INTRODUCTION

The College Creek watershed is relatively small—13.7 square miles—but includes a broad range of land uses (e.g., housing subdivisions, golf courses, shopping centers, a college, an airport, agricultural lands) that are potential sources of non-point discharges of sediment and nutrients. Associated with these different land use types are management practices designed to reduce the runoff of pollutants (e.g., wet retention ponds, dry ponds, filtration swales, rain gardens). Indeed, the federally mandated TMDL "diet" for tributaries to Chesapeake Bay requires local accounting for some regions showing how land-based management practices will reduce runoff of suspended sediment, nitrogen, and phosphorus. Unfortunately, the "downstream" impact of these watershed implementation plans—for practical and logistical reasons—has not always been determined in the field, making it difficult to assess whether pollution reduction targets will be met.

We proposed to examine the spatial arrangement of land use and best management practices in the College Creek watershed and determine the relationship of these land-based variables to long-term measures of water quality. Our primary objective was to compare a more complex, data-based model of sediment and nutrient export from sections of the College Creek watershed with a simpler model of export based on edge-of-stream loading rates. With this field test of the simple model we hope provide guidance to municipalities regarding the potential impact of local TMDL action plans.

METHODS

We used data from the ongoing water quality monitoring program for the College Creek Alliance, initiated as part of a VEE-sponsored program beginning Fall 2004. For that program, nine streams, eight ponds and six tidal creeks in the College Creek watershed are monitored quarterly for water quality at base flow (during non-storm flows).

TMDL Method: The TMDL model was relatively simple to apply. We examined variation in water quality with respect to land use characteristics within each sub-watershed of the College Creek drainage basin (note: we have 23 sampling locations in the watershed, but the tidal locations cannot be used to calculate discharge from the surrounding sub-watershed, since freshwater flow cannot be parsed from saltwater flow at these locations. As a result, only 17 of the 23 sub-watersheds could be analyzed). First, we used GIS to determine the drainage area above each sampling point in the watershed. Analysis of aerial photography was used to determine the total impervious surface area in each sub-watershed. Using GIS, land use types were characterized broadly into developed low impervious, developed high impervious, and forested. These land use categories and their respective areas within each sub-watershed were used with “edge of stream” loading rates (TMDL guidance document, July 2013) in the TMDL model to calculate nitrogen, phosphorus, and sediment discharge from each watershed.

The College Creek watershed lies in James City County and the City of Williamsburg. Environmental planning divisions of these two jurisdictions and from the College of William and Mary were contacted to provide information regarding land use and the locations of best management practices (BMPs) for runoff mitigation. Each BMP has an expected reduction in the discharge of nitrogen and phosphorus (and in some cases, suspended sediment) that we then included as modifications to the initial TMDL model of nutrient and sediment runoff.

Our overall goal was to use the quantitative information on land use area and BMP type, location, and capacity to determine their relationship to water quality as measured over the past four years of monitoring (2011-2014). For that comparison, we had to model water discharge in streams and from ponds to calculate nitrogen, phosphorus and sediment yield from each sub-watershed. Since much of the watershed discharge of water, sediment, and nutrients, however, can occur during storm events, our model of water runoff was linked to our four-year record of rainfall in the watershed.

SWMM Method: We used SWMM—Stormwater Management Model 5.10—to estimate water discharge as runoff past sampling points in the College Creek watershed. Briefly, SWMM is a dynamic hydrology-hydraulic water quality simulation model. It is used for long-term (continuous) simulation of runoff quantity from primarily urban areas. The runoff component operates on a collection of sub catchment areas that receive precipitation and generate runoff. The routing portion transports this runoff through a system of pipes, channels, storage/treatment devices, pumps, and regulators (EPA website). The following options were modified in SWMM relevant to the current project:

<u>SWMM Model Options:</u>

1. Infiltration Model- Curve Number (SCS)
    - Curve Number- Calculate for each subwatershed
    - Soil Drying Time-
2. Routing Model- Kinematic Wave
3. Do Allow Ponding
4. Antecedent Dry Days- 3
5. Width of Overland flow Path- Calculate for each subwatershed
6. Average Surface Slope- Calculate for each subwatershed
7. Manning’s N for impervious areas- 0.015
8. Manning’s N for pervious areas- 0.2
9. Manning’s N for forested areas- 0.6
10. Depth of depression storage on impervious areas- 1mm

11. Depth of depression storage on pervious areas- 2mm
12. Percent of impervious area with no depression storage-
13. Percent of runoff routed from Impervious to Pervious sub-areas-
14. Maximum water depth at junction-
15. Ponded area at junction- Calculate for each subwatershed
16. Conduit/channel shape- Open Rectangular
17. Depth of conduit/channel cross section- Based on field observations
18. Length of conduit/channel cross section- Calculate for each subwatershed
19. Manning's roughness coefficient for conduit/channel- 0.055
20. Initial flow in conduit/channel (baseflow)- Based on field observations
21. Rate of seepage loss into surrounding soil in conduit/channel- 8.375 mm/hr
22. Include Tide gate to prevent backflow at outfall
23. Climate Options
    - Evaporation
24. Flow Units- LPS
25. Include BMPs constructed before 2011

To run SWMM, the following features were used/incorporated:

Rain Gage- January 1, 2011 through May 31, 2015. Data compiled from the Keck Weather Lab, located centrally in the College Creek watershed. Reported every 10 minutes in mm.

Subcatchments- Represent the different subwatersheds and their unique makeup of impervious, pervious, and forested land. Forested land cover comprised a single subcatchment area in each subwatershed, while the impervious and pervious land cover comprised an area together.

Junctions- In SWMM, forest subcatchments meet impervious/pervious subcatchments here.

Conduits- Runoff from subcatchments flows through these channels set to be rectangular and open to mimic streams rather than sewer channels.

Storage Nodes- SWMM uses storage nodes to mimic water retention in BMPs and ponds.

Weirs- Water exit from storage nodes is via weirs only, since orifices get clogged too often.

Outfall- The point where water is discharged from each of the 17 sub-watersheds, also the location of quarterly sampling for water quality.

SWMM is not able to run conduits through a subcatchment similar to real life where water volume increases with channel lengthening. Rather, subcatchments generate a certain amount of runoff and infiltration based on the parameters set. Thus, each subwatershed was divided into smaller sections represented by subcatchments in SWMM. Usually they were based on several larger streams emptying into a pond, or the area draining into a BMP. For subcatchments downstream from other subcatchments in the same subwatershed, conduits were included in SWMM to act as main channels so that water flowing from subcatchments upstream was not running through tributary streams of subcatchments downstream.

Because channels were taking in the entirety of runoff from subcatchments at once instead of gradually as in real life, and because they could not increase in size over their length, channel size in each subwatershed was set to the calculated size of the channel at the outlet. The original length and width were calculated using equations found in a USGS article, “Bankfull Regional Curves for Streams in the Non-Urban, Non-Tidal Coastal Plain Physiographic Province, Virginia and Maryland.” These ideal dimensions, though, would not be appropriate for an urbanized environment such as this area. Using the Center for Watershed Protection (CWP) document “Impacts of Impervious Cover on Aquatic Systems,” I was able find a list of studies that had researched what effects urbanization had on stream channel dimensions. This article stated that a 1999 report by MacCrae and De Andrea “introduced the concept of ultimate channel enlargement based on watershed IC and channel characteristics.”

Although the original report could not be accessed, a graph was reproduced from the report in another CWP document (“Dynamics of Urban Stream Channel Enlargement”) that showed the extent to which percentage impervious surface in the drainage area would increase the natural channel cross area. With knowledge of percent impervious surface in a subcatchment, downstream cross-sectional area was calculated, assuming that on average half of the total response to impervious area had already occurred (i.e., channel enlargement was 50% complete). For example, in a subcatchment with extensive impervious cover, channel size would be expected increase by a factor obtained from the report, and then the original lengths and widths of the channel would multiplied by the square root of that factor to arrive at the final channel dimensions to use for the conduits draining that subcatchment.

Baseflow conditions were assumed to occur as constant flow into conduits from junctions. Conduits within a subwatershed were assumed to have the same baseflow per length irrespective of subcatchment designation. Thus, conduits were given baseflows based on length, and baseflow varied according to month of the year. That intra-annual variation was estimated based on the intra-annual variation in actual precipitation and calculated evapotranspiration in the watershed, obtained from the last five years of Keck Lab weather data.

ArcGIS files identifying the boundaries of each sub-watershed were available prior to the start of the study. When streamlines were included during the study, however, some headwater streams appeared to cross sub-watershed boundaries. Some engineering of headwater systems may route water across apparent subwatershed boundaries, or the subwatershed could have been outlined in error; this small mis-match in a few of the subwatersheds should not have influenced overall results, but it is something to note. Further, ArcGIS used contour lines to create Strahler orders for stream designation. For SWMM, Strahler Order 5 was considered representative of headwater (order 1) streams. On-screen displays were sometimes different from field observations, in that some streams crossed over impervious surfaces or other surfaces that clearly were not streams. Many—but not all—of these mis-matches were edited. Streamlines that ran through ponds were also deleted.

Finally, conduits had to be given a starting and ending elevation for the junctions to which they connected; for SWMM, we used the highest point in each subcatchment and the outlet elevation for these junctions. Because each subcatchment also needed an average slope, however, the same average slope across every subcatchment within a single subwatershed was used to reduce total calculations.

SWMM relies on characterization of both land use and hydrologic features, as presented in the hydrograph map (Figure 1) and land use map (Figure 2), both derived from information obtained from Environmental Planning Divisions of James City County, the City of Williamsburg, and the College of William and Mary (next pages).

