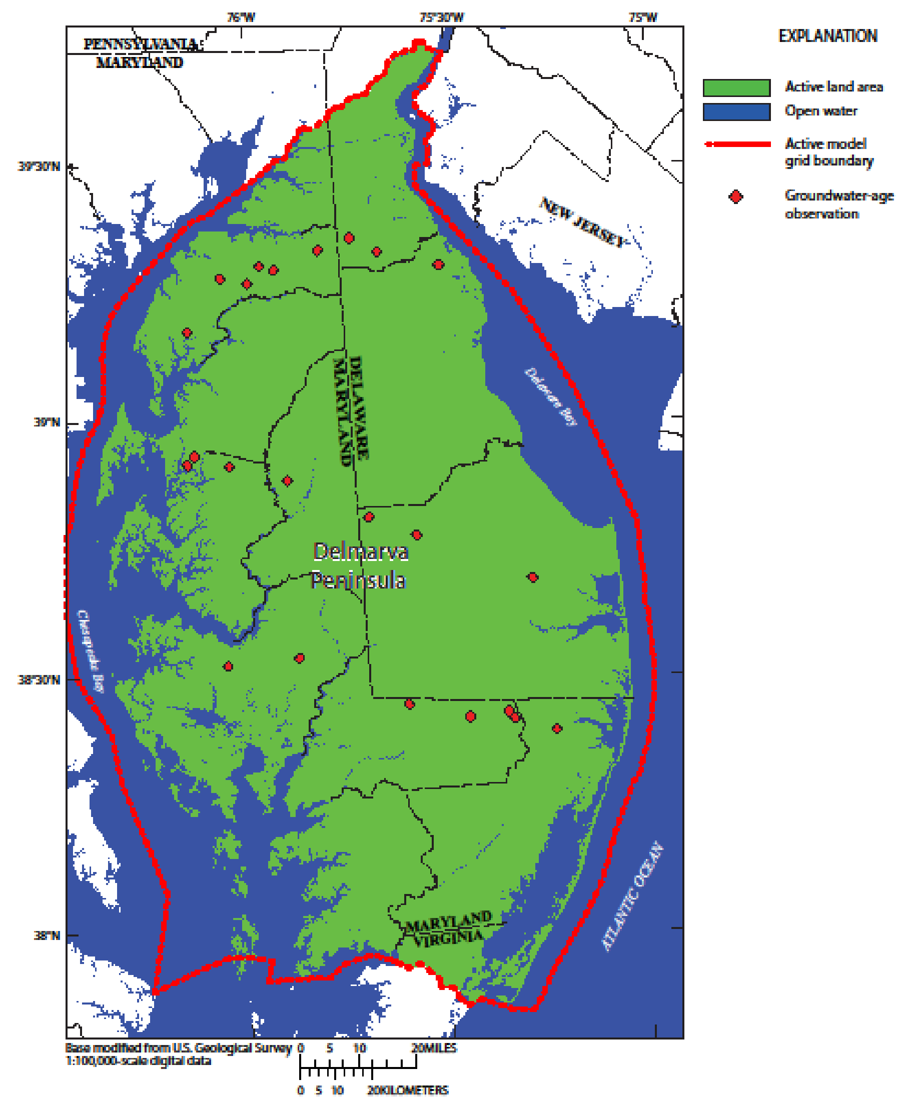


Figure 32. Locations of the 24 wells where samples were collected for groundwater-age observations.

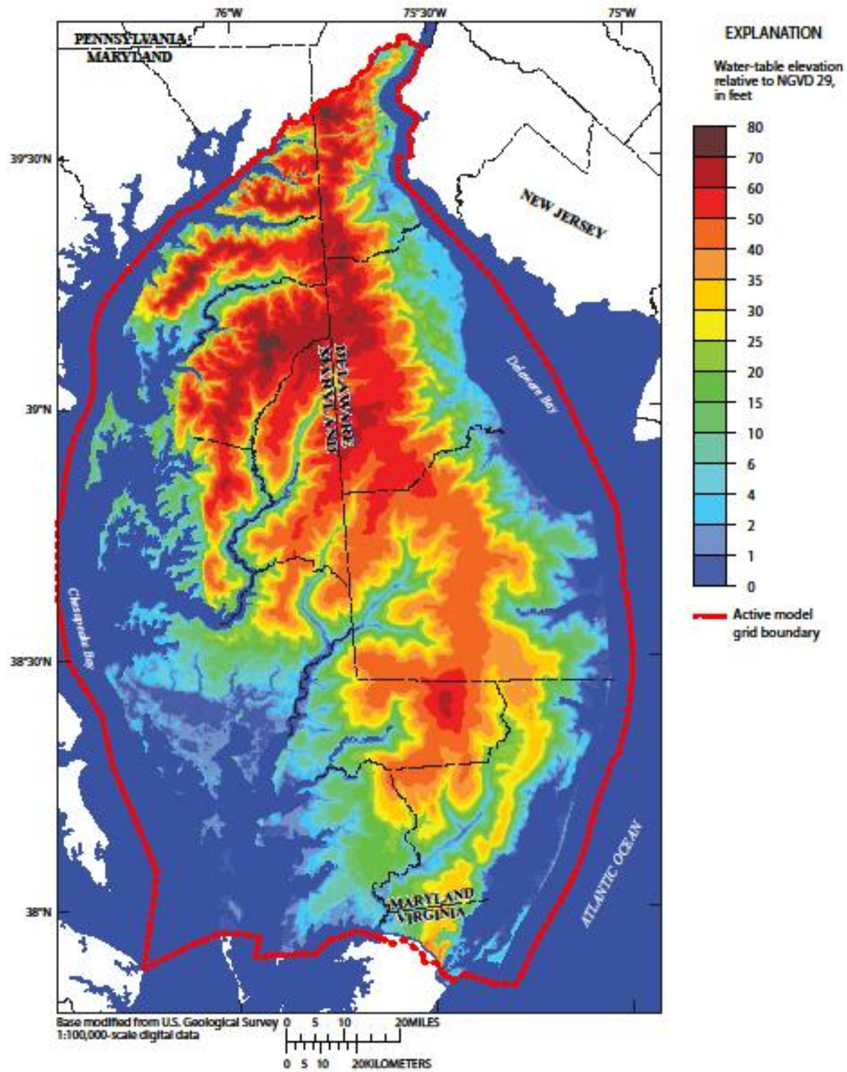


Figure 37. Simulated water table on the Delmarva Peninsula represented by water levels in layer 1 of the model.

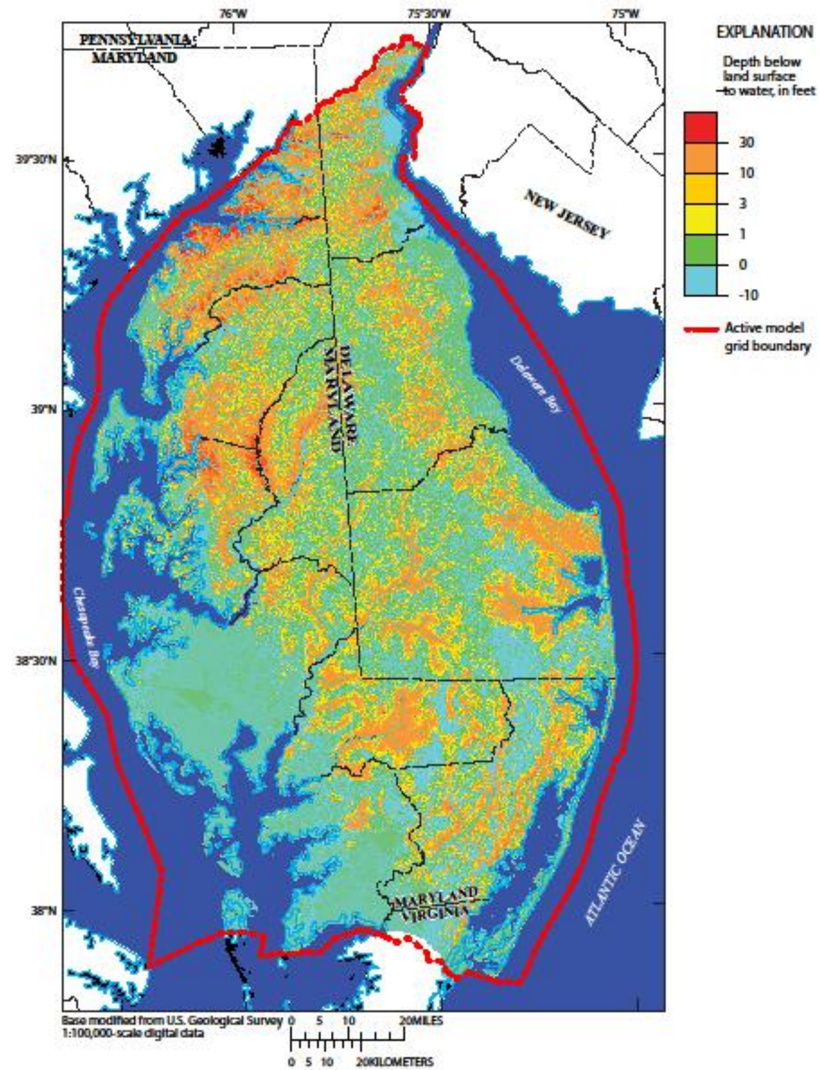
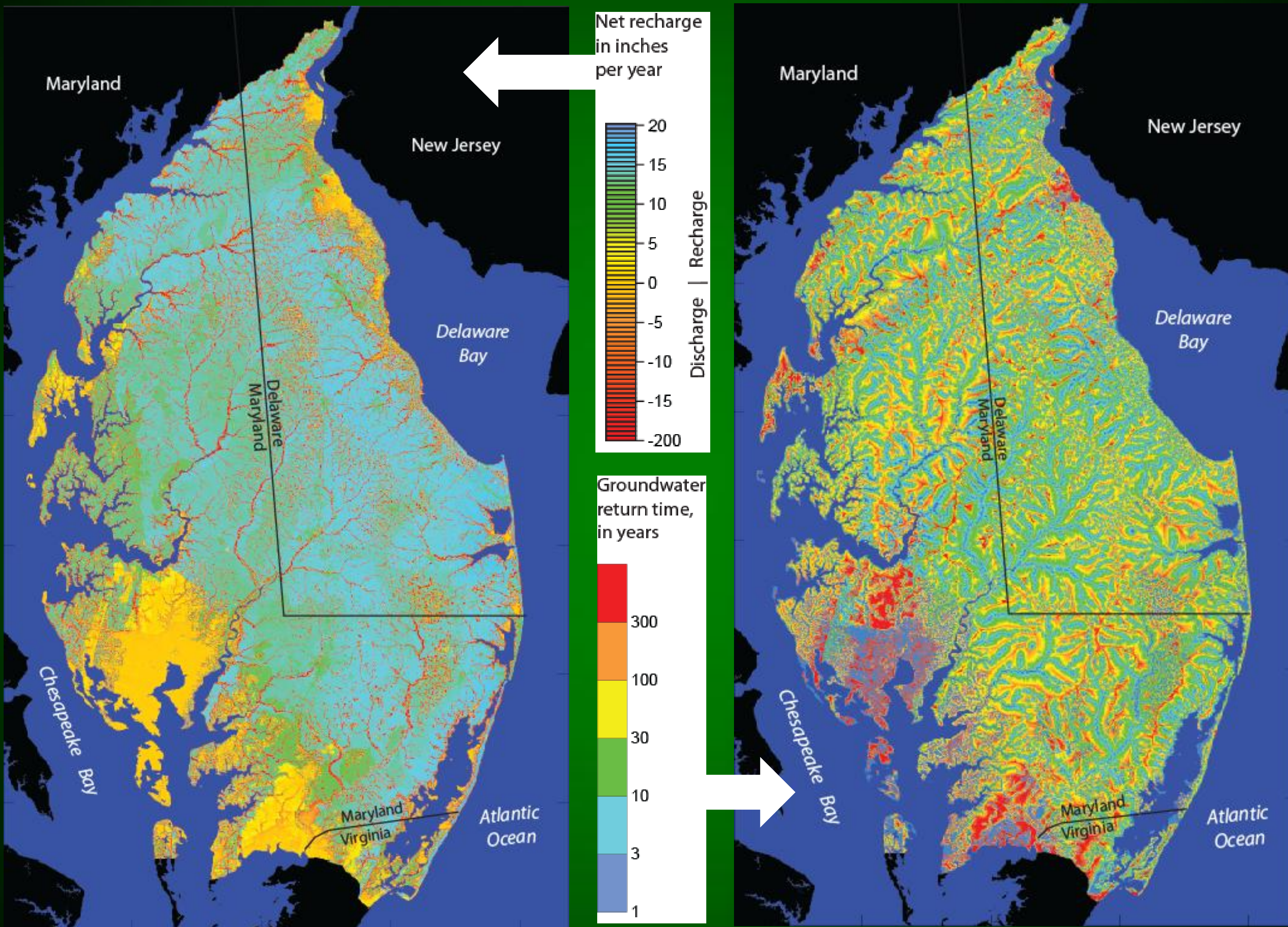
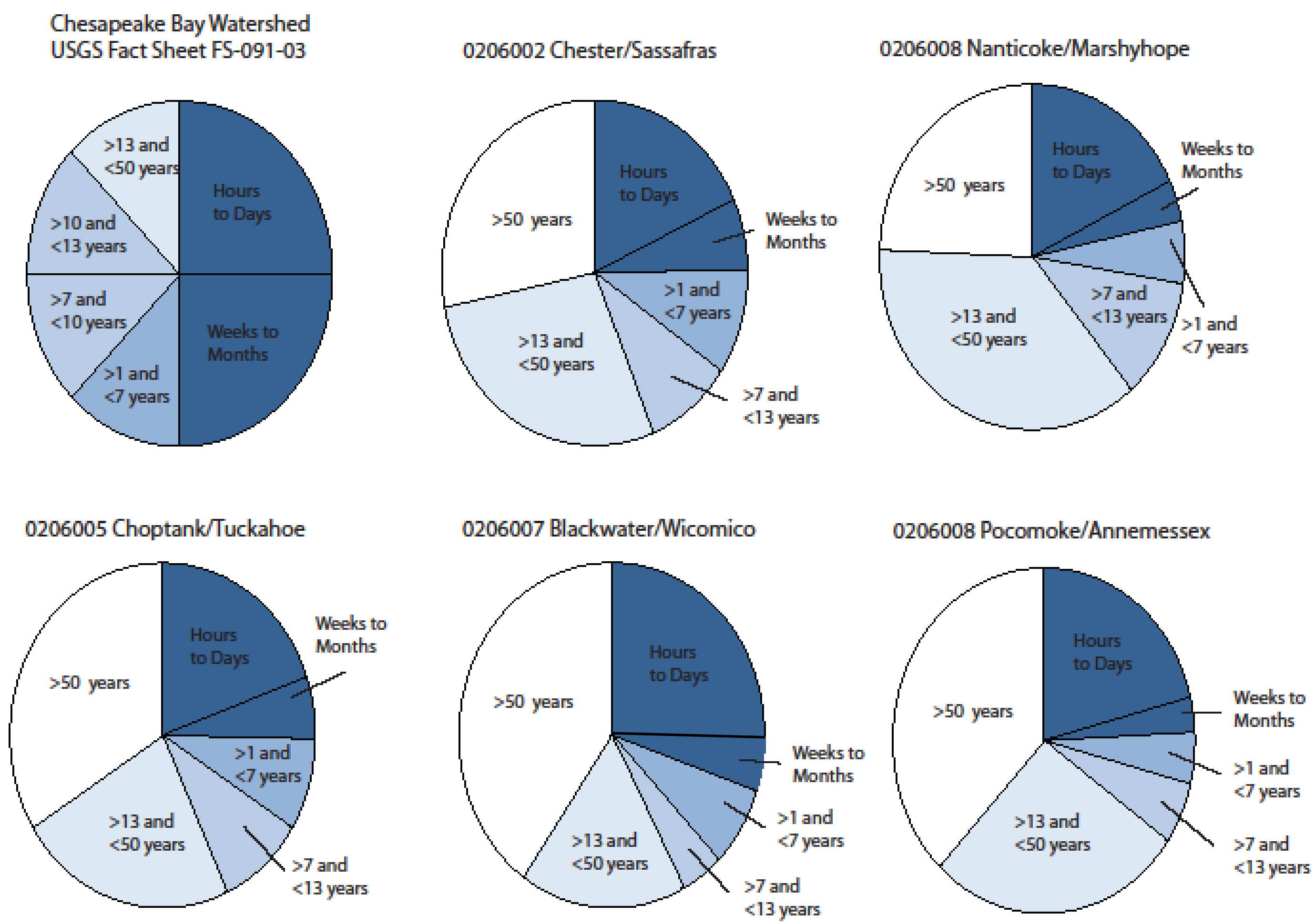


