MARYLAND DEPARTMENT OF NATURAL RESOURCES

Martin O'Malley, Governor
John R. Griffin, Secretary

Patapsco and Back Rivers Water Quality and Habitat Assessment

Maryland Department of Natural Resources
Tidewater Ecosystem Assessment

Tawes Building, D-2, 580 Taylor Avenue
Annapolis, MD 21401
http://dnr.maryland.gov

Toll Free in Maryland:
1-877-620-8DNR, ext: 8630
Out of state call: 410-260-8630
TTY users call via the MD Relay:
711 (within MD)
Out of state call: 1-800-735-2258

Martin O'Malley, Governor

Anthony G. Brown, Lt. Governor

Primary Author:

Renee Karrh rkarrh@dnr.state.md.us

Contributors:

Diana Domotor, Rebecca Golden, Lee Karrh, Brooke Landry, William Romano, Brian Smith, Ben Cole, Sherm Garrison, Thomas Parham, Mark Trice

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Information on the water and habitat quality of Maryland's rivers and bays is available due to the hard work of many dedicated staff including:

- staff who are in the field collecting the samples year-round, sometimes under less than desirable weather conditions
- laboratory staff who perform the chemical tests to determine what exactly is in those water samples
- data management staff who collect the resulting information, confirm the accuracy and quality of the data, and organize and maintain the databases and
- analytical staff who interpret the data to answer the question 'how is the river/Bay doing?'

There are too many individuals to directly name from more than 25 years of monitoring, so we simply wish to commend all of them for their commitment to collecting high quality information and making it available and useful to the citizens of Maryland.

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Overall Condition

Healthy rivers and bays support a diverse population of aquatic life as well as recreational uses, such as swimming and fishing. To be healthy, rivers and bays need to have good water and habitat quality. High levels of nutrients and sediments lead to poor water quality. Poor water quality reduces habitat quality, including water clarity (how much light can get to the bottom) and the amount of dissolved oxygen in the water. In turn, habitat quality affects where plants and animals can live. The Maryland Department of Natural Resources (DNR) is responsible for monitoring water and habitat quality in the Chesapeake Bay and rivers, as well as the health of aquatic plants and animals. DNR staff use this information to answer common questions like "How healthy is my river?", "How does my river compare to other rivers?", "What needs to be done to make my river healthy?" and "What has already been done to improve water and habitat quality in my river?"

How healthy are the Patapsco River and the Back River?

The Patapsco River and Back River basin has high to extremely human population densities and intense urban land use (more than 50% of the watershed area). Point sources are the largest sources of nitrogen and phosphorus loadings, and urban run-off is the largest source of sediment loadings. Stream health is poor in five of the seven sub-watersheds, and five of these sub-watersheds are designated as a high priority for restoration efforts.

Water quality is poor but has improved. Phosphorus and sediment loadings to the North Branch Patapsco have decreased. Nitrogen, phosphorus and sediment levels have decreased in non-tidal streams in the Patapsco River sub-watersheds. Nitrogen levels have decreased in both rivers but are still too high. Phosphorus levels have improved in both rivers and sediment levels have improved in the Patapsco River.

Habitat quality is impaired for underwater grasses due to high algal densities and poor water clarity. Severe algal blooms are common in the Patapsco in the summer. Sediment levels are too high in the Back River. Habitat quality for bottom dwelling animals is impaired in the main Patapsco River and in shallow water areas around Fort McHenry. Summer dissolved oxygen levels in the shallow water areas of the Patapsco were better at Fort Armistead, Masonville Cove, and Fort Smallwood. Summer dissolved oxygen levels in Back River were good but indicate poor habitat quality due to excessive algal densities.

Underwater grasses populations have been limited or not present in the Patapsco and Back Rivers. Phytoplankton (algae and bacteria) and bottom dwelling animals are not healthy in most areas sampled in Patapsco and Back rivers.

Table 1. Summary of trends for non-tidal loadings (1985-2010) and water quality parameters trends (1999-2010).
Loadings trends are only available for one station. Improving trends are in green, degrading trends are in red. *: Nitrogen, phosphorus and sediment levels decreased at all stations from 1985-2010.

	Loadings			Water Quality		
	Nitrogen	Phosphorus	Sediments	Nitrogen	Phosphorus	Sediments
Non-tidal Patapsco		INCREASE	DECREASE	*	*	*
				*	DECREASE	*
				*	*	*
				*	DECREASE	*
				*	DECREASE	DECREASE

Table 2. Summary of tidal habitat quality and water quality parameters.
Algal densities, water clarity, inorganic phosphorus and sediments either 'Meet' or 'Fail' SAV habitat requirements (Appendix 5). Dissolved nitrogen levels below the level for nitrogen limitation 'Meet' criteria, otherwise 'Fail' criteria. Summer bottom dissolved oxygen levels above 3 mg/l 'Meet' criteria, otherwise 'Fail' criteria. Annual trends for 1999-2010 either 'Increase' or 'Decrease' if significant at $p \leq 0.01$; blanks indicate no significant trend. Improving trends are in green, degrading trends are in red. Nitrogen trends are for total nitrogen, phosphorus trends are for total phosphorus, water clarity trends are for Secchi depth. Depth 'Shallow' is from the shallow water monitoring program, 'Open' is from the long-term monitoring program.