Hydrographic Features of Non Tidal College Creek Subwatersheds

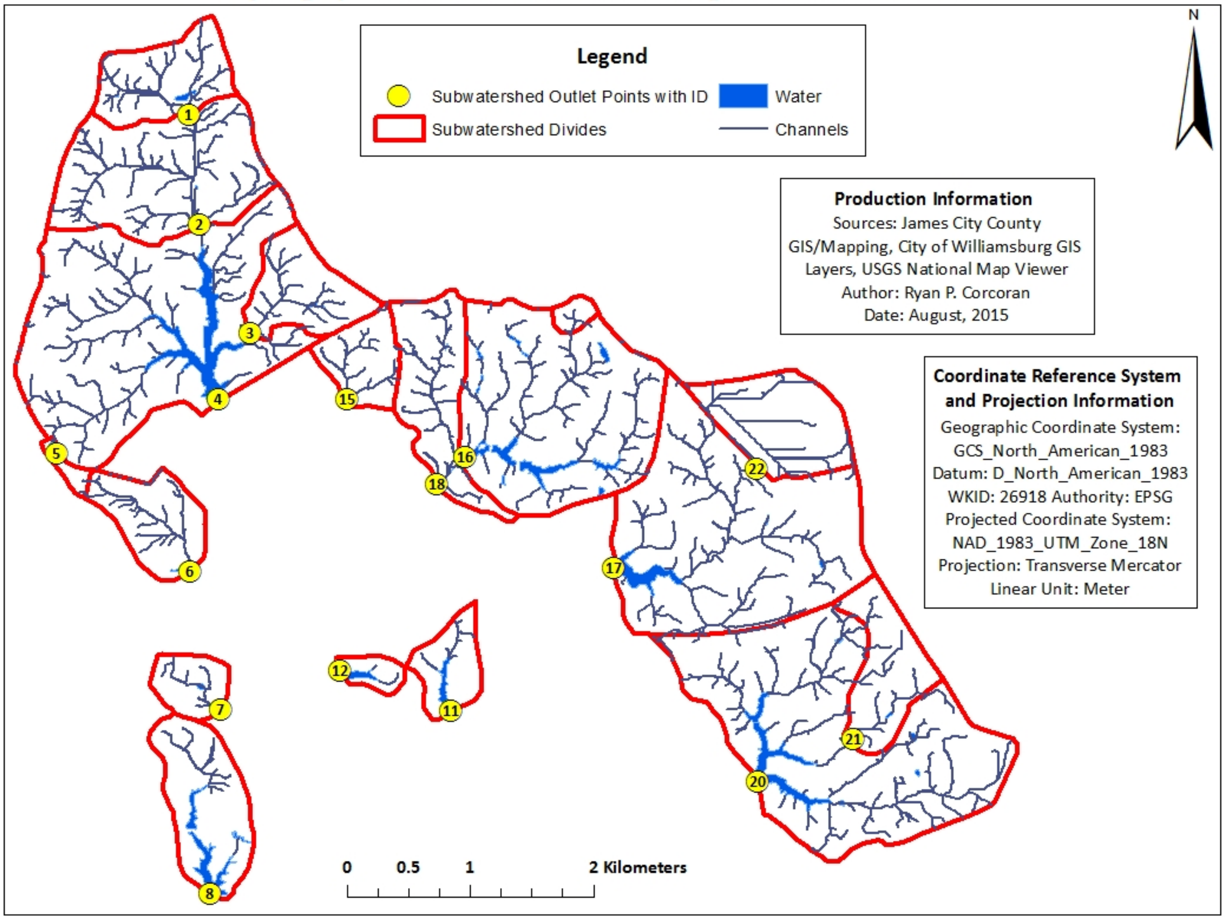


Figure 1. The hydrographic map above shows the locations of the non-tidal, freshwater runoff sub-catchments in the College Creek watershed and their hydrologic characteristics (streams and ponds/lakes). The yellow ID numbers refer to sampling nodes where measures of water quality have been recorded quarterly since 2004. Some of the sub-catchments are nested in large catchments (e.g., the outlet from sub-catchment #4 receives runoff from sub-catchments 1, 2, 3, 4, and 5).

Non Tidal College Creek Subwatersheds by Land Use

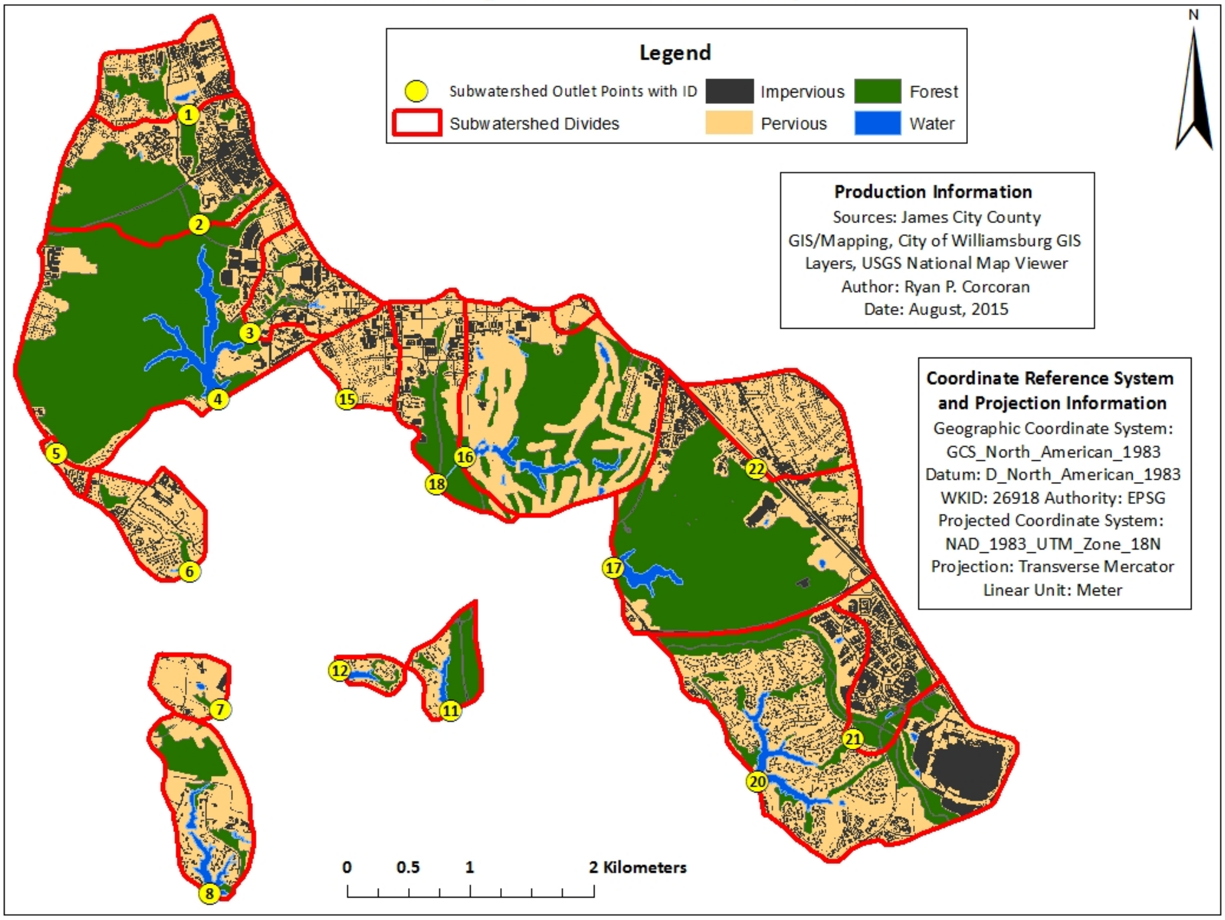


Figure 2. The land use map above shows the separation into forested and developed land, with developed lands further sub-divided into pervious and impervious. These land-use classifications we used by area to estimate the TMDL runoff of total nitrogen, phosphorus, and suspended sediment (Tables 1-3). The SWMM model also incorporated land use to estimate the total volume of water runoff, which was then coupled with water quality measures to calculate nutrient and sediment discharge, for comparison with TMDL estimates.

For the SWMM method, all of the freshwater subwatersheds in the College Creek watershed were characterized and modelled for runoff. Subwatershed #18 is shown below as an example (Figure 3):

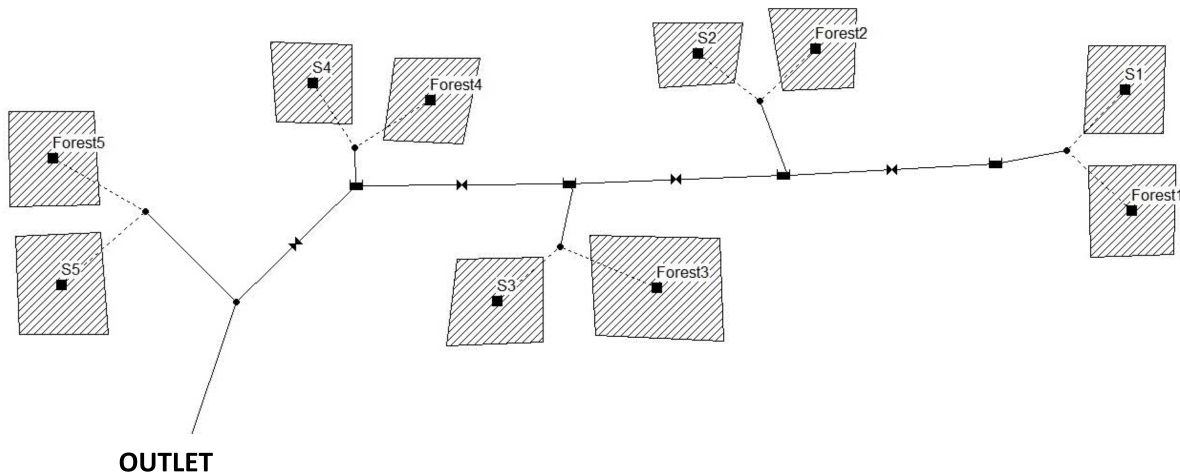


Figure 3. SWMM model structure for subwatershed #18, showing the relative contributions by area for different land-use types as water is routed through pipes and streams in the watershed to the subwatershed outlet. For this subwatershed, five different sub-catchments were identified as contributing areas, with each further broken down into forested or developed.

Further, because many of the 17 subwatersheds are nested inside larger subwatersheds, we had to add the discharges of sediment and nutrients within those catchments to obtain the total yields.

Finally, we compared the annual estimates of sediment and nutrient discharge from the 17 subwatersheds using the TMDL and SWMM methods.

RESULTS & DISCUSSION

Water Quality: Results from over 10 years of quarterly measures of water quality from the discharge points of each of the 17 subwatersheds is shown in Appendix I. The water quality data from 2011 through 2014 were used with the SWMM method estimate TSS, N, and P discharge from each of subwatersheds (see SWMM Method below).

TMDL Method: The estimates of annual yield of sediment and nutrients from the 17 sub-watersheds in the College Creek watershed varied with land-use and sub-watershed area (Tables 1-3). Collectively, these non-tidal waters in the College Creek watershed annually deliver over 200 tons of sediment, 20,000 pounds of nitrogen and 1,500 pounds of phosphorus downstream toward the James River.

Table 1. Summary of sub-watershed areas and estimated annual yield of total suspended sediment (TSS), using the TMDL method. Reductions refer to credits for BMPs and other retention basins (lakes, ponds) in each sub-watershed.

Sub-shed	Area ha	TSS tons/y	Reductions	New Total TSS
1	64	21	1.1	19.9
2	215	62	1.3	60.7
3	58	21	3.1	17.9
4	575	133	77.0	56.0
5	6	2	0.2	1.8
6	55	17	0.1	16.9
7	27	6	0.0	6.0
8	74	13	9.5	3.5
11	32	6	3.5	2.5
12	11	3	1.5	1.5
15	40	14	0.0	14.0
16	228	37	30.3	6.7
17	351	78	46.6	31.4
18	309	59	30.3	28.7
20	358	124	73.5	50.5
21	63	27	0.6	26.4
22	77	26	0.0	26.0

Table 2. Summary of sub-watershed areas and estimated annual yield of total phosphorus (P), using the TMDL method. Reductions refer to credits for BMPs and other retention basins (lakes, ponds) in each sub-watershed.