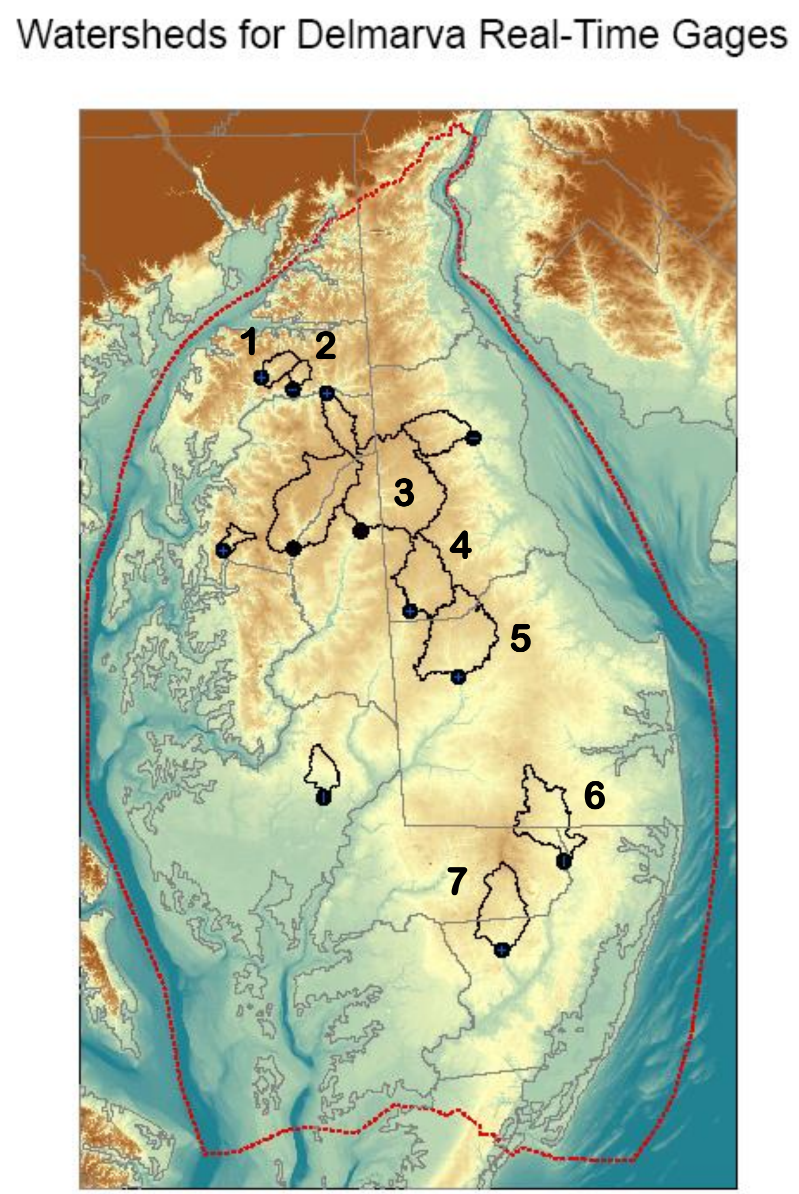
Figure 39. Simulated depth of the water table beneath the land surface. Negative values represent artesian conditions.


Maryland
New Jersey
Delaware Bay
Delaware
Maryland
Chesapeake Bay
Maryland
Virginia
Atlantic Ocean
Net recharge in inches per year
20
15
10
5
0
-5
-10
-15
-200
Discharge | Recharge
Groundwater return time, in years
300
100
30
10
3
1
Maryland
New Jersey
Delaware Bay
Delaware
Maryland
Chesapeake Bay
Maryland
Virginia
Atlantic Ocean


Chesapeake Bay Watershed
USGS Fact Sheet FS-091-03
>13 and <50 years
Hours to Days
>10 and <13 years
>7 and <10 years
Weeks to Months
>1 and <7 years
0206002 Chester/Sassafras
>50 years
Hours to Days
Weeks to Months
>1 and <7 years
>13 and <50 years
>7 and <13 years
0206008 Nanticoke/Marshyhope
>50 years
Hours to Days
Weeks to Months
>7 and <13 years
>13 and <50 years
>1 and <7 years
0206005 Choptank/Tuckahoe
>50 years
Hours to Days
Weeks to Months
>1 and <7 years
>13 and <50 years
>7 and <13 years
0206007 Blackwater/Wicomico
>50 years
Hours to Days
Weeks to Months
>1 and <7 years
>13 and <50 years
>7 and <13 years
0206008 Pocomoke/Annemessex
>50 years
Hours to Days
Weeks to Months
>1 and <7 years
>13 and <50 years
>7 and <13 years

Seven watersheds had substantial stream nitrate Data and were used:

1. Morgan Creek
2. Chesterville Branch
3. Choptank River
4. Marshyhope Creek
5. Nanticoke River
6. Pocomoke River
7. Nassawango Creek