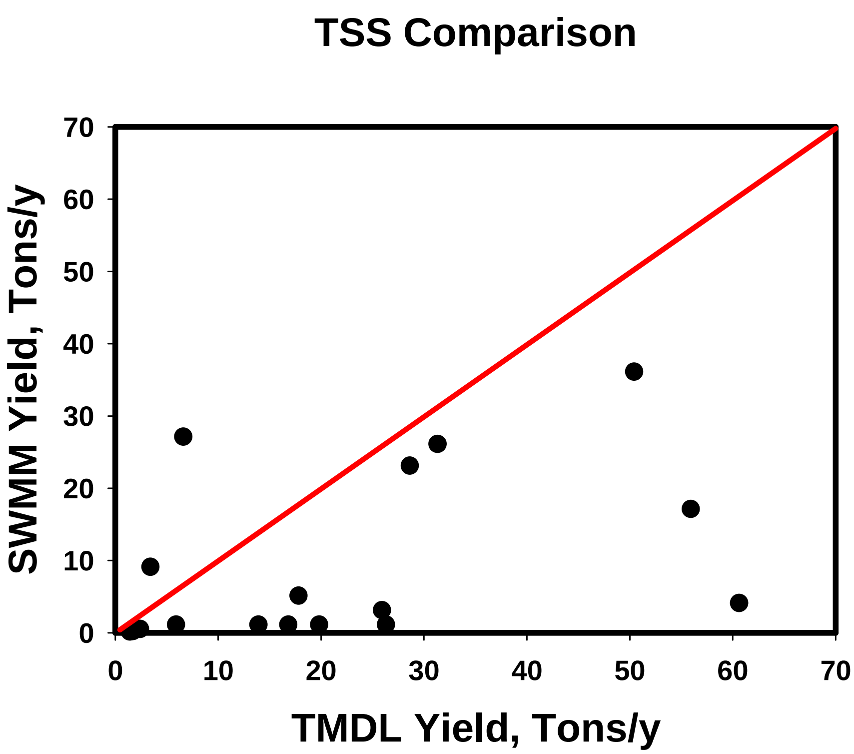
Sub-shed	Area ha	P lbs/y	Reductions	New Total P
1	64	128	6.6	121.4
2	215	350	8.0	342.0
3	58	126	18.7	107.3
4	575	730	316.0	414.0
5	6	15	1.5	13.5
6	55	108	1.0	107.0
7	27	44	0.0	44.0
8	74	93	52.3	40.7
11	32	33	15.0	18.0
12	11	17	7.7	9.3
15	40	88	0.0	88.0
16	228	242	171.1	70.9
17	351	430	192.4	237.6
18	309	368	171.1	196.9
20	358	729	324.1	404.9
21	63	152	3.5	148.5
22	77	163	0.0	163.0

Table 3. Summary of sub-watershed areas and estimated annual yield of total nitrogen (N), using the TMDL method. Reductions refer to credits for BMPs and other retention basins (lakes, ponds) in each sub-watershed.

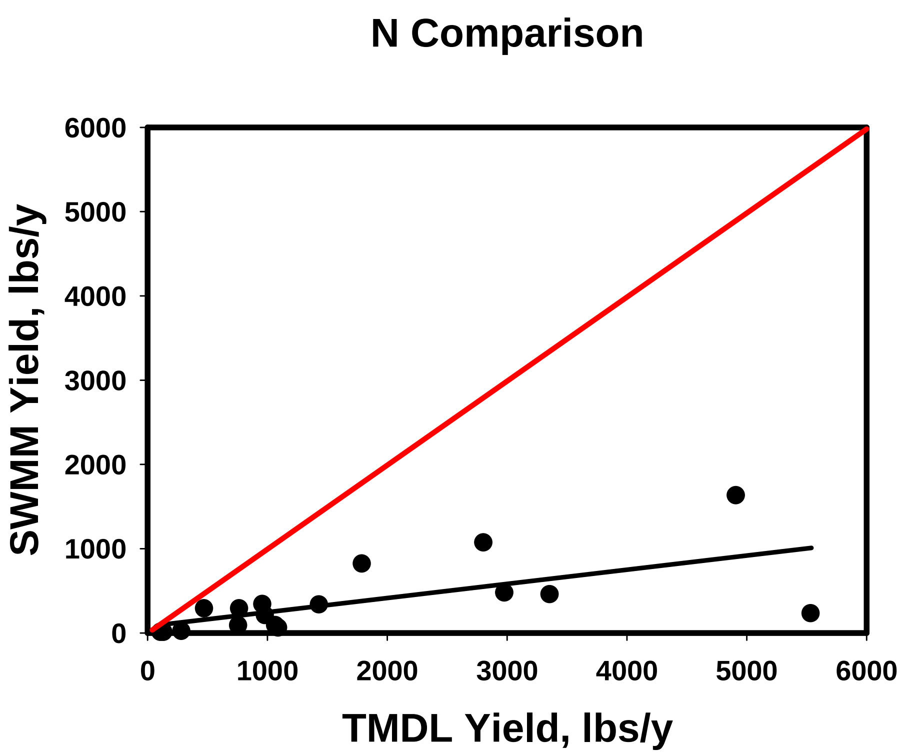
Sub-shed	Area ha	N lbs/y	Reductions	New Total N
1	64	1099	27	1072
2	215	3017	33	2984
3	58	1041	77	964
4	575	6896	1356	5540
5	6	121	6	115
6	55	991	5	986
7	27	478	0	478
8	74	1074	303	771
11	32	360	72	288
12	11	173	35	138
15	40	763	0	763
16	228	2952	1158	1794
17	351	4200	838	3362
18	309	3966	1158	2808
20	358	6137	1221	4916
21	63	1109	13	1096
22	77	1437	0	1437

SWMM Method: Output from the SWMM method varied annually owing to differences in precipitation. For comparison with output from the TMDL method, we averaged the annual discharge of TSS, N and P from the four years of running SWMM (2011-2014), for comparison with TMDL discharge.

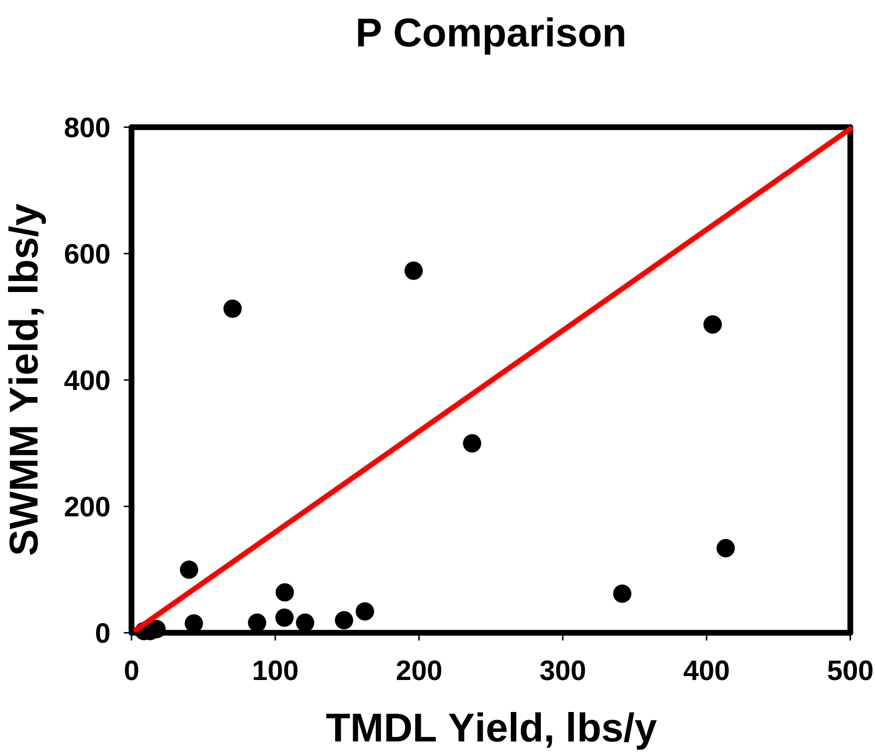
For annual yield of total suspended sediment, SWMM tended to underestimate TSS, sometimes dramatically so (red line is the 1:1 line for which estimates using the two methods would be identical). For subwatershed 17, 18, and 20, yields were large and somewhat similar; for subwatersheds 8 (draining a high-income housing development) and 16 (draining a golf course), SWMM estimates were actually larger than TMDL estimates. Most notable, however, were the 10 subwatersheds for which the SWMM method estimated very low TSS yields that were less than 20% of TMDL estimates (subwatersheds 1, 2, 5, 6, 7, 11, 12, 15, 21, and 22).



For the annual yield of total nitrogen, SWMM underestimated N yield in all 17 subwatersheds, on average 17% of TMDL yield. One obvious reason for the underestimate is that water quality data for N were available for total dissolved species and not particulate species. For example, a recent study in the Maryland Piedmont region estimated that stormwater particulate N accounted for 65% of the total N export from a headwater stream draining a forested catchment (Inamdar et al. 2015). Further, this underestimation was systematic, i.e., the line describing the relationship between TMDL and SWMM yield was significant (linear regression on figure below; r = 0.63; P = 0.006). Given that particulate N export is highly variable and tends to increase during storm events, our coupling of water discharge with dissolved N concentrations measured at base flow conditions led to a systematic underestimation of total N yield.



Finally, for the annual yield of total phosphorus, the overall comparison was similar to that seen for TSS. Subwatersheds 8, 16, and 18 had larger SWMM yields of P relative the TMDL yield, and P yields from subwatersheds 17 and 20 were fairly large and similar for both estimation methods. Seven of the remaining 12 subwatersheds had SWMM estimates of P yield that were less than 20% of the TMDL estimate.



SWMM-estimated discharge of sediment and nutrients in the majority of subwatersheds in the College Creek watershed was less than 20% of the estimated discharge using the TMDL method. In addition to the previously mentioned lack of particulate nitrogen data to couple with the stormwater management model, we suspect that our parameterization of SWMM requires some additional adjustment to mimic stormwater flows more closely. If we assume the TMDL estimate is reasonable, then either the SWMM water discharge is too low and/or the sediment and nutrient concentrations are too low. Low estimates of any of these values would lead to lower calculated TSS and nutrient yield using SWMM. We are encouraged, however, that for most watersheds the underestimation was systematic, indicating the two methods (SWMM and TMDL) tended to vary similarly. Since 30-40 parameters in each subwatershed remained the same or were calculated the same, then adjustment of these parameters will affect the resulting discharge more than the actual areas of impervious, pervious, and forested cover. GIS data supplied relative land use areas and lengths of streams; decisions in SWMM actually defined what those land use areas mean and how they reacted in the models. Moving forward, it is these options that can make this approach to stormwater management more realistic. Eventually we hope to improve the water discharge estimates and obtain validation for the stormwater management model by comparing discharge during storms with gauged measures, if we can find them.

The overall goal of this project was field verification: to determine whether the simple estimate of annual sediment and nutrient discharge using TMDL loading rates agreed with a more complex SWMM estimate garnered from field measures of precipitation and water quality. None of the 17 subwatersheds exhibited agreement with respect to nitrogen, and only two subwatersheds (17 and 20) showed reasonable agreement for both TSS and total P. Even with the general disagreement between methods, it is important to consider these differences among subwatersheds because reductions in nutrient and sediment discharge from the College Creek watershed are part of the three-phase, Chesapeake Bay TMDL watershed implementation plan. Much of the watershed includes Municipal Separate Storm Sewer Systems (MS4) where stormwater retrofits and other implementation plans will be required to meet required reductions in nutrient and sediment discharge. Reduction targets from MS4 permit areas will be 5% by 2018, 40% by 2023, and 100% by 2028. Our data provides the antecedent conditions prior to watershed implementation plans in these regulated MS4 permitting areas in the College Creek watershed, against which future load reductions can be compared.

Literature Used

Center for Watershed Protection, "Dynamics of Urban Stream Channel Enlargement".

Center for Watershed Protection, "Impacts of Impervious Cover on Aquatic Systems" March 2003.

EPA Storm water management model applications manual, July 2009 revision (used for instructions on how to design BMPs in SWMM using storage nodes and weirs).

Inamdar, S., G. Dhillon, S. Singh, T. Parr, and Z. Qin. 2015. Particulate nitrogen exports in stream runoff exceed dissolved nitrogen forms during large tropical storms in a temperate, headwater, forested watershed. J. Geophys. Res. Biogeosci., 120, doi:10.1002/2015JG002909.

James City County Guidelines for Design and Construction of Stormwater Management BMPs, 1999 (used to identify BMPs in the College Creek watershed as dry detention ponds).

MacRae, C. and M. DeAndrea. 1999. Assessing the Impact of Urbanization on Channel Morphology. 2nd International Conference on Natural Channel Systems. Niagara Falls, Ontario. 1999.

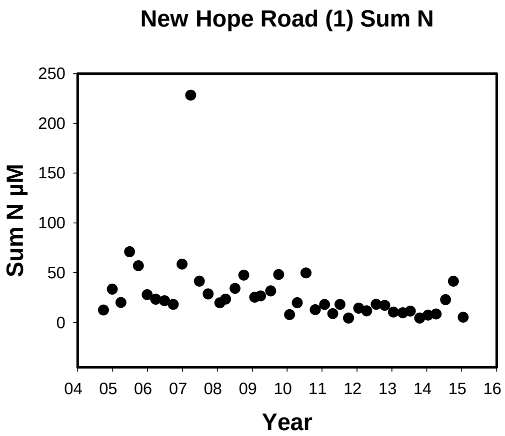
Schueler, T. and C. Lane. 2012. Recommendations of the expert panel to define removal rates for urban stormwater retrofit projects. Chesapeake Stormwater Network.

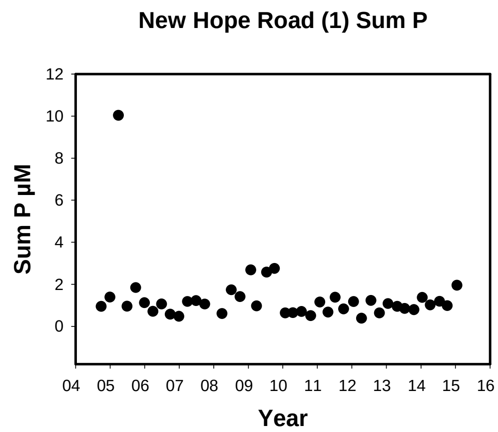
SWMM 5.0 User's Manual.

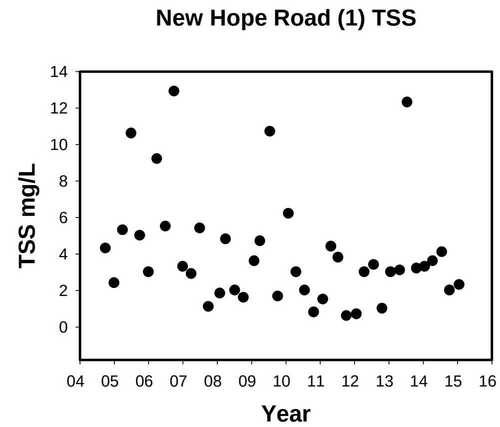
USGS, Bankfull Regional Curves for Streams in the Non-Urban, Non-Tidal Coastal Plain Physiographic Province, Virginia and Maryland, 2007.

VDOT Governance Document Drainage Manual, Revised Oct. 2014, Chapter 11- "Stormwater Management" (used to find the dimensions of BMPS, such as proper depth).

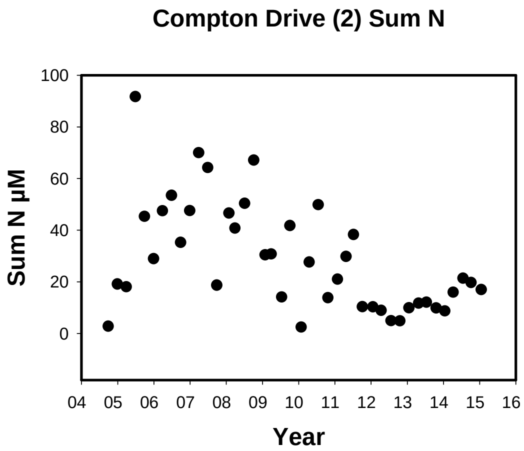
APPENDIX I : Nutrient and TSS Summary by Subwatershed (#)

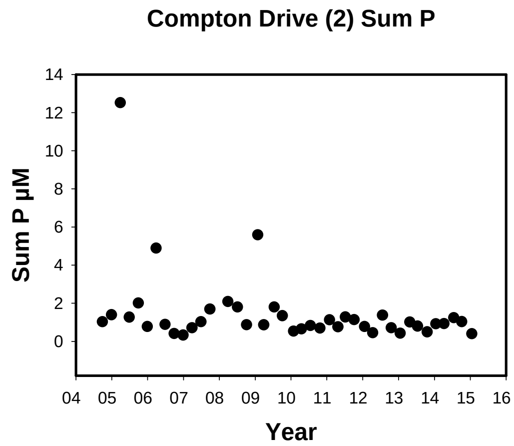


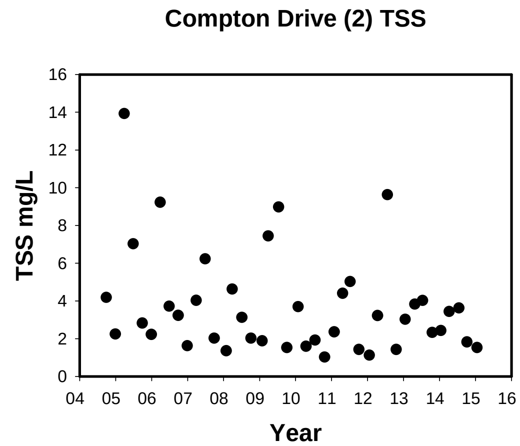




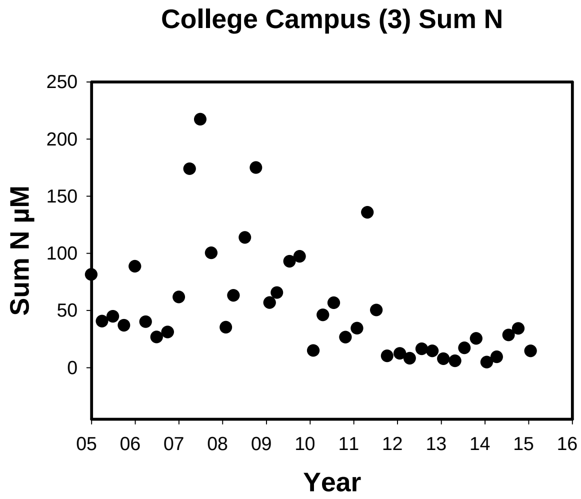
The New Hope Road watershed comprises the upper reaches of College Creek. Construction of the High Street commercial and residential area from 2008-10 was evident in increased P runoff during those years, although TSS was always variable. Inclusion of a large stormwater retention pond downstream of most of the development appears to have reduced N runoff downstream (lower and less variable 2011-14).

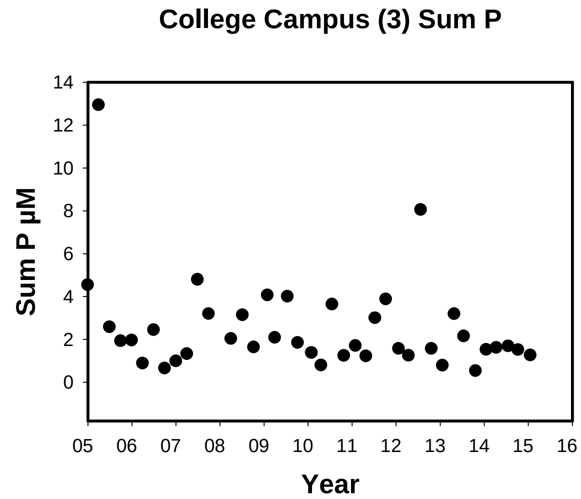


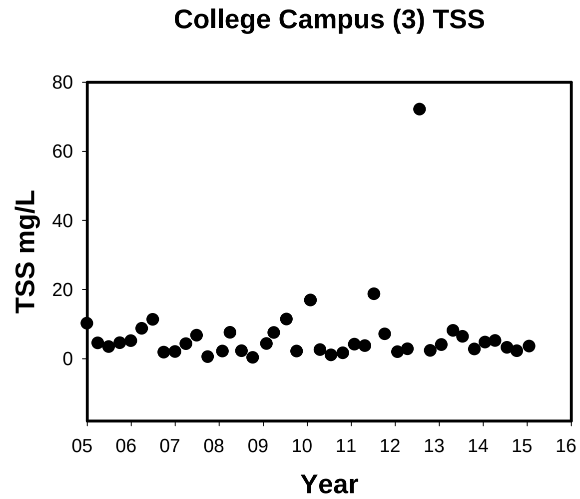




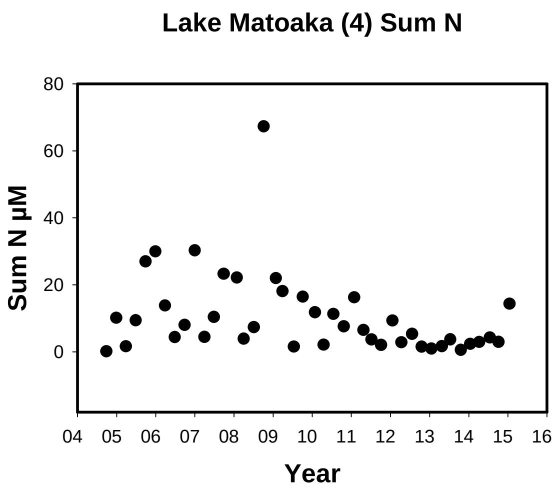
The Compton Drive sampling location lies downstream of New Hope Road and thus receives runoff from that sub-watershed. The significant reduction in concentration and variation of dissolved nitrogen beginning in 2011 is evident, and appears to be caused by operation of the stormwater retention pond in the New Hope Road sub-watershed. N concentration appears to be increasing over the last few years, however. Total Phosphorus has remained low throughout the study period, and TSS has remained somewhat more variable throughout the study period. One might have anticipated the stormwater pond would decrease TSS and total P as sediments settled in the basin, but that effect has not been observed.