USGS

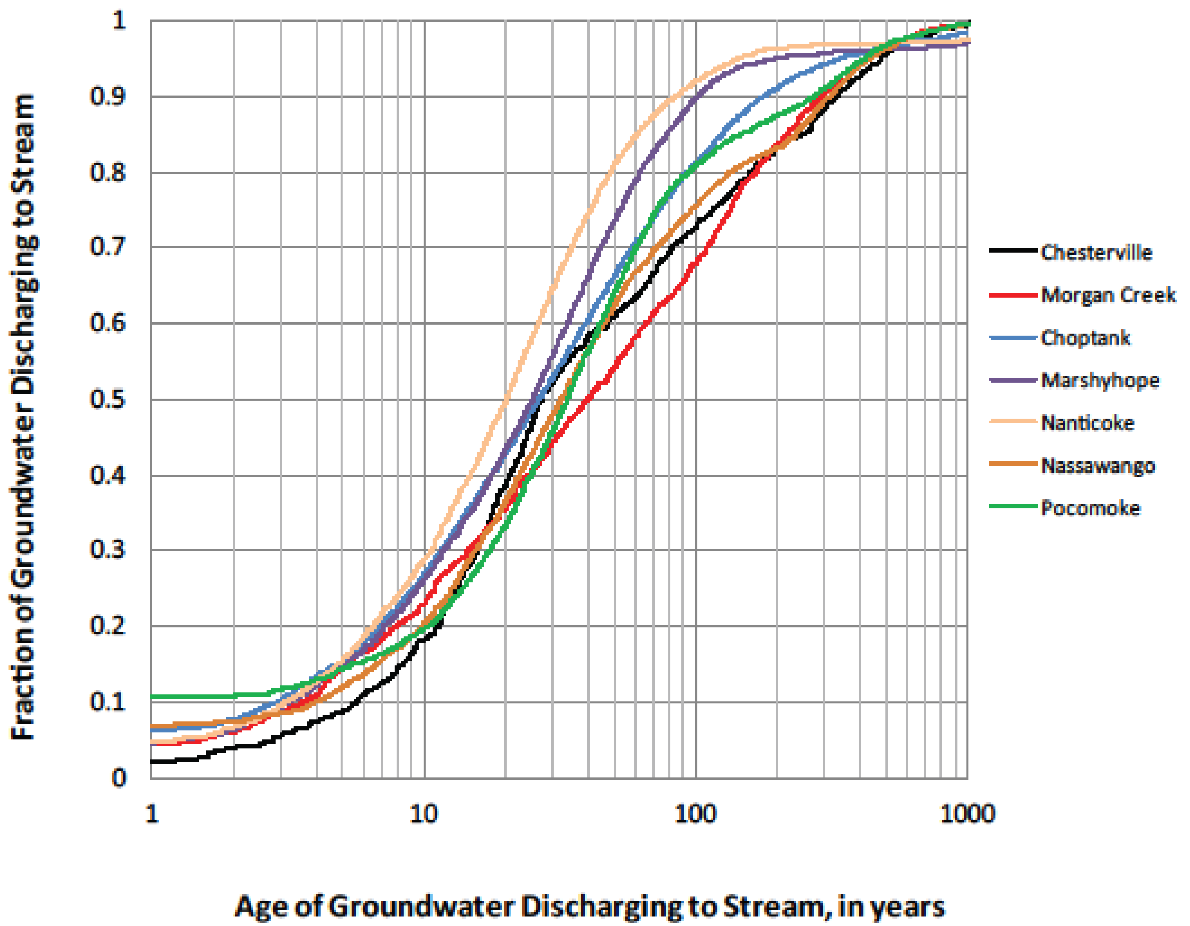
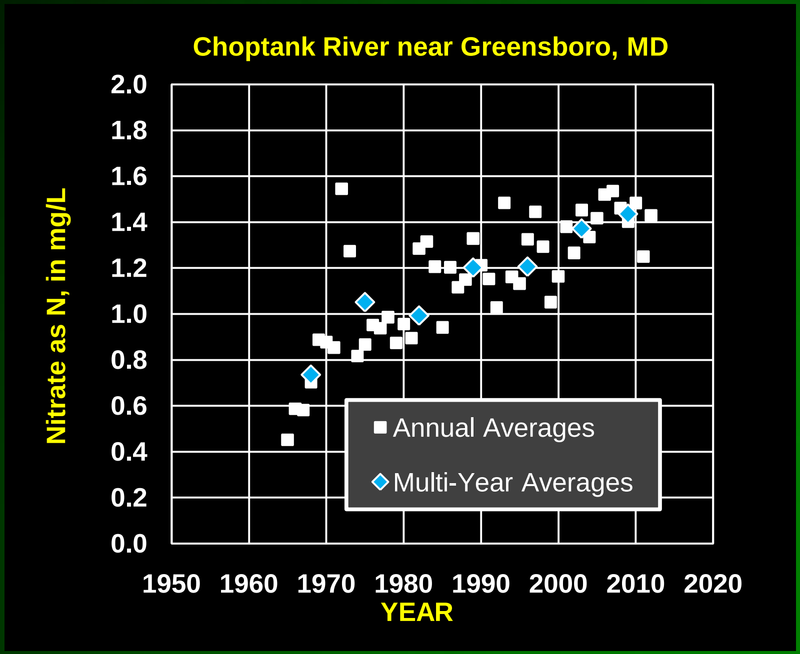
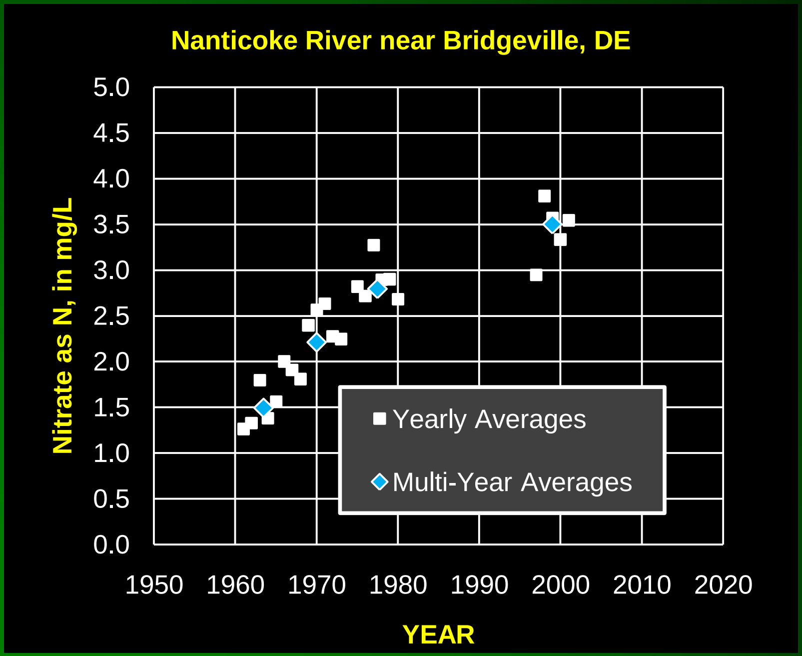
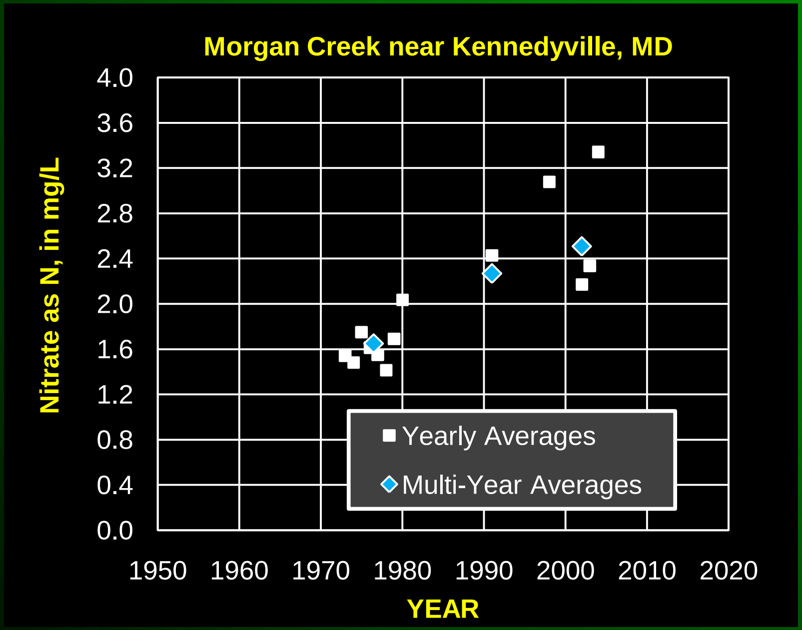
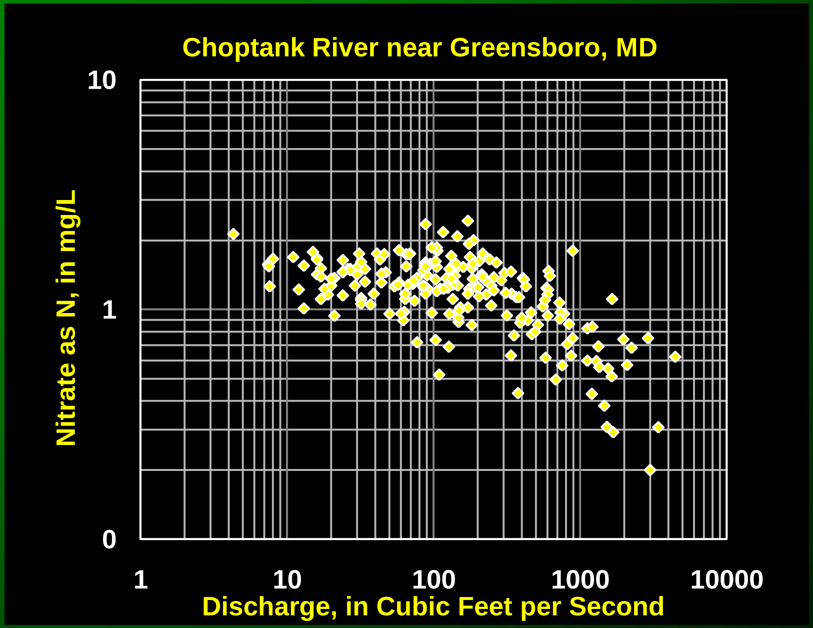


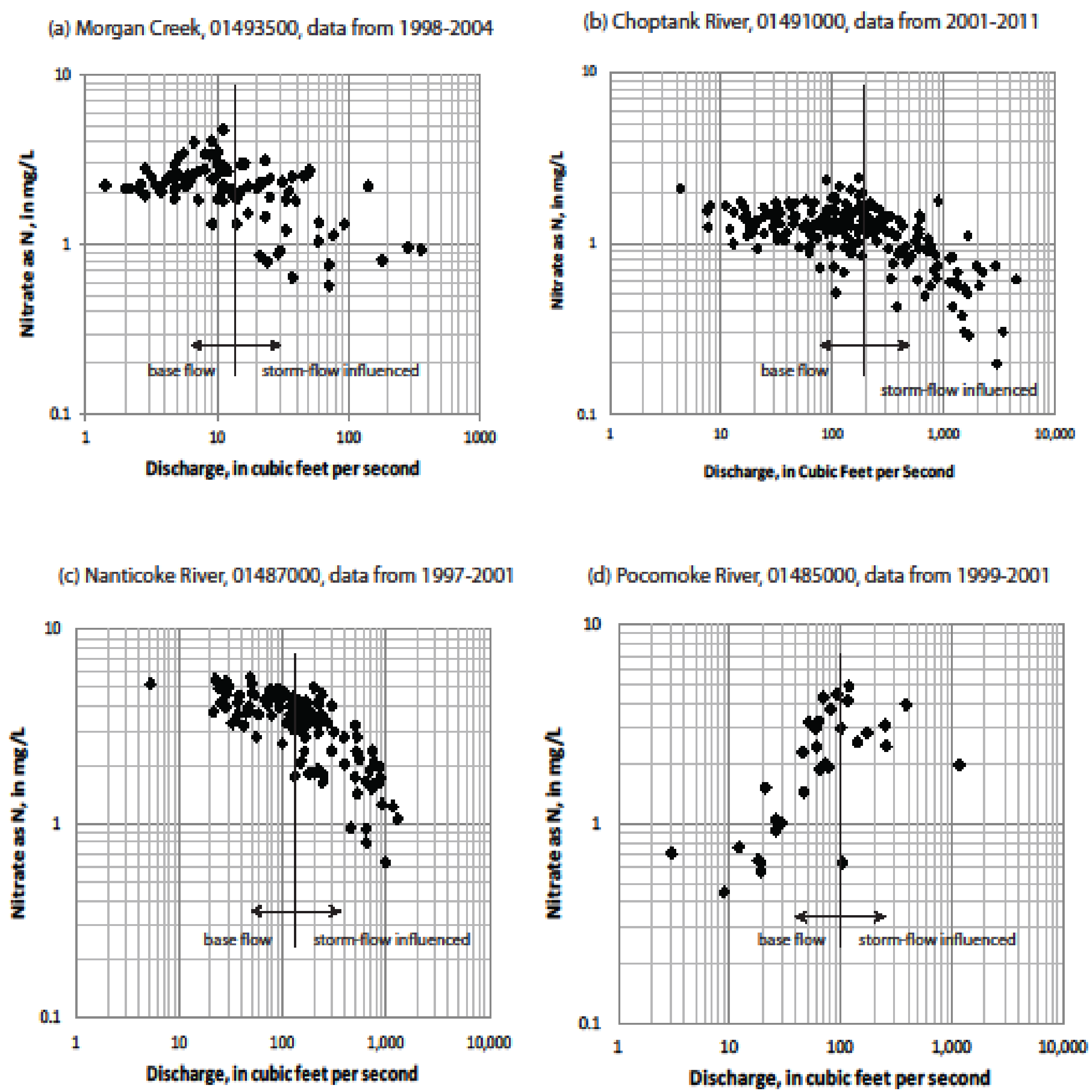
Figure 17. Cumulative distribution of simulated base-flow age at the real-time stream gages used in this study.


Choptank River near Greensboro, MD
Nitrate as N, in mg/L
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1950 1960 1970 1980 1990 2000 2010 2020
YEAR
Annual Averages
Multi-Year Averages


Nanticoke River near Bridgeville, DE
Nitrate as N, in mg/L
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
1950 1960 1970 1980 1990 2000 2010 2020
YEAR
Yearly Averages
Multi-Year Averages


Morgan Creek near Kennedyville, MD
Nitrate as N, in mg/L
4.0
3.6
3.2
2.8
2.4
2.0
1.6
1.2
0.8
0.4
0.0
1950 1960 1970 1980 1990 2000 2010 2020
YEAR
Yearly Averages
Multi-Year Averages


Choptank River near Greensboro, MD
Nitrate as N, in mg/L
10
1
0
1 10 100 1000 10000
Discharge, in Cubic Feet per Second



(a) Morgan Creek, 01493500, data from 1998-2004
Nitrate as N, in mg/L
10
1
0.1
1
10
100
1000
base flow
storm-flow influenced
Discharge, in cubic feet per second
(b) Choptank River, 01491000, data from 2001-2011
Nitrate as N, in mg/L
10
1
0.1
1
10
100
1,000
10,000
base flow
storm-flow influenced
Discharge, in Cubic Feet per Second
(c) Nanticoke River, 01487000, data from 1997-2001
Nitrate as N, in mg/L
10
1
0.1
1
10
100
1,000
10,000
base flow
storm-flow influenced
Discharge, in cubic feet per second
(d) Pocomoke River, 01485000, data from 1999-2001
Nitrate as N, in mg/L
10
1
0.1
1
10
100
1,000
10,000
base flow
storm-flow influenced
Discharge, in cubic feet per second

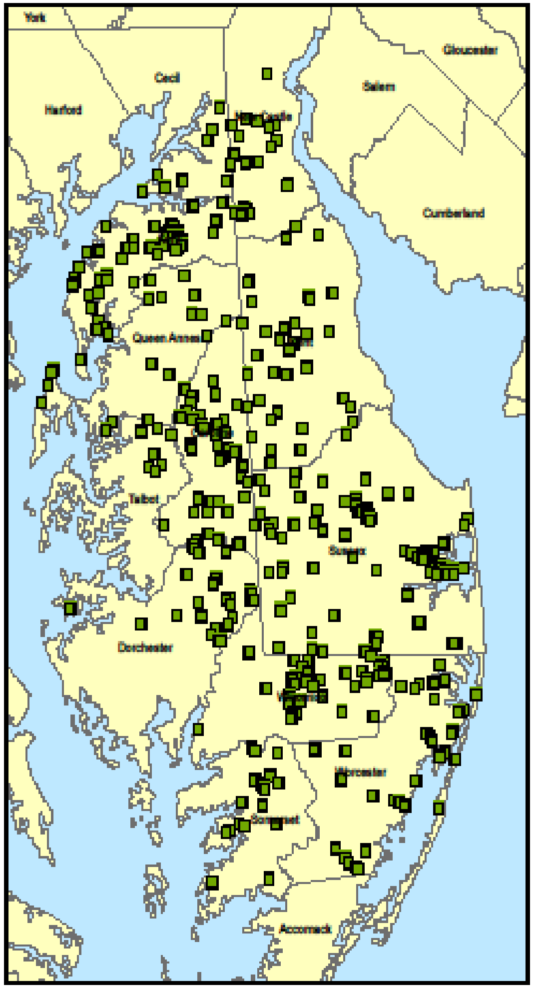


Figure 21. Locations of shallow wells (<100 ft) on the Delmarva Peninsula with groundwater nitrate concentration data.