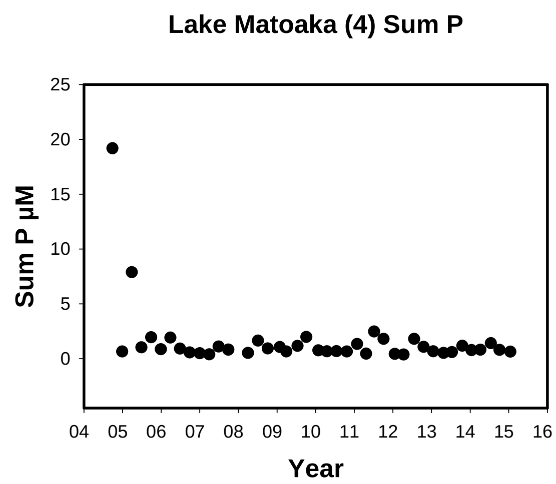


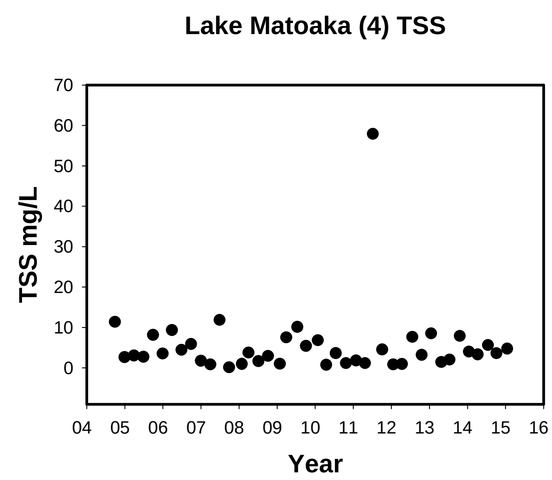




The College Campus location is downstream from the main portion of the College of William and Mary campus. Between 2007 and 2011, new dormitories and a science center were constructed, which may have contributed to the elevated N concentrations during those years. Similar to the College Creek sites (1 and 2), however, that N variability dropped dramatically 2012-15. Phosphorus and TSS levels have remained variable, with some apparent steadying in the past year. The College Campus location has at least three BMPs in place upstream of the water sampling location.

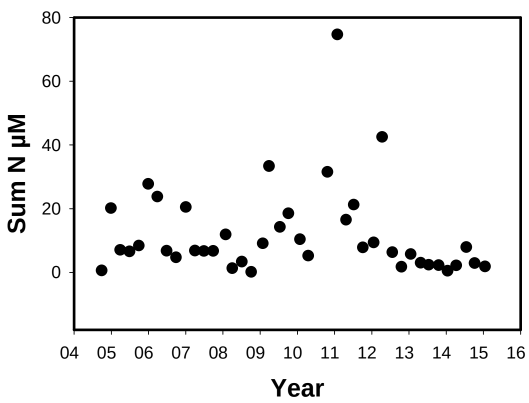




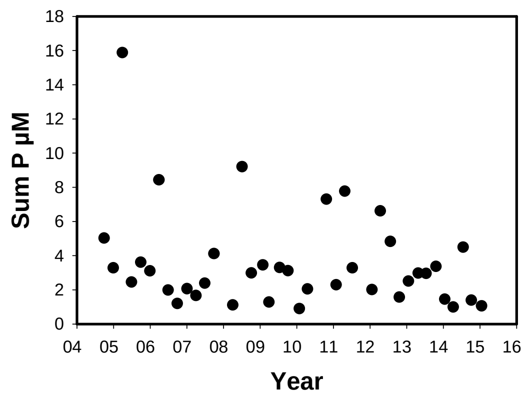


Lake Matoaka is downstream from the three prior sampling sites and thus receives discharge from those sub-watersheds, in addition to other contributing areas. Dissolved nitrogen exhibited a gradual decrease in concentration 2007-11 and has remained very low since then. Both total P and TSS have always been low—the lake has an extended water retention time of some 75 days, allowing ample time for sediment settling and P removal. Most inorganic N is likely removed from the lake via algal and plant uptake and denitrification.

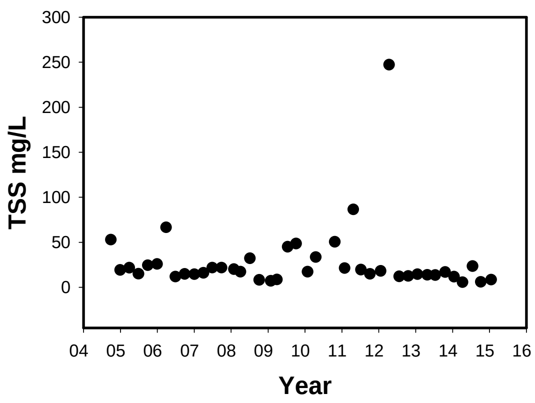
Stormwater Pond (5) Sum N



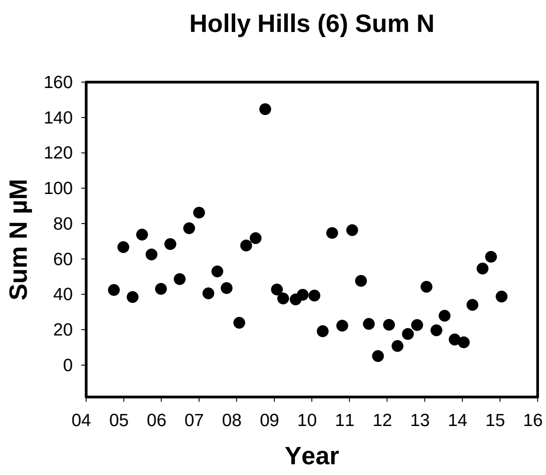
Stormwater Pond (5) Sum P

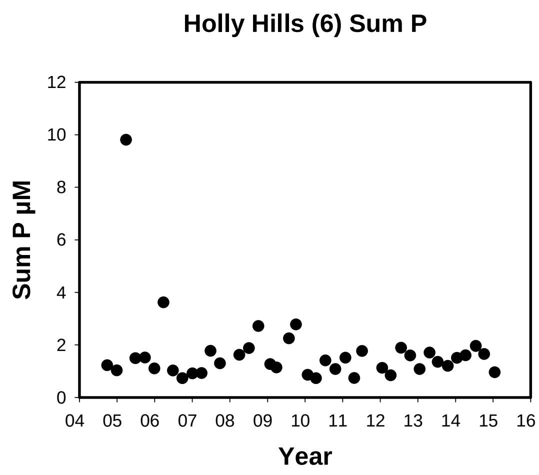


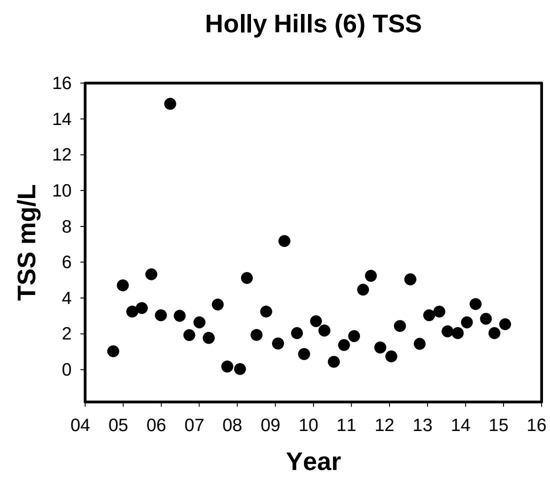
Stormwater Pond (5) TSS



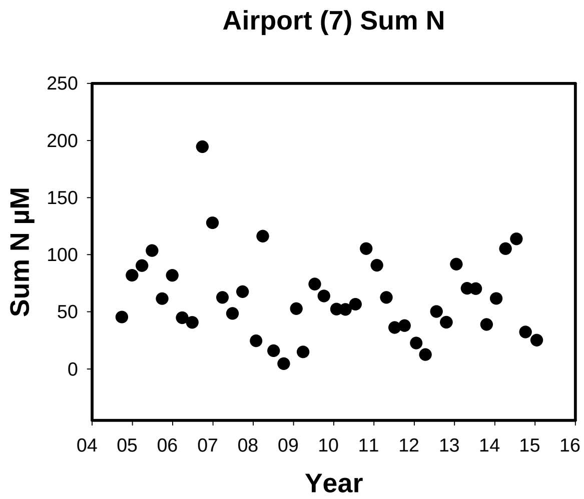
Site 5 is a stormwater pond that receives runoff from two state roads in Williamsburg. The pond is maintained by VDOT.

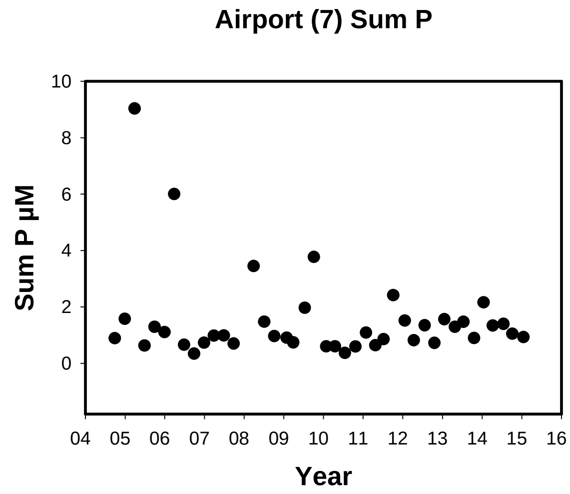

Holly Hills (6) Sum N
Sum N µM
Year
160
140
120
100
80
60
40
20
0
04 05 06 07 08 09 10 11 12 13 14 15 16

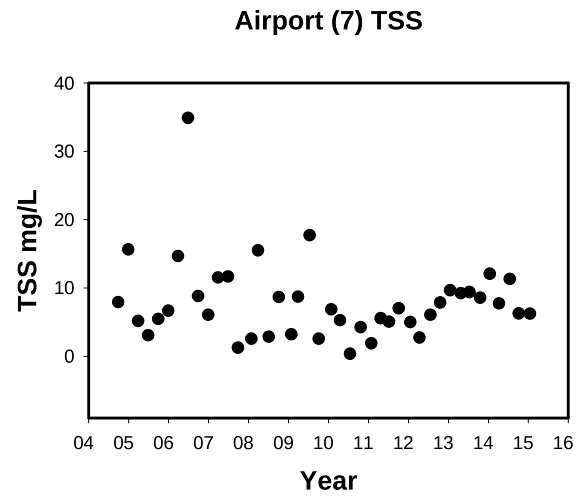

Holly Hills (6) Sum P
Sum P µM
Year
12
10
8
6
4
2
0
04 05 06 07 08 09 10 11 12 13 14 15 16


Holly Hills (6) TSS
TSS mg/L
Year
16
14
12
10
8
6
4
2
0
04 05 06 07 08 09 10 11 12 13 14 15 16

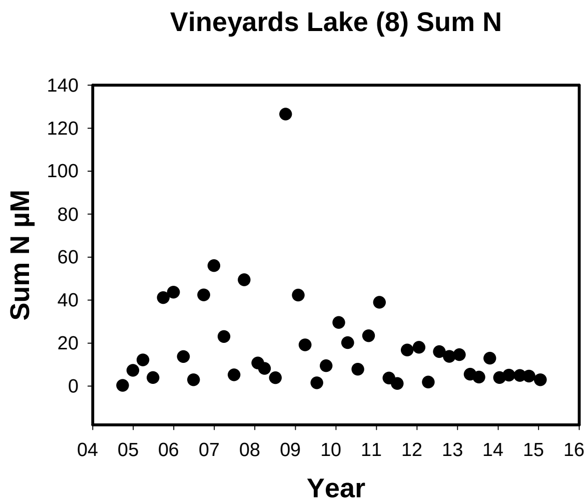
Site 6 is located downstream from an upscale housing sub-division. A stormwater pond is located just upstream from the stream sampling point. Nitrogen concentrations did not decrease after 2011 to the same extent as observed from other locations, and in fact have increased since a low in 2012. Total phosphorus has remained low and steady throughout the sampling interval, and TSS has remained fairly low and variable. No substantial changes in watershed land use occurred throughout the sampling period 2004 to 2015.