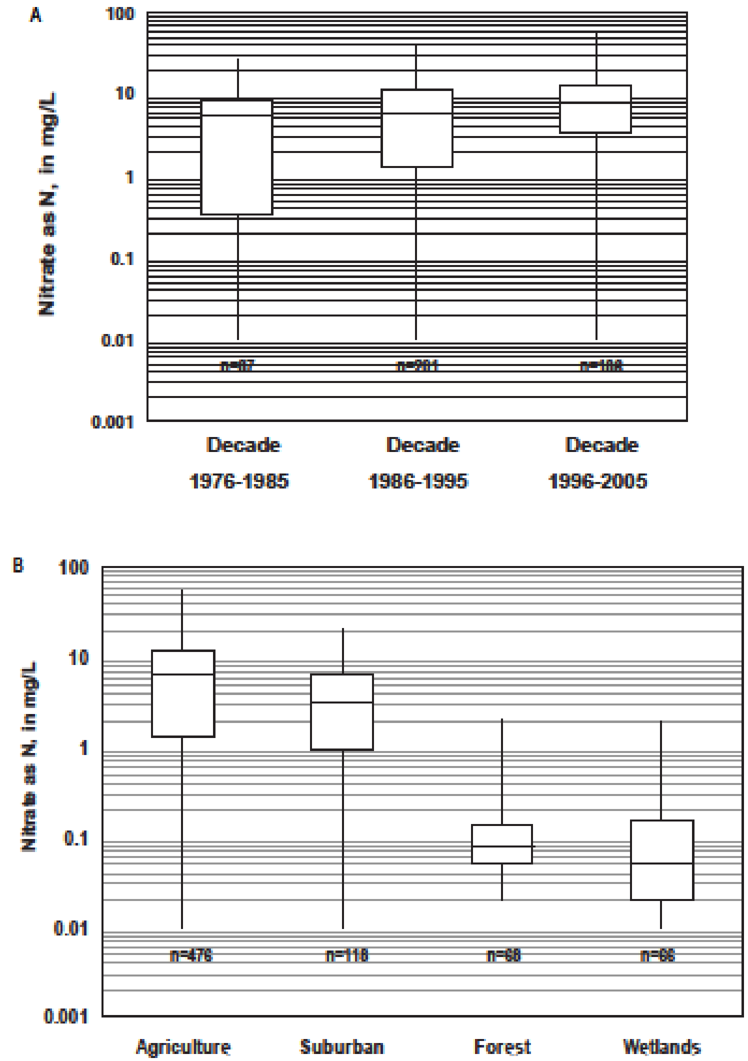


Figure 22. Mean concentration of nitrate in groundwater by (A) decade and (B) land cover type.

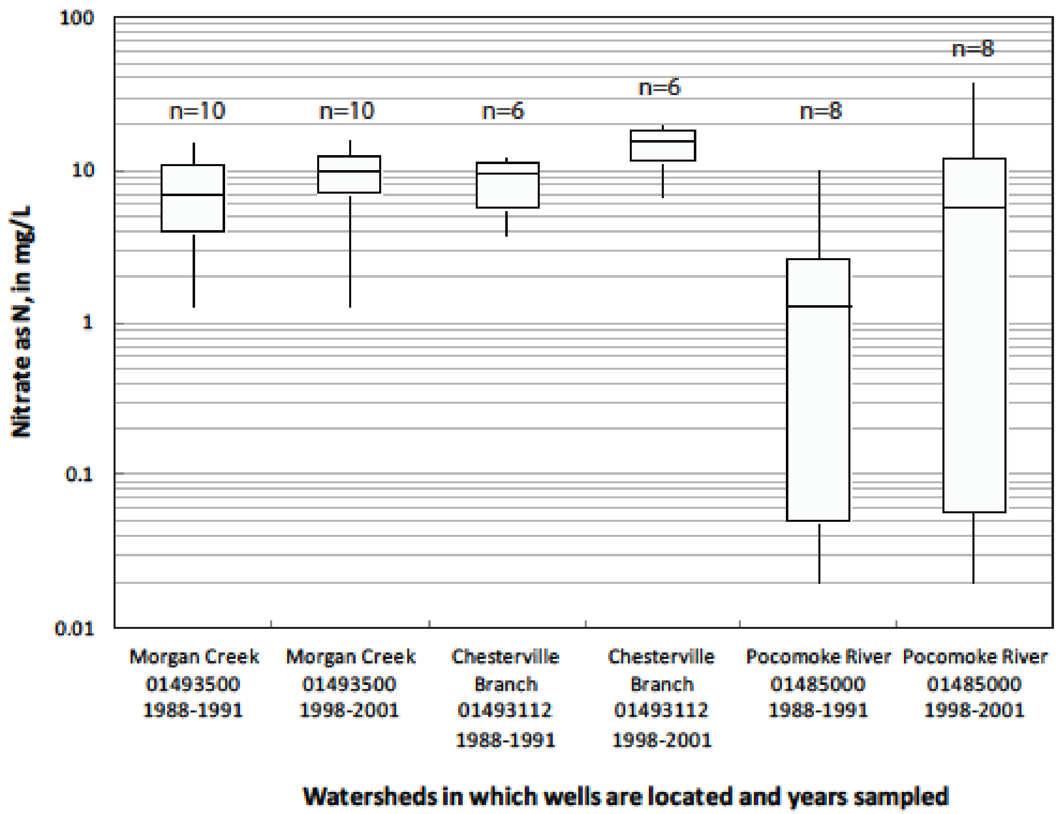


Figure 28. Nitrate concentrations in groundwater resampled from wells after nine or more years

Nitrate Mass-Balance Regression Equation

Simulated surface water concentration in stream = Soil Term x Riparian Term (Denitrification) x $\sum_{n=1}^{\text{No. pathlines}}$ Concentration at water table at recharge year x Denitrification rate along flow path

Simulated groundwater concentration in ag field well = Soil Term x Concentration at water table at recharge year x Denitrification rate along flow path

FUE & PUE =Fertilizer and Poultry Uptake Efficiencies

Concentration at water table at recharge year = Recharge Rate x {Fertilizer Load x [1 - FUE] + Poultry Load x [1 - PUE]}

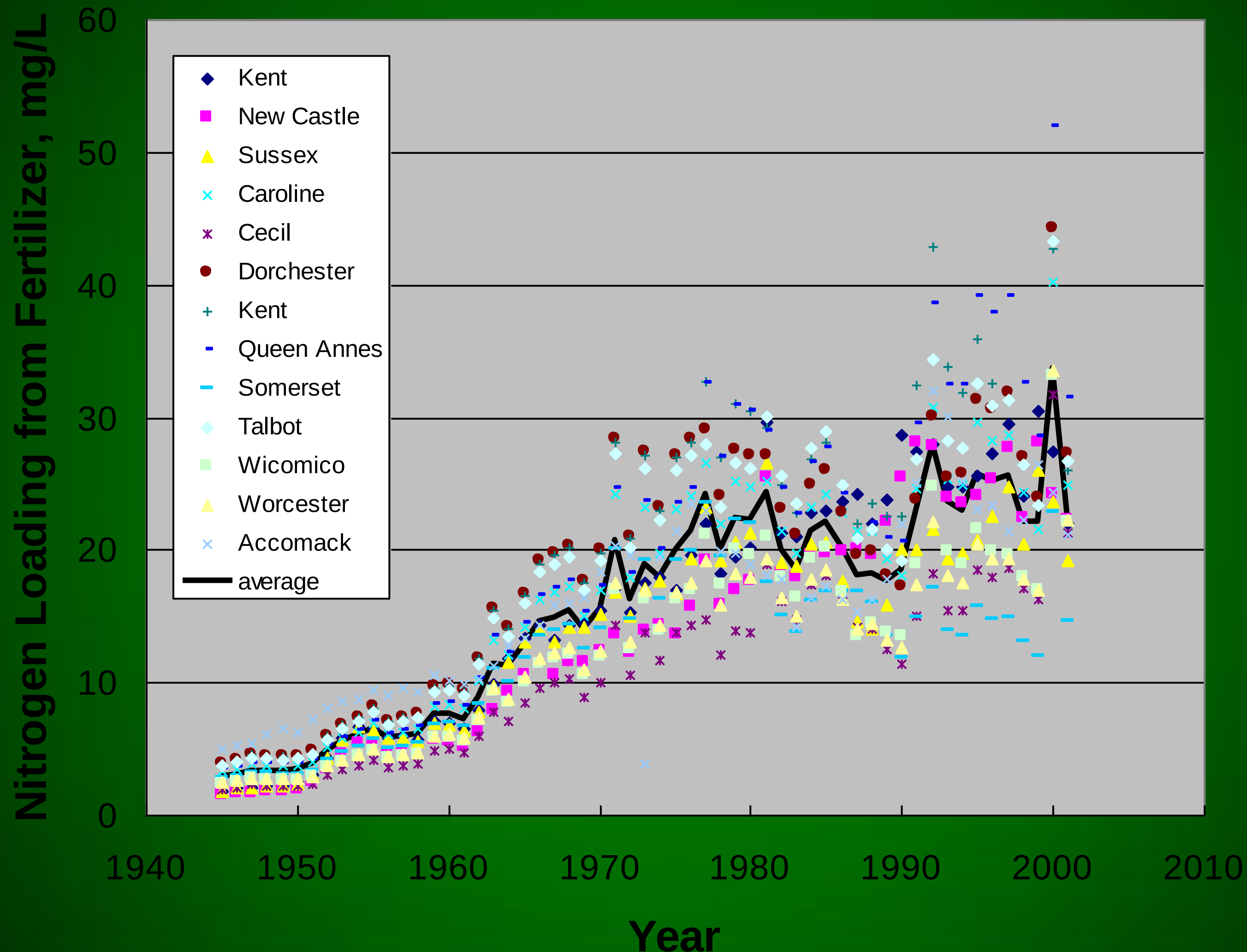
Soil Term $= (S/5)^m$

Riparian Term $= (AREA)^n$

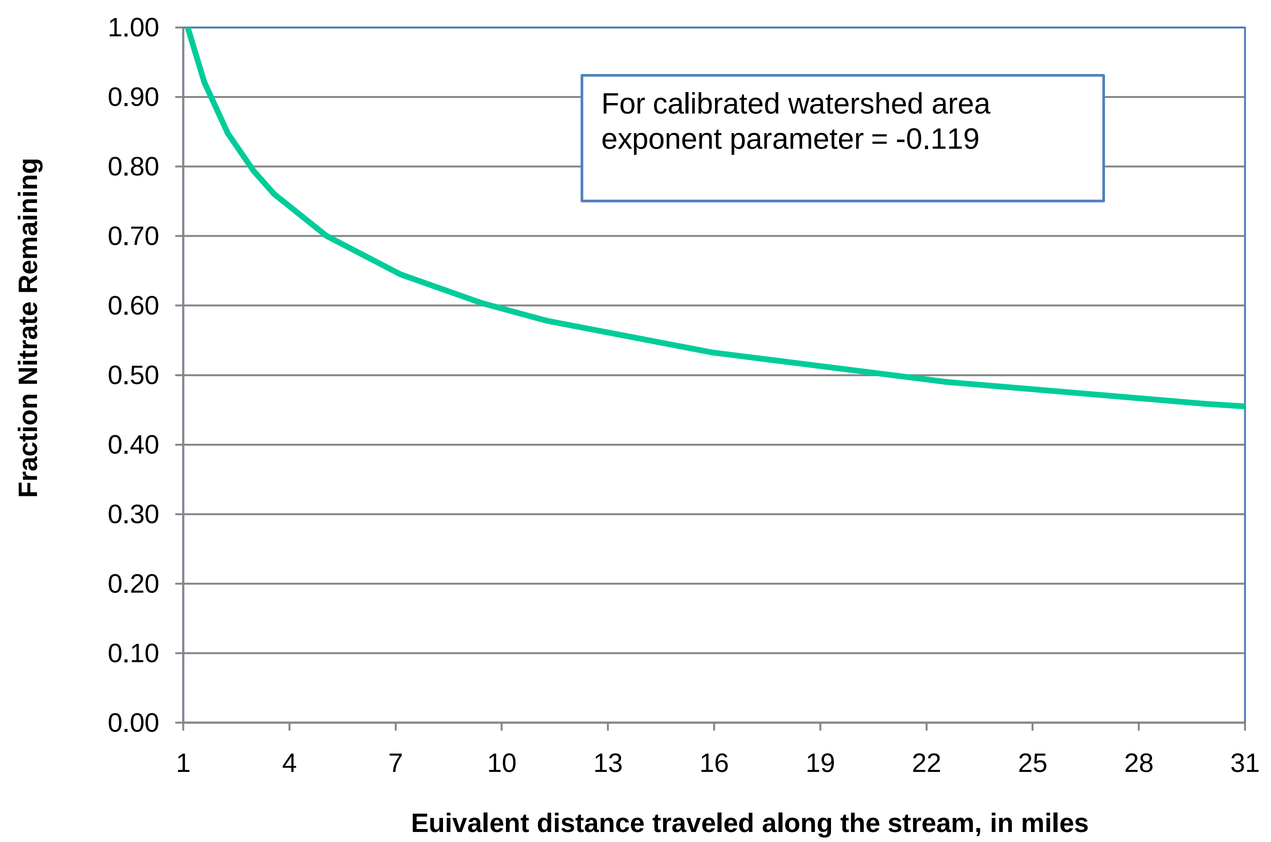
S = soil drainage factor

AREA is for the watershed In square miles

USGS

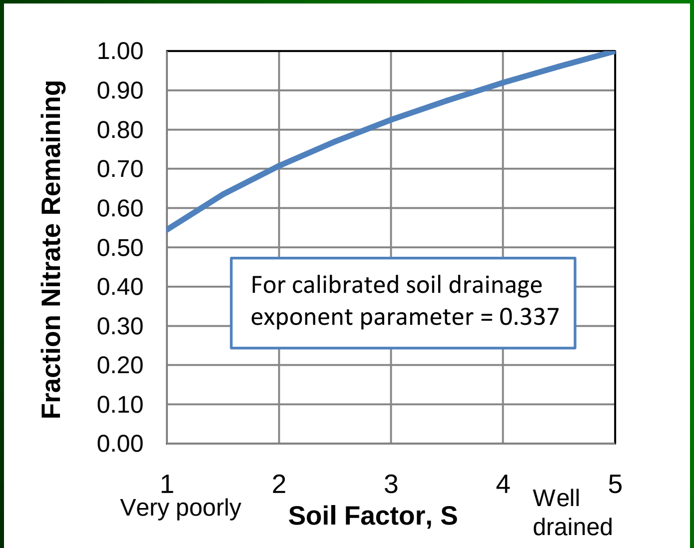

Nitrogen Loading from Fertilizer, mg/L
0
10
20
30
40
50
60
1940
1950
1960
1970
1980
1990
2000
2010
Year
Kent
New Castle
Sussex
Caroline
Cecil
Dorchester
Kent
Queen Annes
Somerset
Talbot
Wicomico
Worcester
Accomack
average

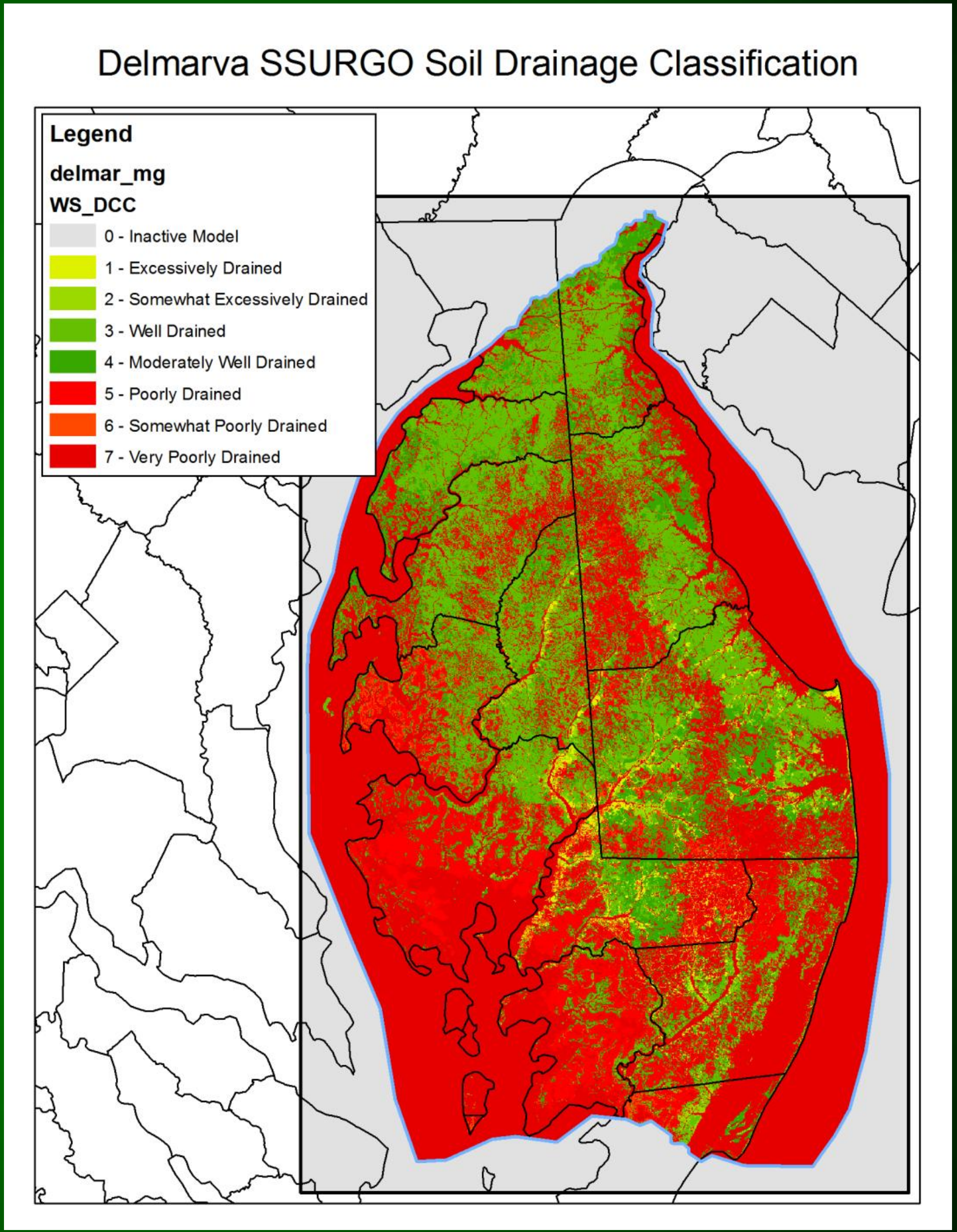
Stream and Riparian Denitrification



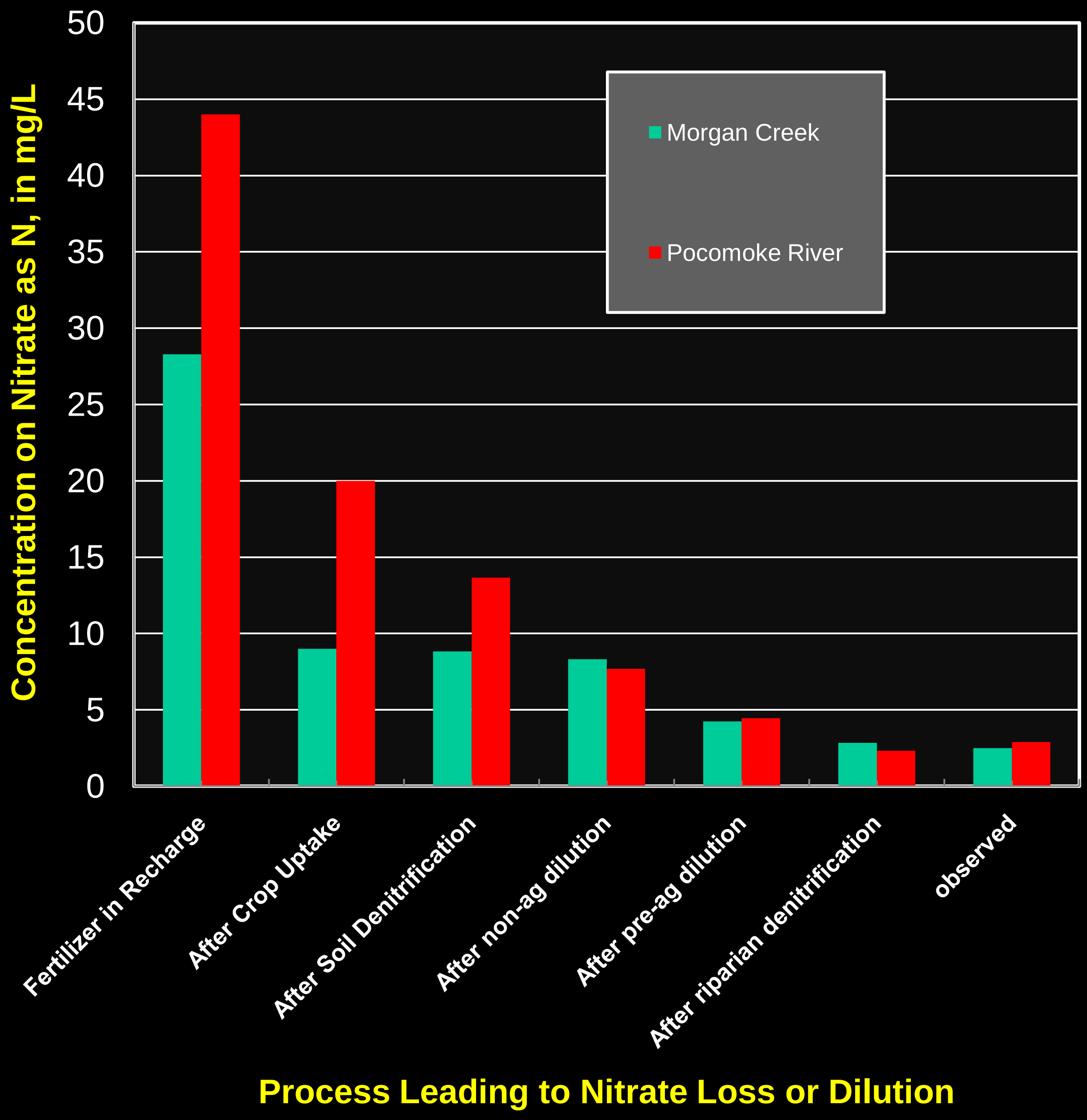
Soil Factor (S) in Equation:

1. Very poorly drained
2. Somewhat poorly drained
3. Poorly drained
4. Moderately well drained
5. Well drained
6. Somewhat excessively drained
7. Excessively drained





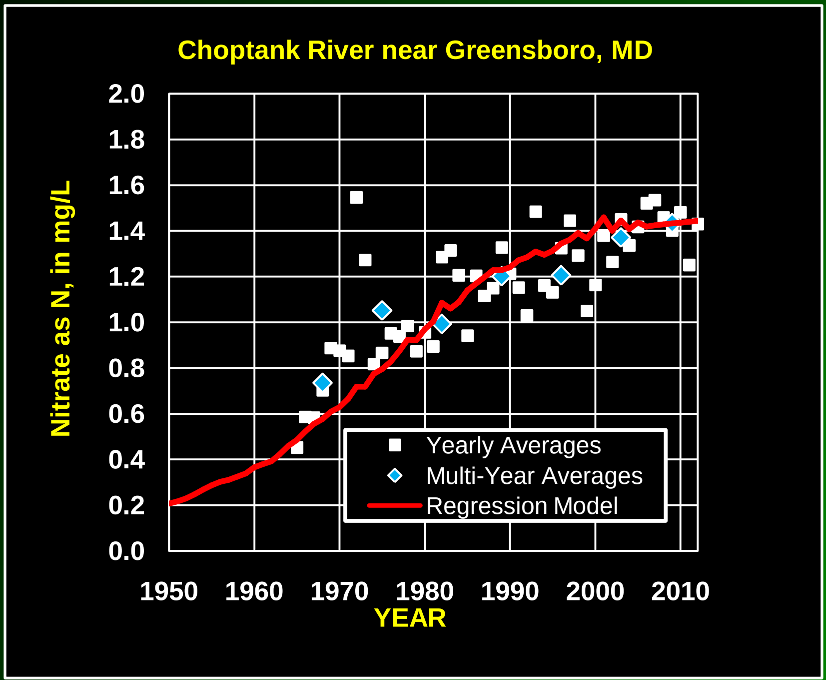
USGS

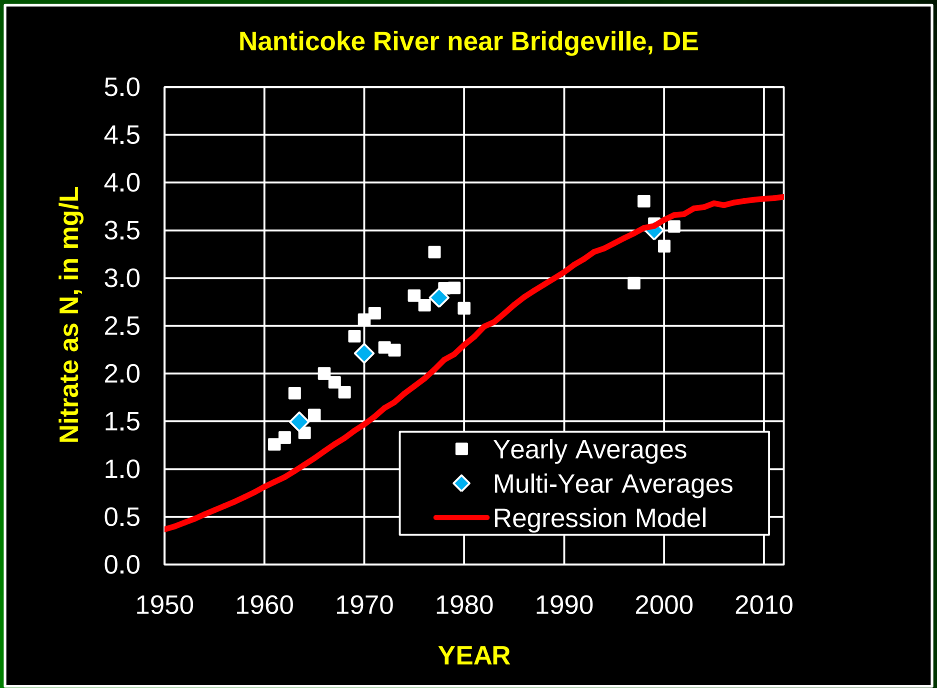

Concentration on Nitrate as N, in mg/L
50
45
40
35
30
25
20
15
10
5
0
Morgan Creek
Pocomoke River
Fertilizer in Recharge
After Crop Uptake
After Soil Denitrification
After non-ag dilution
After pre-ag dilution
After riparian denitrification
observed
Process Leading to Nitrate Loss or Dilution