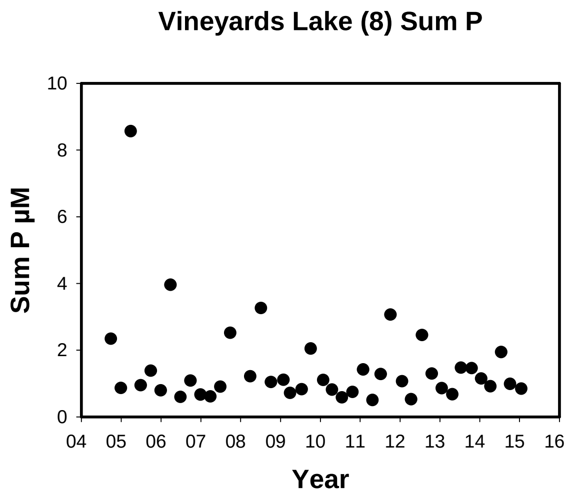


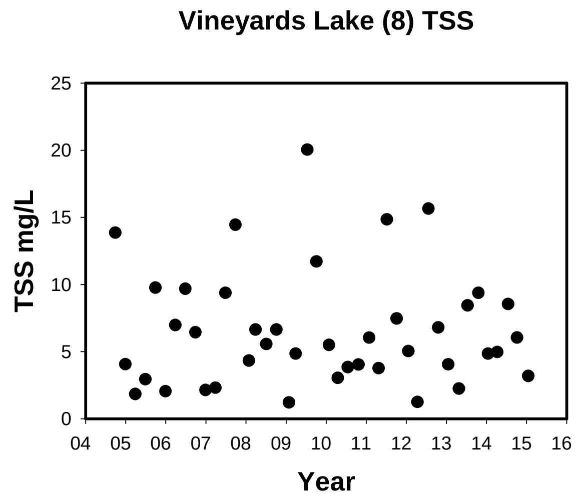




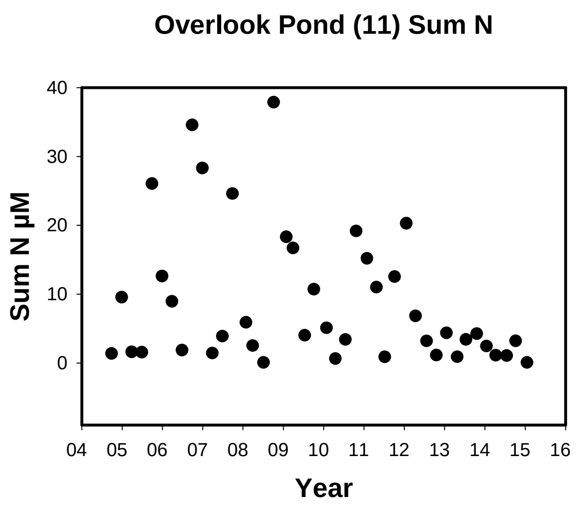
The Airport site is a small stream located adjacent to the local Williamsburg airport and to a mulching/recycling operation and is immediately downstream from the old town dump. The dump is no longer active but leaching is suspected. The mulching operation is active. Airport runoff discharges farther downstream of the sampling point. Nitrogen levels in the stream have remained high and variable throughout the sampling period. Total Phosphorus has remained fairly low, and TSS has remained elevated, perhaps due to sediment runoff from the mulching operation.

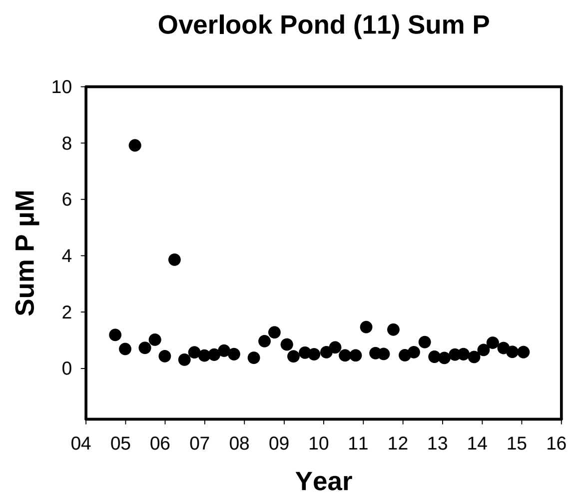


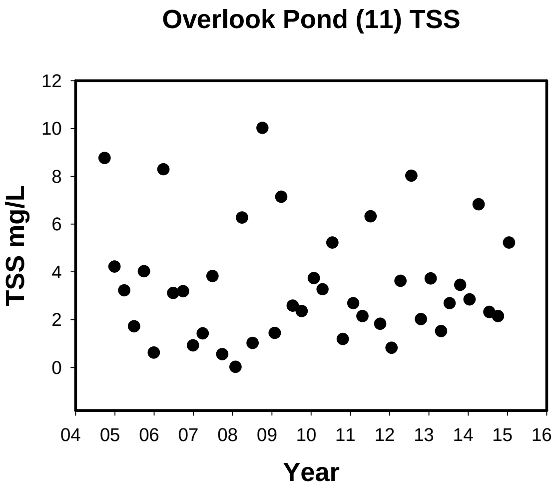




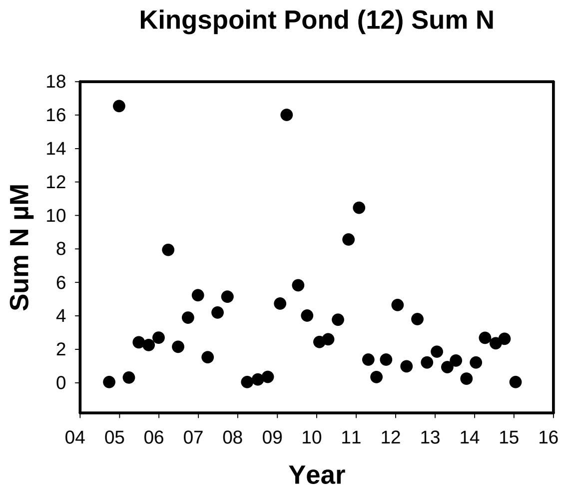
Vineyards Lake is a stormwater retention pond located in an affluent neighborhood in Williamsburg, VA. No large changes in land use have occurred in the watershed during the sampling period. Dissolved Nitrogen decreased beginning in 2012 and has remained low. Total Phosphorus has remained low throughout the sampling period, and TSS has been fairly low but variable throughout the sampling period.

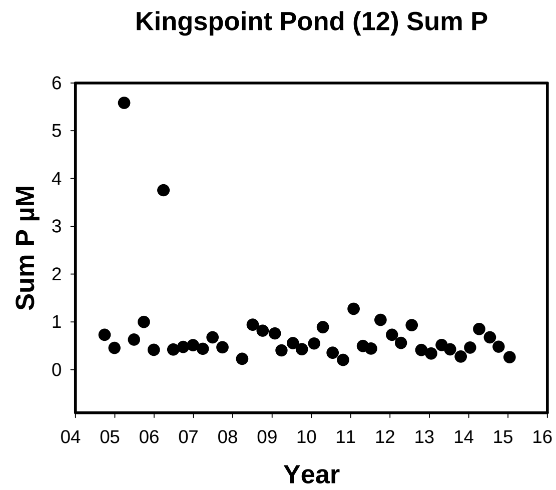

Overlook Pond (11) Sum N
Sum N µM
40
30
20
10
0
04
05
06
07
08
09
10
11
12
13
14
15
16
Year

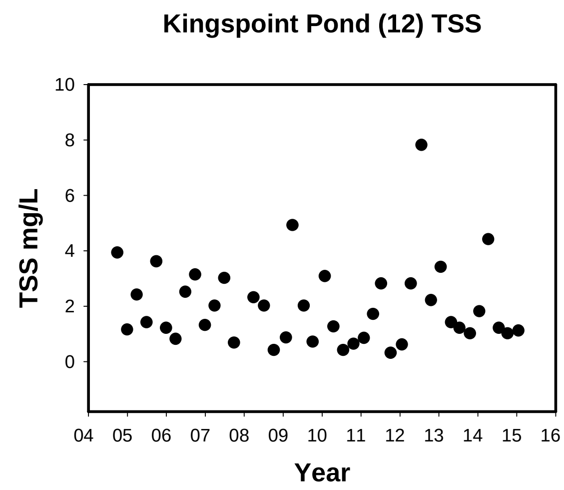

Overlook Pond (11) Sum P
Sum P µM
10
8
6
4
2
0
04
05
06
07
08
09
10
11
12
13
14
15
16
Year



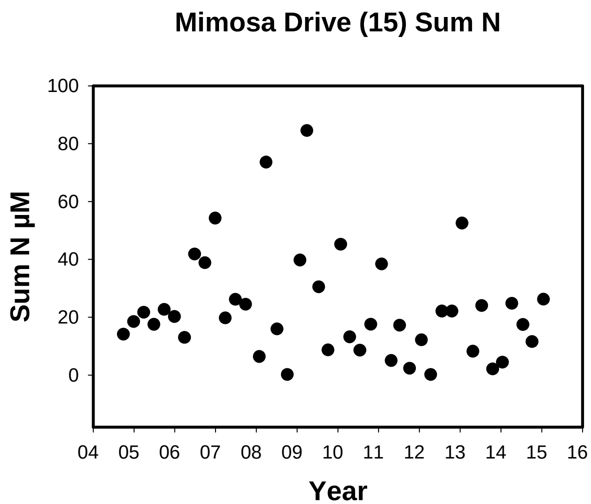
Overlook Pond is located in a built-out, wooded suburb (Kingspoint) over 60 years old. Lots are fairly large and wooded; no recent development over the last 15 years. Dissolved Nitrogen concentrations have always been low and appear to have dropped to near zero beginning in 2013. Total Phosphorus is very low, and TSS levels are on average very low as well. In prior years, we have characterized the Kingspoint subdivision as having the cleanest water in Williamsburg.