Regression Number	Fertilizer Uptake Efficiency	Manure Uptake Efficiency	Percent Increase in Uptake Efficiencies	Riparian and Stream Denitrificaiton loss exponent	Soil Deintirficaiton loss exponent	Number of Parameters estimated	Sum of Squared Weighted Residuals	Standard Error of Regression
1	83%	83%	0	0	0	2	6141	89
2	82%	70%	0	0	0.670	3	5721	83
3	72%	63%	0	-0.152	0	3	2394	35
4	72%	46%	0	-0.146	0.425	4	2139	31
5	67%	47%	24%	-0.119	0.377	5	1651	25
10% upper parameter value limit	70%	62%	40%	-0.120	0.77	5	2056	40
10% lower parameter value limit	64%	32%	12%	-0.155	0.1	5	2056	40
10% limits as percent of value	4%	32%	38%	13%	82%	5	2056	40

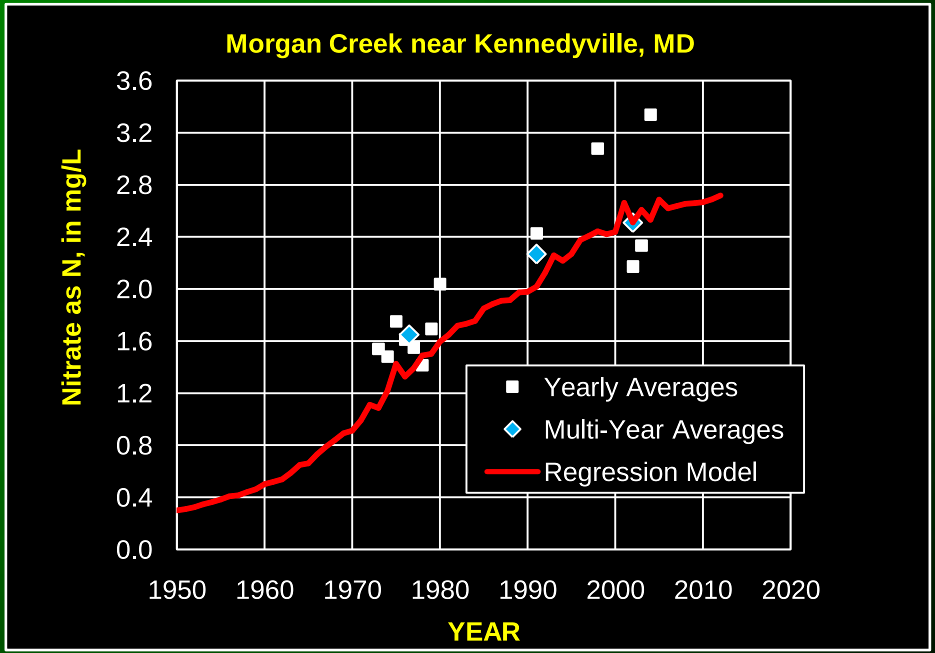
USGS

Watershed Name	Type of Observation	Year of Observation	Observed value, as mean nitrate concentration, in mg/L	Standard Error	Weight, as 1/(standard error)	Simulated value from regression equation, in mg/L	Residual, in mg/L	Squared weighed residual	Natural log of observed value	Natural log of simulated value	Residual of natural log values	Squared weighted residual of natural logs
Chesterville Branch	SW	1999	6.47	0.140	7.14	3.37	3.10	489.42	1.87	1.22	0.65	25.5
Morgan Creek	SW	1976	1.62	0.054	18.52	1.81	-0.19	12.42	0.48	0.59	-0.11	4.1
Morgan Creek*	SW	1990	2.27	0.376	2.66	2.36	-0.10	0.07	0.82	0.86	-0.04	0.0
Morgan Creek*	SW	2002	2.55	0.084	59.52	2.61	-0.06	14.78	0.94	0.96	-0.03	0.1
Marshyhope Creek	SW	1977	1.07	0.065	15.38	0.88	0.19	8.37	0.07	-0.13	0.19	10.0
Nassawango Creek	SW	1999	0.31	0.041	24.39	1.09	-0.78	359.77	-1.17	0.08	-1.26	502.4
Pocomoke River	SW	1990	2.31	0.815	1.23	1.90	0.41	0.25	0.84	0.64	0.19	0.1
Pocomoke River	SW	2000	2.60	0.263	19.01	2.18	0.42	65.13	0.96	0.78	0.18	0.5
Nanticoke River	SW	1965	1.55	0.126	7.91	1.33	0.22	3.14	0.44	0.28	0.16	3.9
Nanticoke River	SW	1971	2.29	0.087	11.45	1.93	0.36	17.40	0.83	0.66	0.17	2.7
Nanticoke River*	SW	1998	2.95	0.137	7.30	2.68	0.27	3.93	1.08	0.99	0.10	0.5
Nanticoke River*	SW	2001	4.12	0.107	46.60	4.09	0.03	2.06	1.42	1.41	0.01	0.0
Choptank River	SW	1968	0.72	0.035	28.71	0.76	-0.04	1.04	-0.33	-0.28	-0.05	2.1
Choptank River	SW	1976	0.89	0.051	19.68	1.07	-0.18	12.91	-0.12	0.07	-0.19	15.8
Choptank River	SW	1982	1.00	0.038	26.32	1.27	-0.27	51.69	0.00	0.24	-0.24	45.0
Choptank River	SW	1989	1.21	0.026	38.44	1.43	-0.21	67.09	0.19	0.36	-0.16	45.5
Choptank River	SW	1996	1.24	0.035	28.64	1.45	-0.21	35.53	0.22	0.37	-0.16	25.0
Choptank River*	SW	2003	1.35	0.038	26.38	1.46	-0.11	8.39	0.30	0.38	-0.08	5.3
Choptank River*	SW	2009	1.46	0.042	118.93	1.46	0.00	0.00	0.38	0.38	0.00	0.0
Morgan Creek	GW	1990	7.70	1.500	0.67	6.26	1.44	0.93	2.04	1.83	0.21	0.02
Morgan Creek	GW	1999	9.40	1.300	0.77	6.90	2.50	3.71	2.24	1.93	0.31	0.06
Chesterville Branch	GW	1989	8.50	1.400	0.71	8.81	-0.31	0.05	2.14	2.18	-0.04	0.00
Chesterville Branch	GW	2000	14.20	2.000	0.50	7.62	6.58	10.82	2.65	2.03	0.62	0.10
Pocomoke River	GW	1990	2.40	1.200	0.83	9.56	-7.16	35.64	0.88	2.26	-1.38	1.33
Pocomoke River	GW	1999	9.50	4.500	0.22	12.55	-3.05	0.46	2.25	2.53	-0.28	0.00
STSR							**ASR**	**SSWR**				**SSLR**
2181.0							**285.9**	**1205.0**				**690.1**



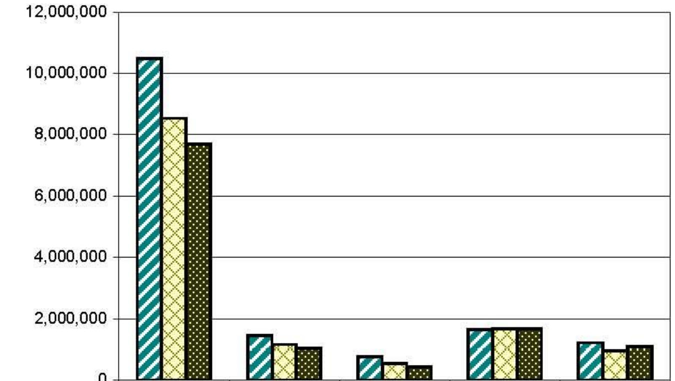


Best Fit for Four Parameters with constant Fertilizer and Manure Uptake Efficiences through Time



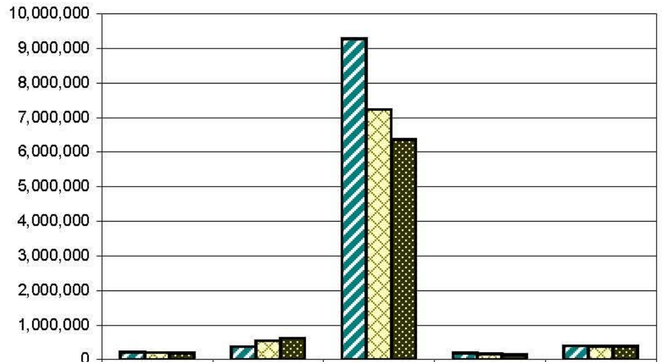
USGS

Phase 2 - Eastern Shore of Chesapeake Bay (Non-Federal & Federal) Total Nitrogen Loads, Delivered



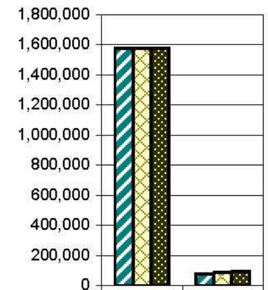
	Agriculture	Urban	Septic	Forest	Wastewater
2009	10,476,704	1,450,719	761,191	1,653,000	1,215,921
2017 Target	8,534,715	1,158,065	531,986	1,664,538	955,028
2020 Target	7,702,435	1,032,642	433,755	1,669,483	1,090,233

Agriculture



	AFO	CAFO	Crop	Pasture	Nursery
2009	223,260	374,104	9,280,152	196,964	402,224
2017 Target	203,170	545,417	7,236,542	159,506	390,081
2020 Target	194,560	618,836	6,360,709	143,452	384,877

Forest

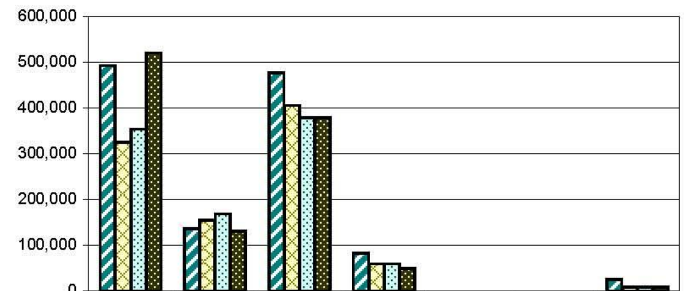


	Forest	Harvested Forest
2009	1,576,233	76,767
2017 Target	1,576,233	88,306
2020 Target	1,576,233	93,251

Urban

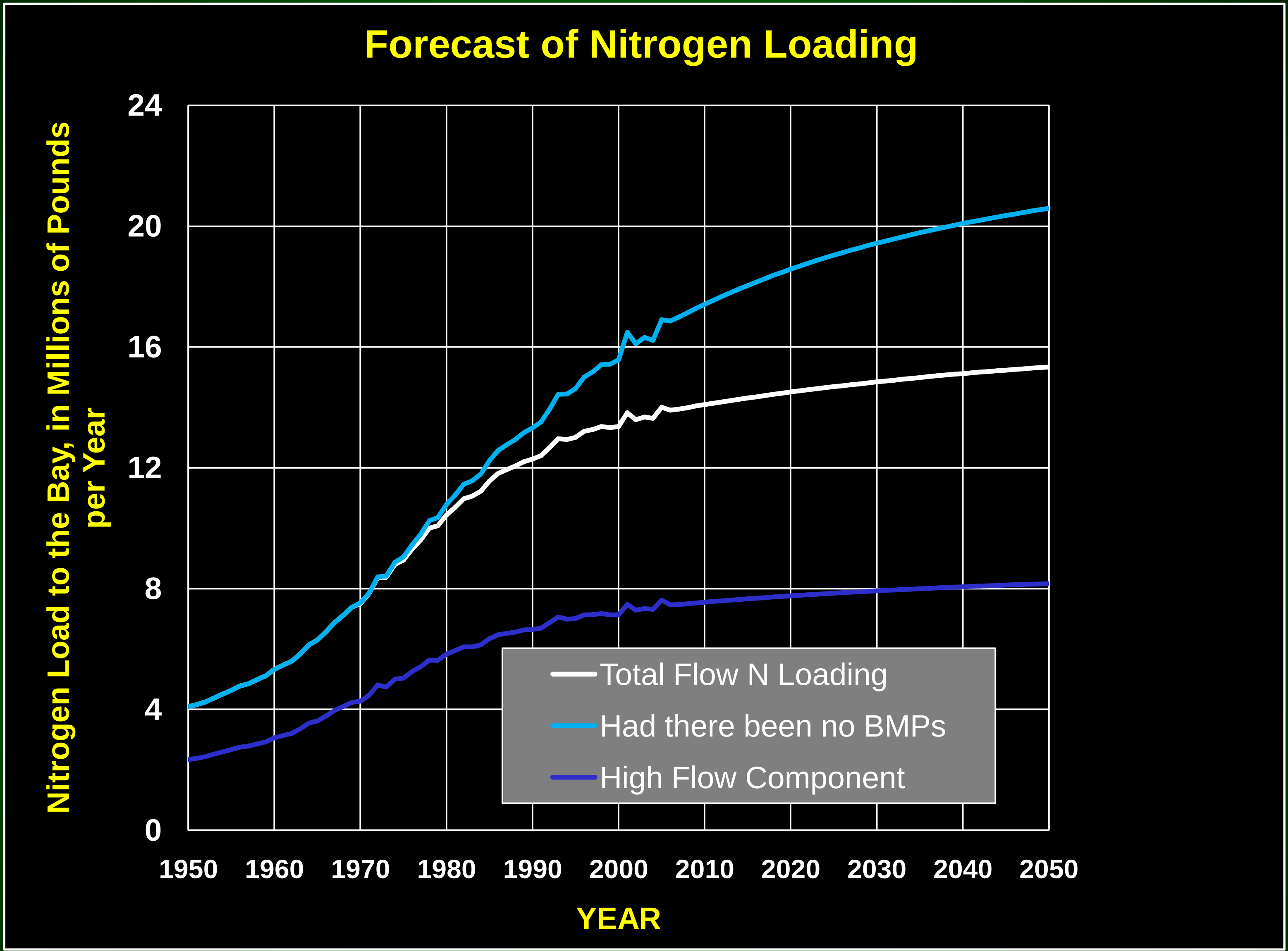
	County Phase I/II MS4	Municipal Phase II MS4	State Phase II MS4	SHA Phase I/II MS4	Regulated Industrial Facilities	Construction	Extractive	Non-regulated	Federal Developed
2009	140,106	71,755	2,276	28,905	19,080	15,247	20,074	1,153,110	164
2017 Target	106,714	58,028	1,780	22,401	14,900	46,760	17,066	890,295	122
2020 Target	92,403	52,144	1,567	19,614	13,108	60,265	15,777	777,660	104

Wastewater

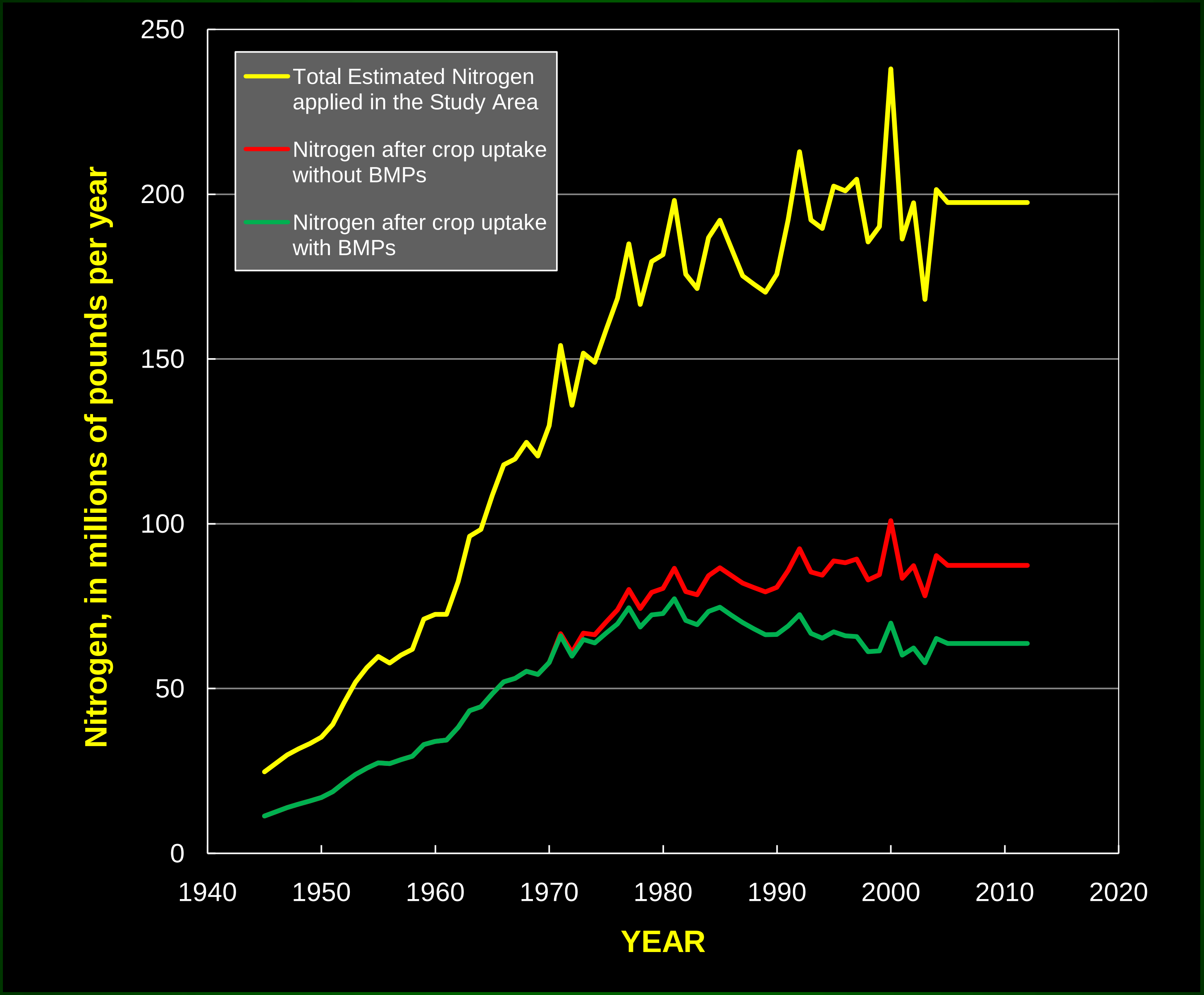


	Major Municipal	Minor Municipal	Major Industrial	Minor Industrial	Major Federal Municipal	Minor Federal Municipal	CSO
2009	493,398	136,277	477,778	82,665	0	47	25,756
2017 Projected	325,418	154,949	406,081	59,632	0	74	8,874
2020 Projected	354,046	168,984	379,500	59,632	0	84	8,874
2020 Target	520,841	131,240	379,500	49,761	0	17	8,874

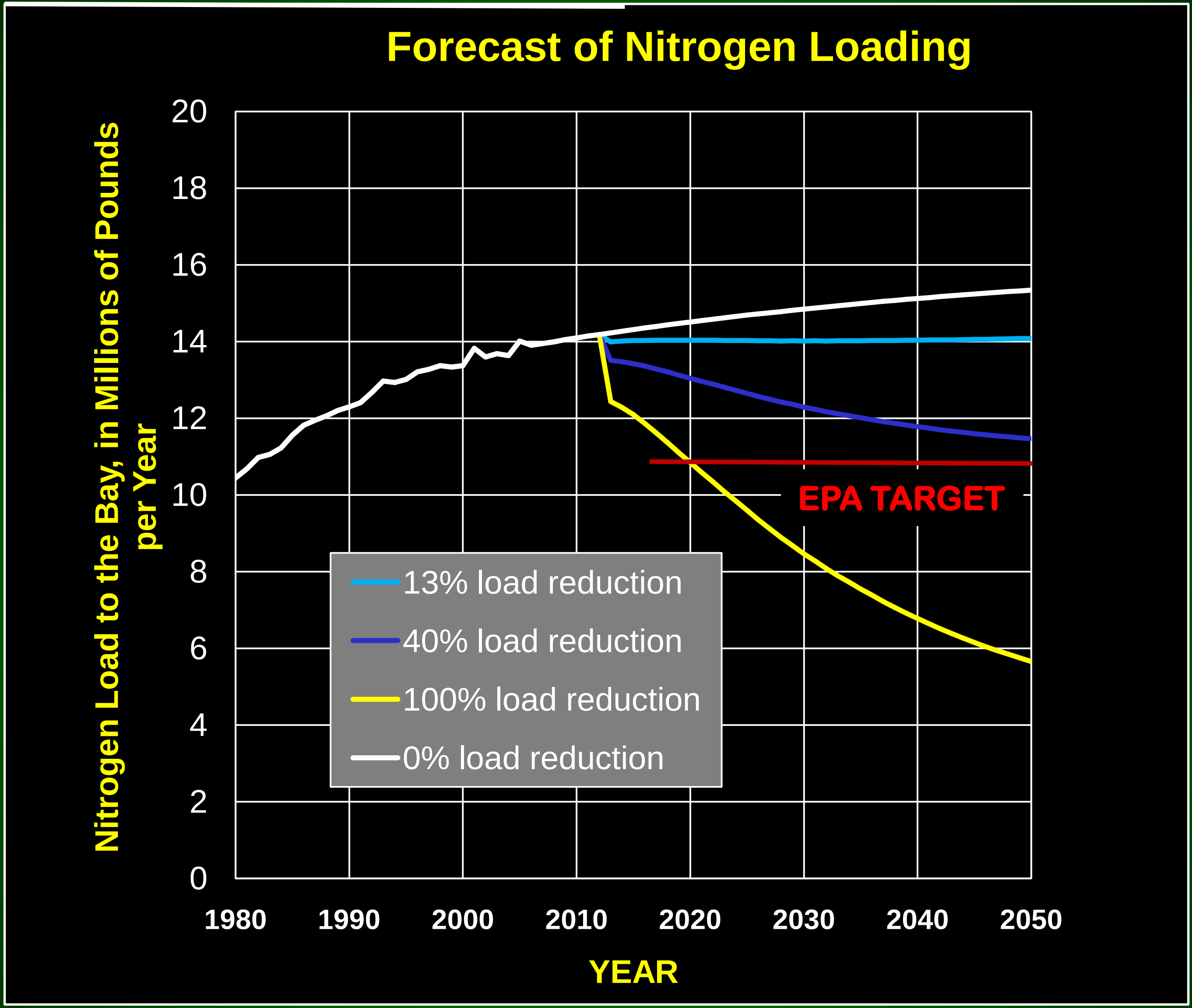
*Delivered loads calculated using delivery factors provided by EPA.


Forecast of Nitrogen Loading
Nitrogen Load to the Bay, in Millions of Pounds per Year
24
20
16
12
8
4
0
1950
1960
1970
1980
1990
2000
2010
2020
2030
2040
2050
YEAR
Total Flow N Loading
Had there been no BMPs
High Flow Component

USGS



Total Estimated Nitrogen applied in the Study Area
Nitrogen after crop uptake without BMPs
Nitrogen after crop uptake with BMPs
Nitrogen, in millions of pounds per year
YEAR
0
50
100
150
200
250
1940
1950
1960
1970
1980
1990
2000
2010
2020



Forecast of Nitrogen Loading
Nitrogen Load to the Bay, in Millions of Pounds per Year
20
18
16
14
12
10
8
6
4
2
0
1980
1990
2000
2010
2020
2030
2040
2050
YEAR
EPA TARGET
13% load reduction
40% load reduction
100% load reduction
0% load reduction

USGS

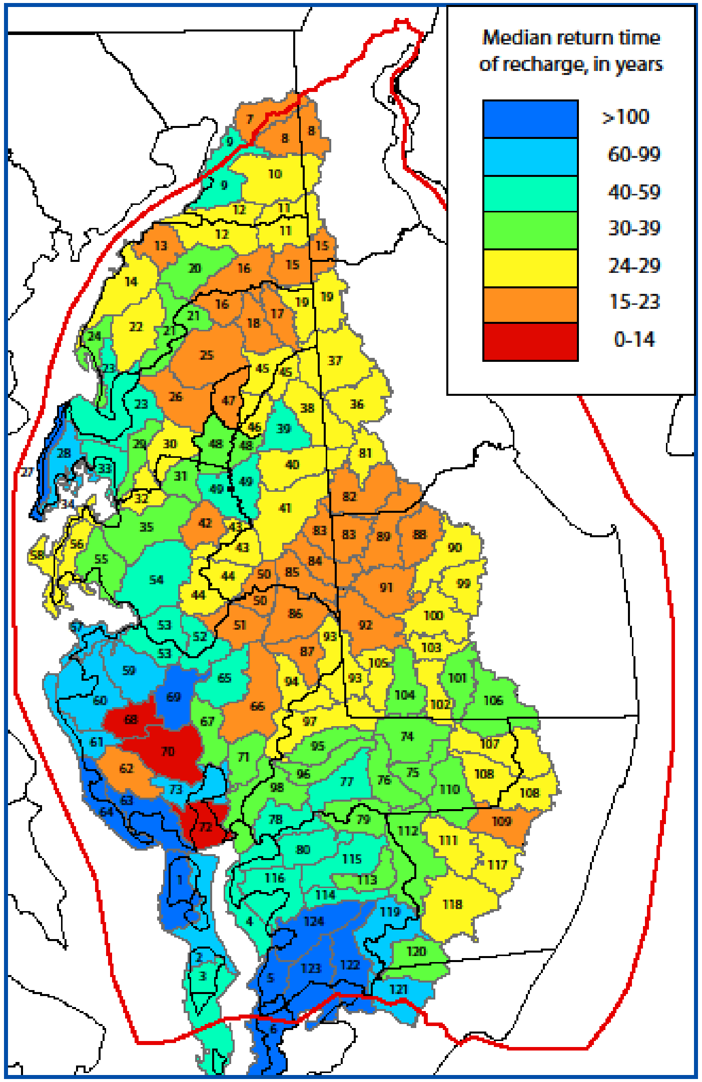


Figure 37. Map of median return time of recharge simulated by Sanford and others (2012), averaged by USGS 12-digit hydrologic unit code (HUC-12).