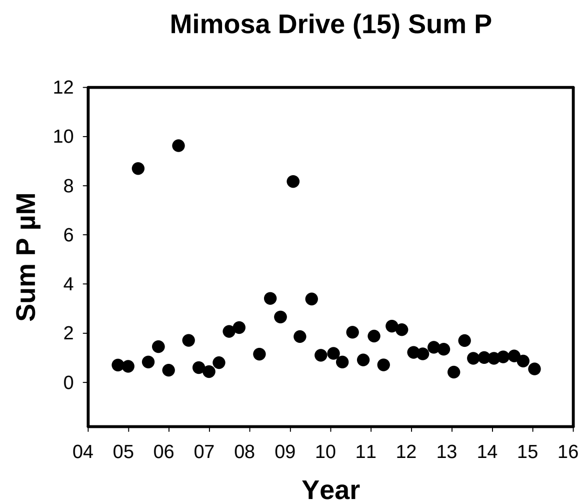


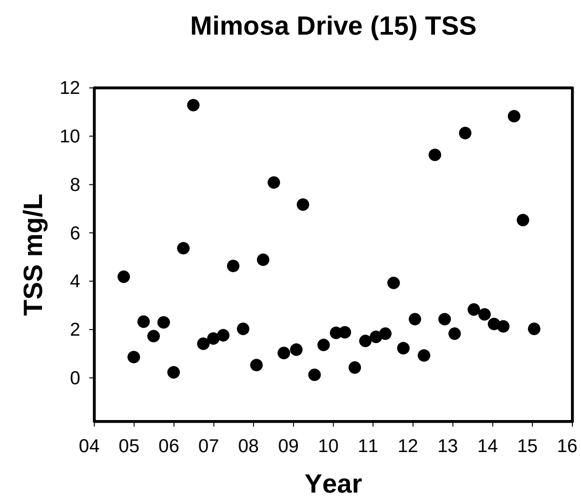




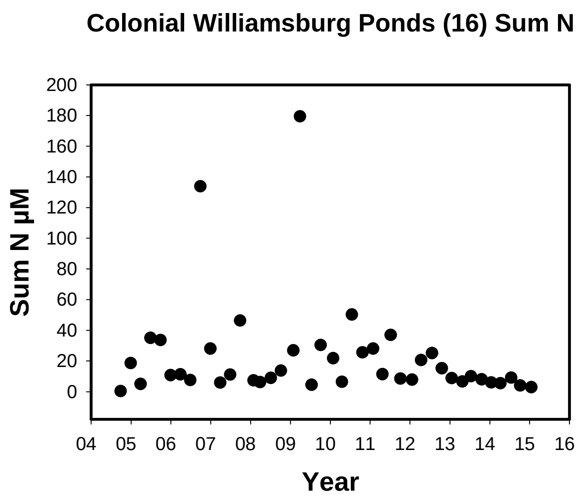
Kingspoint Pond is the second pond in the Kingspoint subdivision, characterized by older homes (~60 years) on large, wooded lots. Dissolved Nitrogen, Total Phosphorus, and TSS levels have been for the most part very low throughout the sampling period. Water clarity in Kingspoint is remarkable in that one can easily see the bottom of the pond in 10 feet of water; in some other ponds in the study, water clarity is only 1-2 feet.

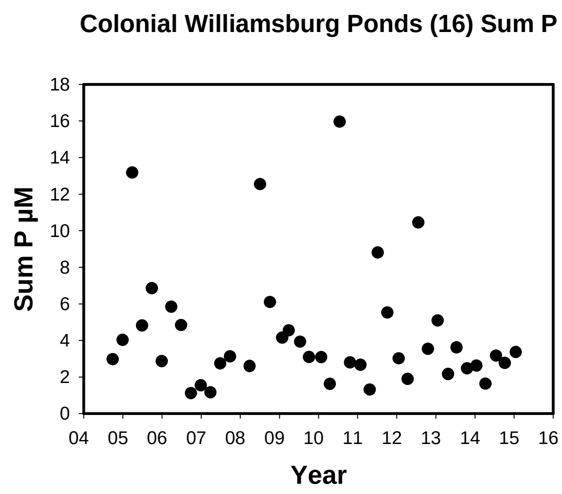


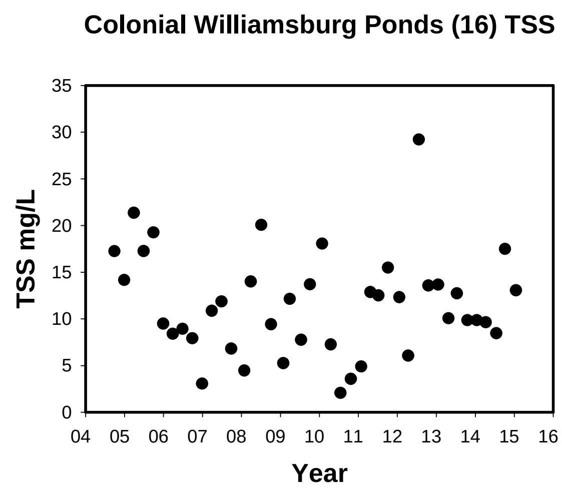




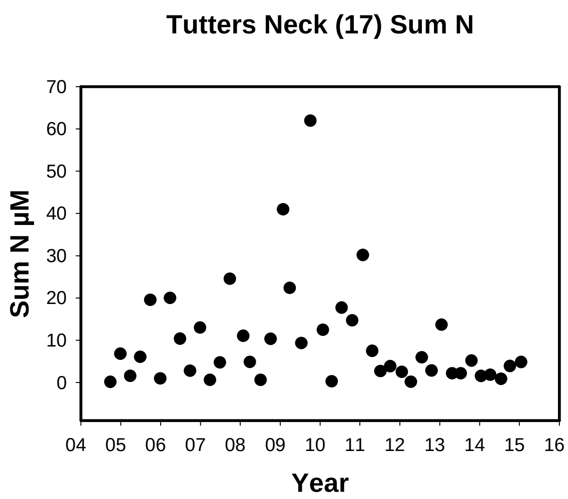
Mimosa Drive is a stream location in an older section of Williamsburg where there are no stormwater retention ponds. Housing lots are of variable size and have been largely built out. Over the 10-year study period, dissolved nitrogen has been variable but no recent decrease in N has been observed (unlike many other locations in the watershed). Total Phosphorus has always been low, although TSS has varied throughout the sampling period and appears to be increasing slightly in recent years.

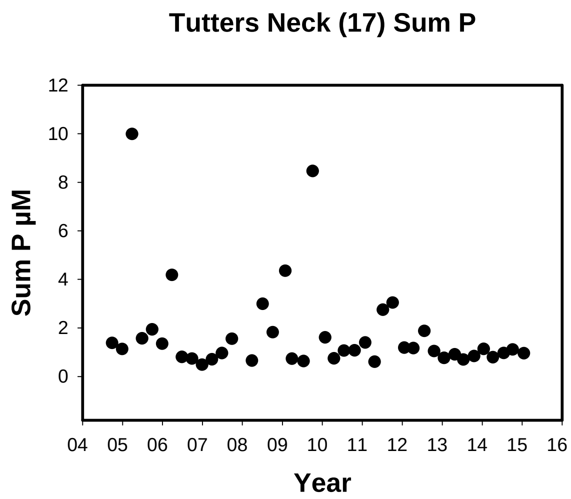


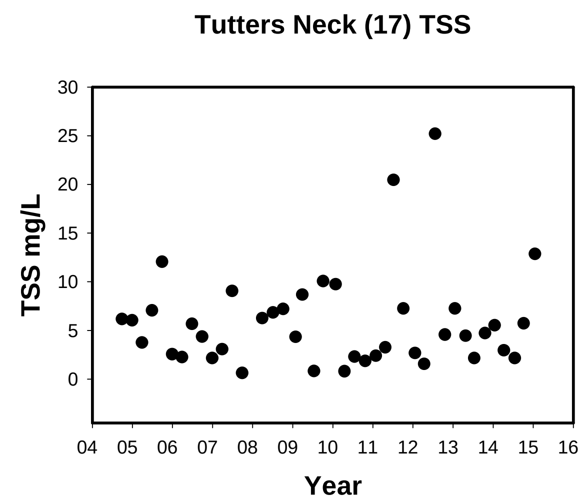




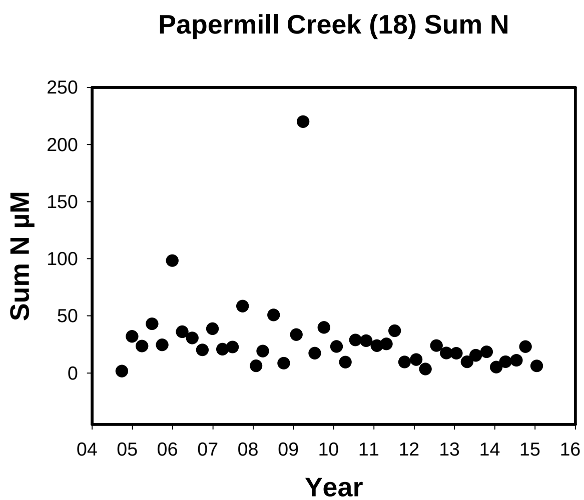
The CW Ponds are sampled at the outlet from a series of 3-4 ponds that drain a portion of the Golden Horseshoe Golf Course. Dissolved Nitrogen values have been variable over the sampling period but have dropped in the last three years. Total Phosphorus has been variable and sometimes fairly high; TSS typically has been high.