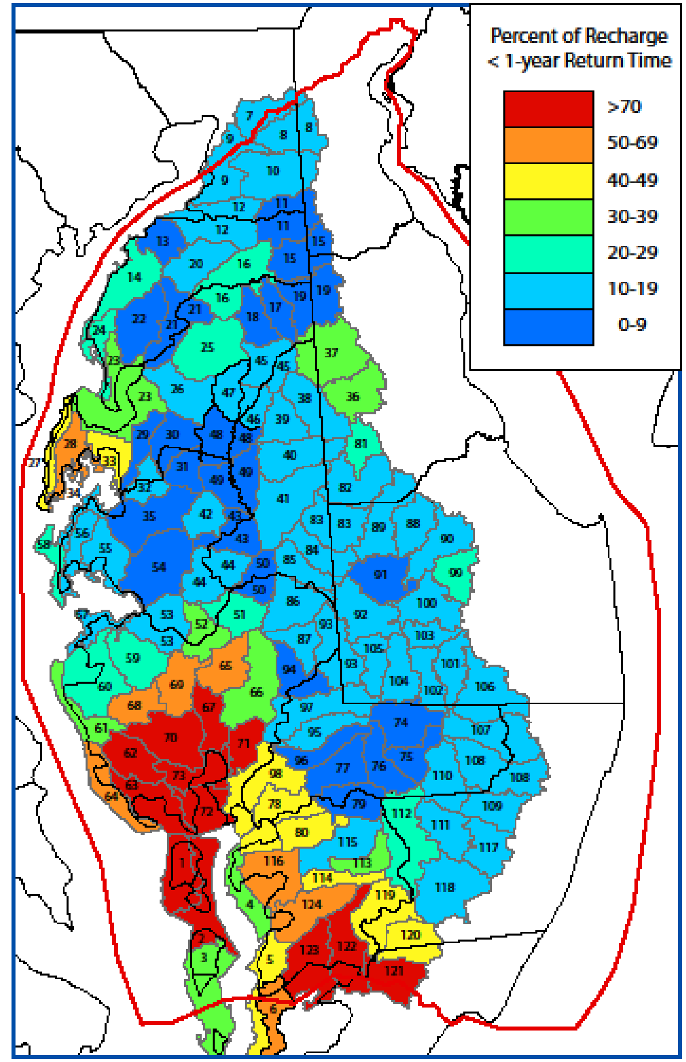
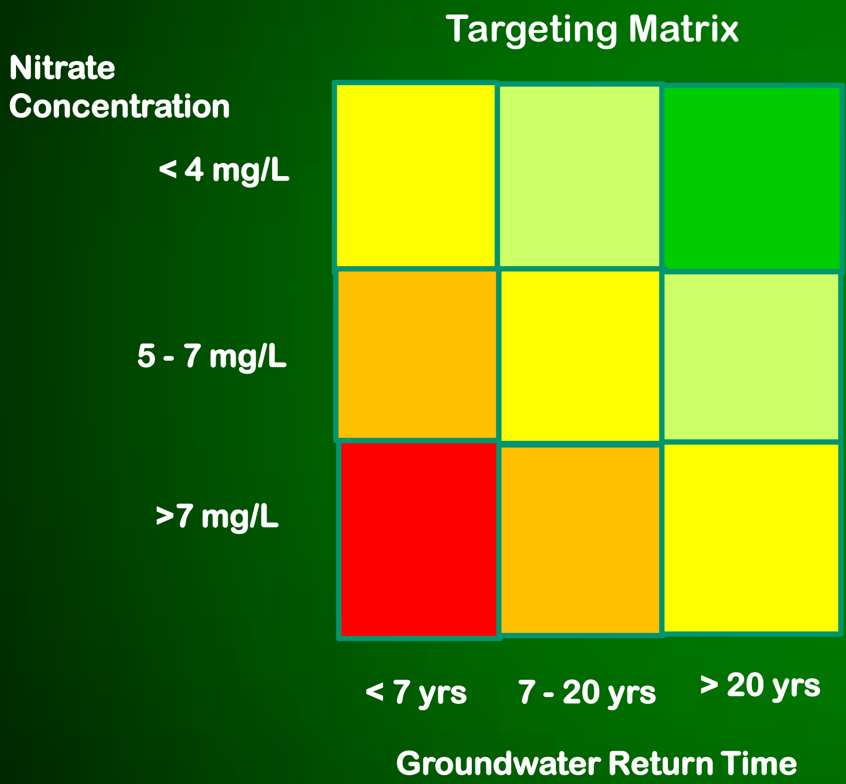
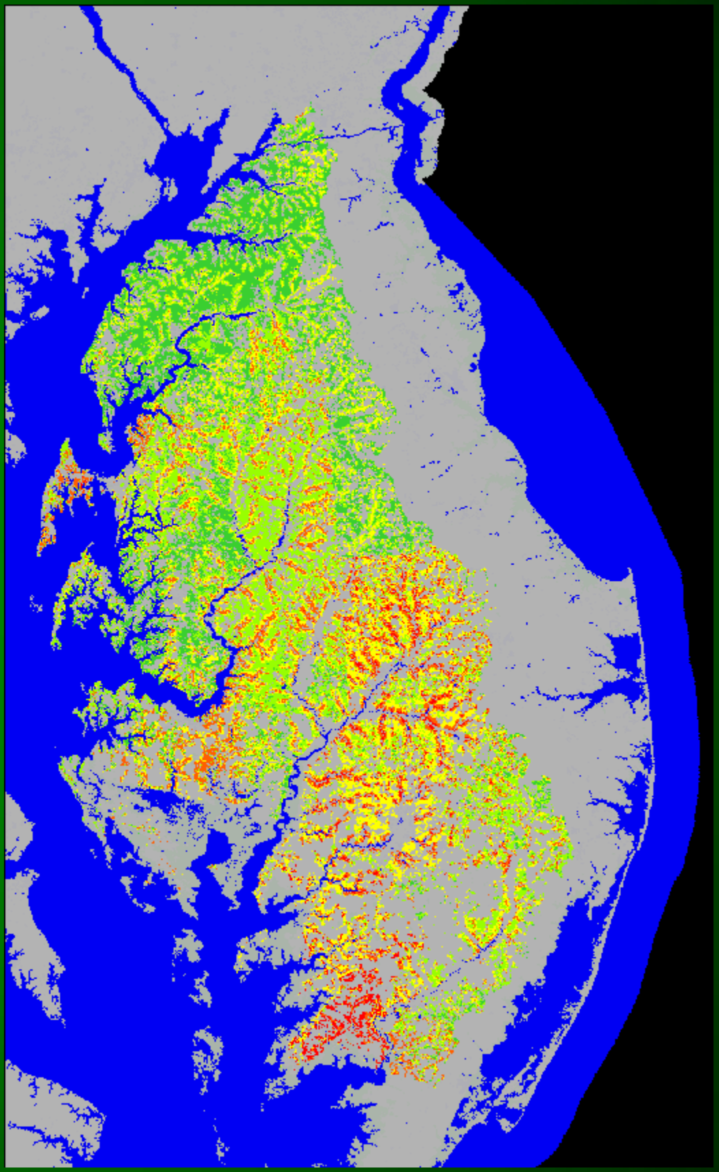


Figure 36. Map of percent recharge that is in a riparian zone simulated by the groundwater model, by USGS 12-digit hydrologic unit code (HUC-12).

Targeting that Includes Response Time and Nitrogen Delivered to the Bay





USGS

Targeting that Includes Response Time and Nitrogen Delivered to the Bay

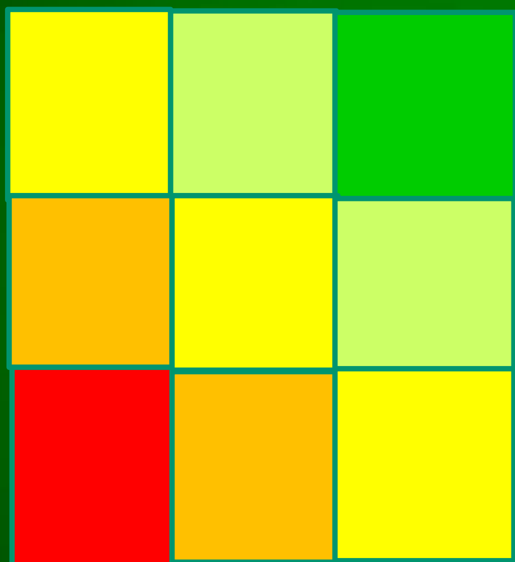
Targeting Matrix

Nitrate Concentration

< 4 mg/L

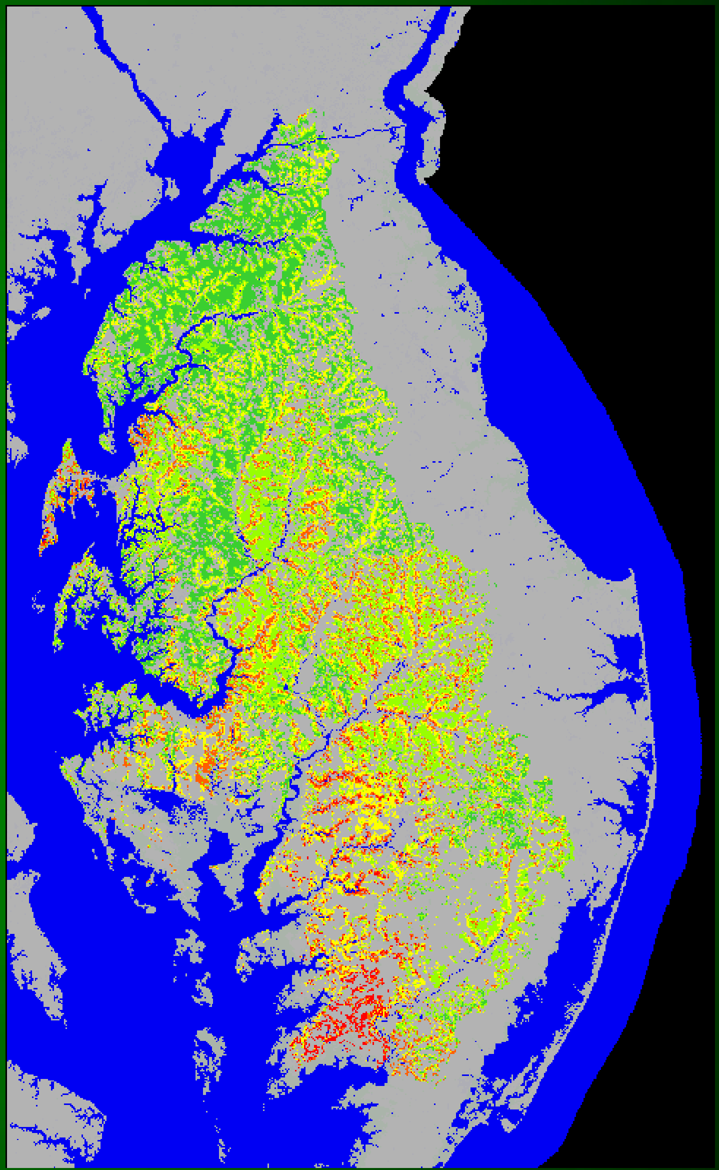
5 - 7 mg/L

>7 mg/L



< 7 yrs | 7 - 20 yrs | > 20 yrs

Groundwater Return Time



Summary and Conclusions

Results from a groundwater flow model were coupled to a nitrate-mass-balance regression model and calibrated against stream nitrate data.

The calibrated model suggests that nitrogen uptake efficiencies on the Eastern Shore may be improving over time.

Response time of nitrogen delivery to the Bay on the Eastern Shore is on the order of several decades

EPA targets are for reduced loading of ~20% (3 million lbs/yr) on the Eastern Shore.   This cannot be accomplished by reducing land surface applications by 20%, as loads will continue to rise 13%.

The new model can help target areas where reduced nitrogen loadings would be the most beneficial at reducing total loadings to the Bay.

USGS