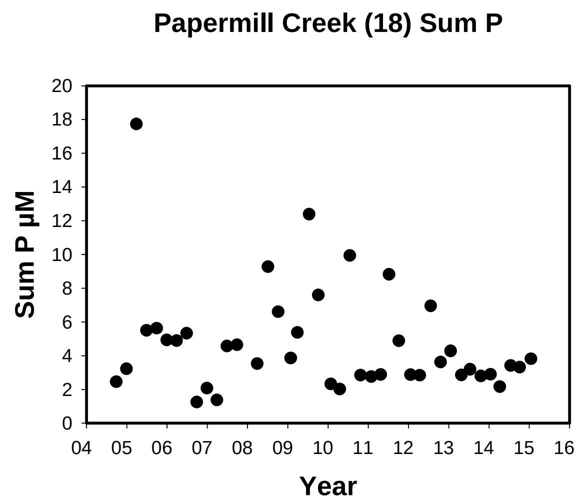


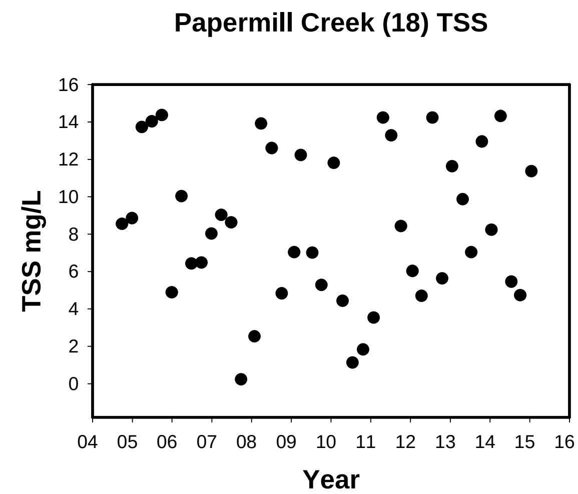




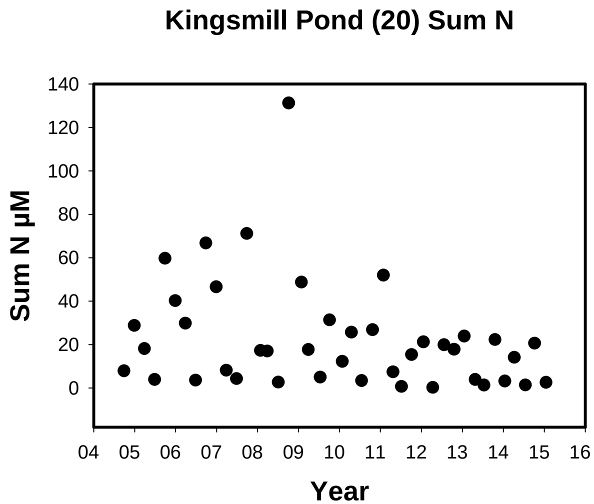
Tutters Neck is a pond located downstream from recent development of the new Riverside Hospital complex in Williamsburg. The hospital was under construction in 2011 and 2012 and opened for business in April 2013. A large stormwater pond is located on the 25-acre hospital site. Dissolved Nitrogen in Tutters Neck Pond dropped in 2011, with slight elevation at the beginning of 2013. Total Phosphorus has generally been low, with a small increase during the hospital construction phase. TSS levels have been low overall, but were highest during the hospital construction phase.

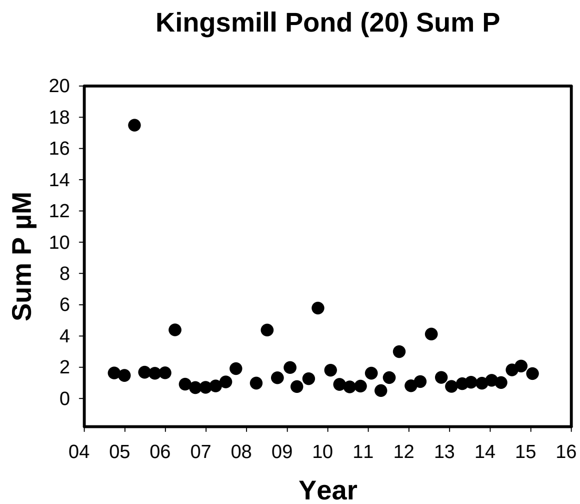


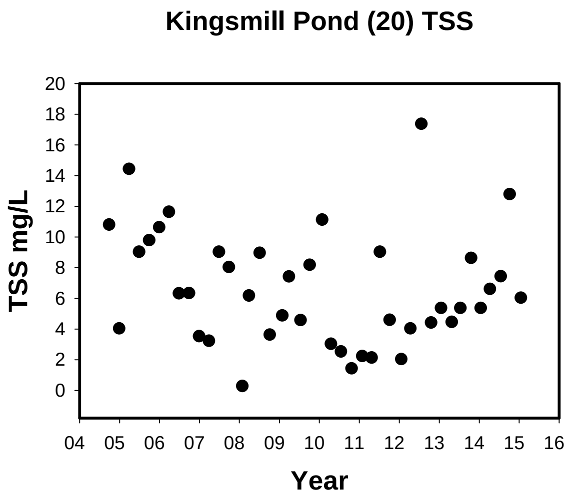




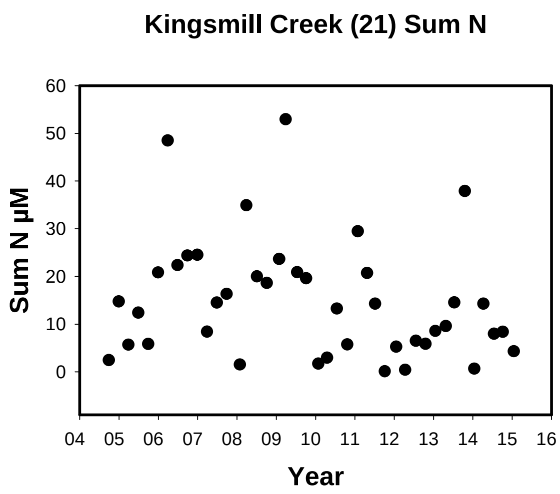
Papermill Creek is located in a wetland complex a few hundred meters downstream from the Colonial Williamsburg Ponds. Dissolved Nitrogen levels appear to have gradually decreased over the sampling period, and Total Phosphorus currently is lower than during 2009-2012. TSS levels have been high and variable throughout the sampling period.

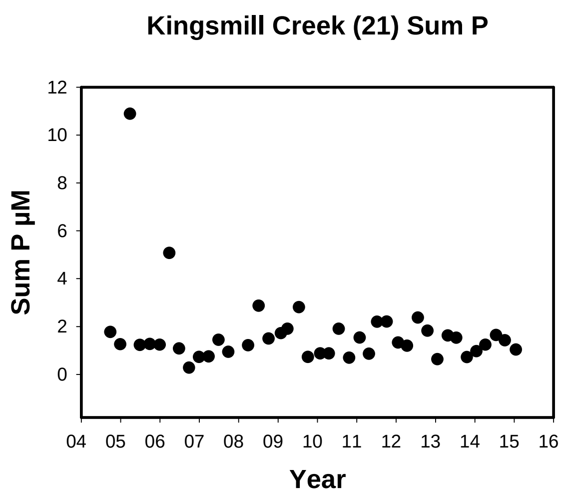


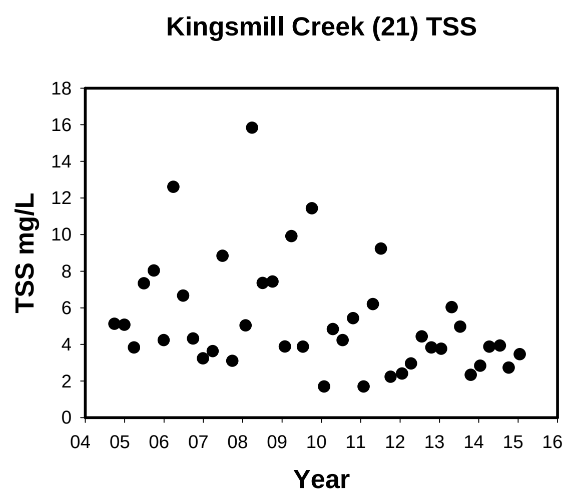




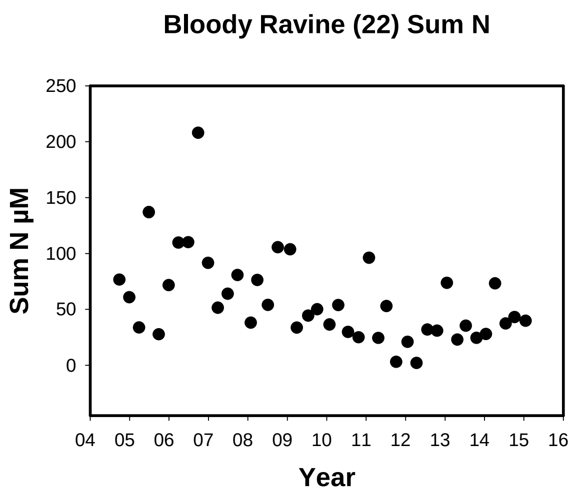
Kingsmill Pond is located in the Kingsmill subdivision—an affluent resort community along the James River featuring single-family homes built adjacent to three 18-hole golf courses. Dissolved Nitrogen has varied throughout the sampling period but that variability decreased beginning in 2011. Total Phosphorus levels have always been low, and TSS levels have varied but are not that high, although TSS has increased since 2012.

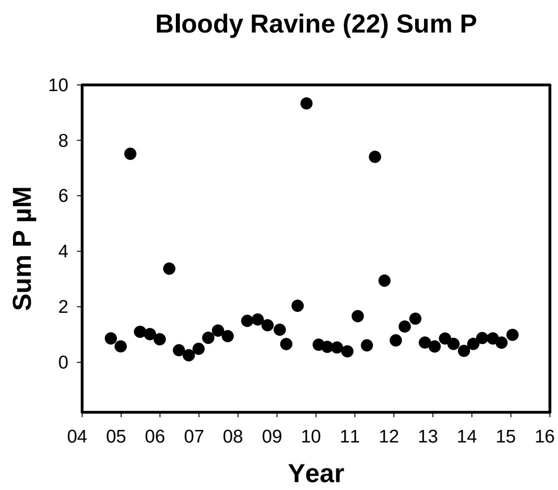


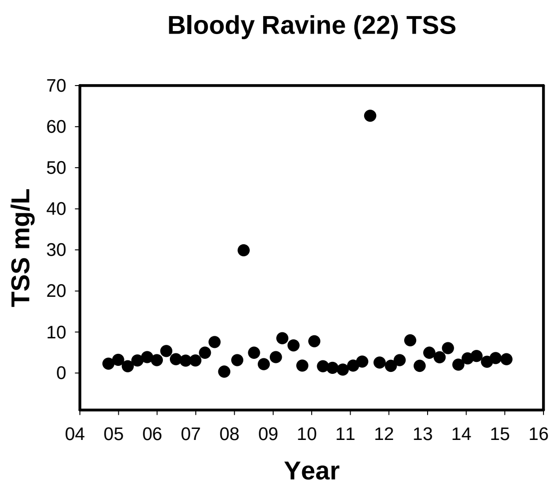




Kingsmill Creek is a small stream that runs through a developed portion of the Kingsmill Resort in Williamsburg. Dissolved Nitrogen has exhibited a slight decrease in average concentration over the last three years. Total Phosphorus has remained low and steady over the years, whereas TSS appears to have decreased in the last year, relative to more variable levels in prior years.







Bloody Ravine (so-named for a Civil War battle during which the ravine's waters ran red with the blood of fallen soldiers) drains an older housing development of low- to middle-income families. No stormwater ponds are in the watershed. Dissolved Nitrogen levels are slightly lower and less variable after 2009, but are still fairly high relative to other streams. In contrast, Total Phosphorus and TSS levels are both fairly low, with occasional outliers.