River	Water Depths	Habitat Quality			Water Quality		
		Algal densities	Water Clarity	Summer Bottom Dissolved Oxygen	Nitrogen	Phosphorus	Sediments
Patapsco River	Shallow	FAIL	FAIL	MEET*	FAIL	MEET	MEET
	Open	FAIL	FAIL	FAIL	FAIL	MEET DECREASE	MEET DECREASE
Back River	Open	FAIL	FAIL	MEET*	FAIL DECREASE	FAIL DECREASE	FAIL

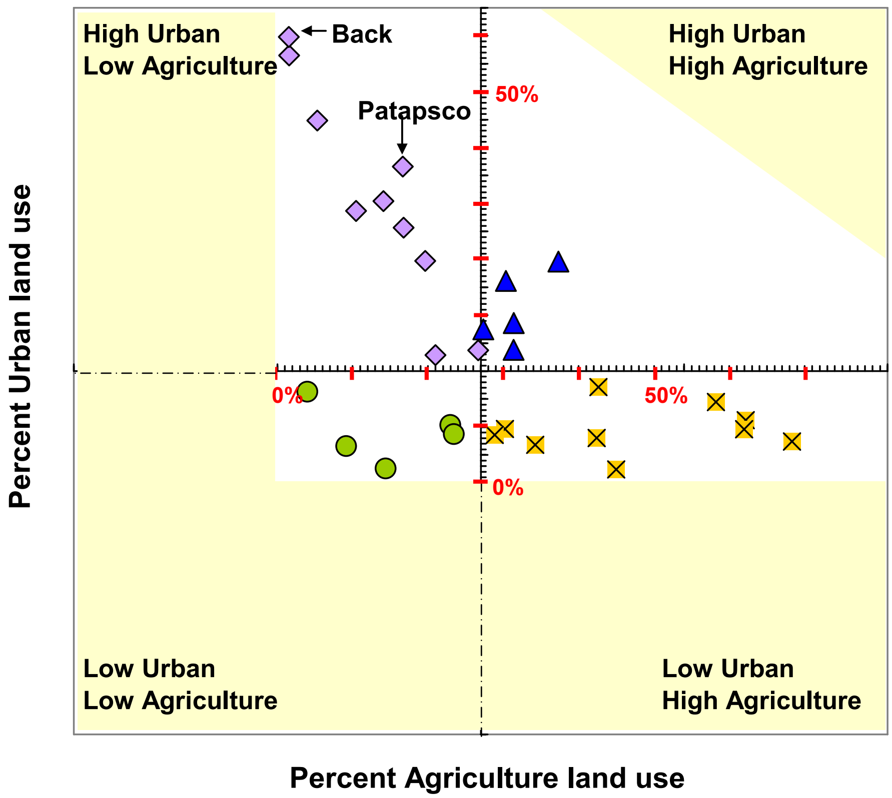

Figure 1. Classification of Maryland rivers and bays by land use.
The medians of all systems percent agriculture and percent urban land use are used to create a grid with four categories. Systems with percent urban less than the median are considered low urban. Systems with percent agriculture less than the median are considered low agriculture. Each system was categorized based on placement on the grid. Note that yellow areas are not mathematically possible (i.e. there is not a negative percent agriculture land use, and it is not possible for percent agriculture + percent urban to be greater than 100%). These groupings were used to evaluate each system relative to other rivers with similar land use characteristics.

How does the Patapsco River and the Back River compare to other rivers?

The Patapsco and Back rivers are in the 'High Urban, Low Agriculture' land use category (Figure 1). Nitrogen and phosphorus levels in the water and water clarity are also moderate compared to other rivers, while sediment levels are lower (Figure 2). However, summer bottom dissolved oxygen levels in the Patapsco River are the lowest of all rivers in Maryland and greatly degraded.

In many ways, Back River water and habitat quality is the worst of all Maryland rivers. Percent urban land use in the Back River watershed is the highest (and percent agriculture is the lowest) of all Maryland rivers. Nitrogen and phosphorus levels in the water and algal densities levels are also the highest, and water clarity is the worst. Sediment levels are the highest among the high urban watersheds. Even though summer bottom dissolved oxygen levels are the highest of the 'High Urban, Low Agriculture' systems, this is an indication of poor habitat quality due to high nutrient levels and algal densities.

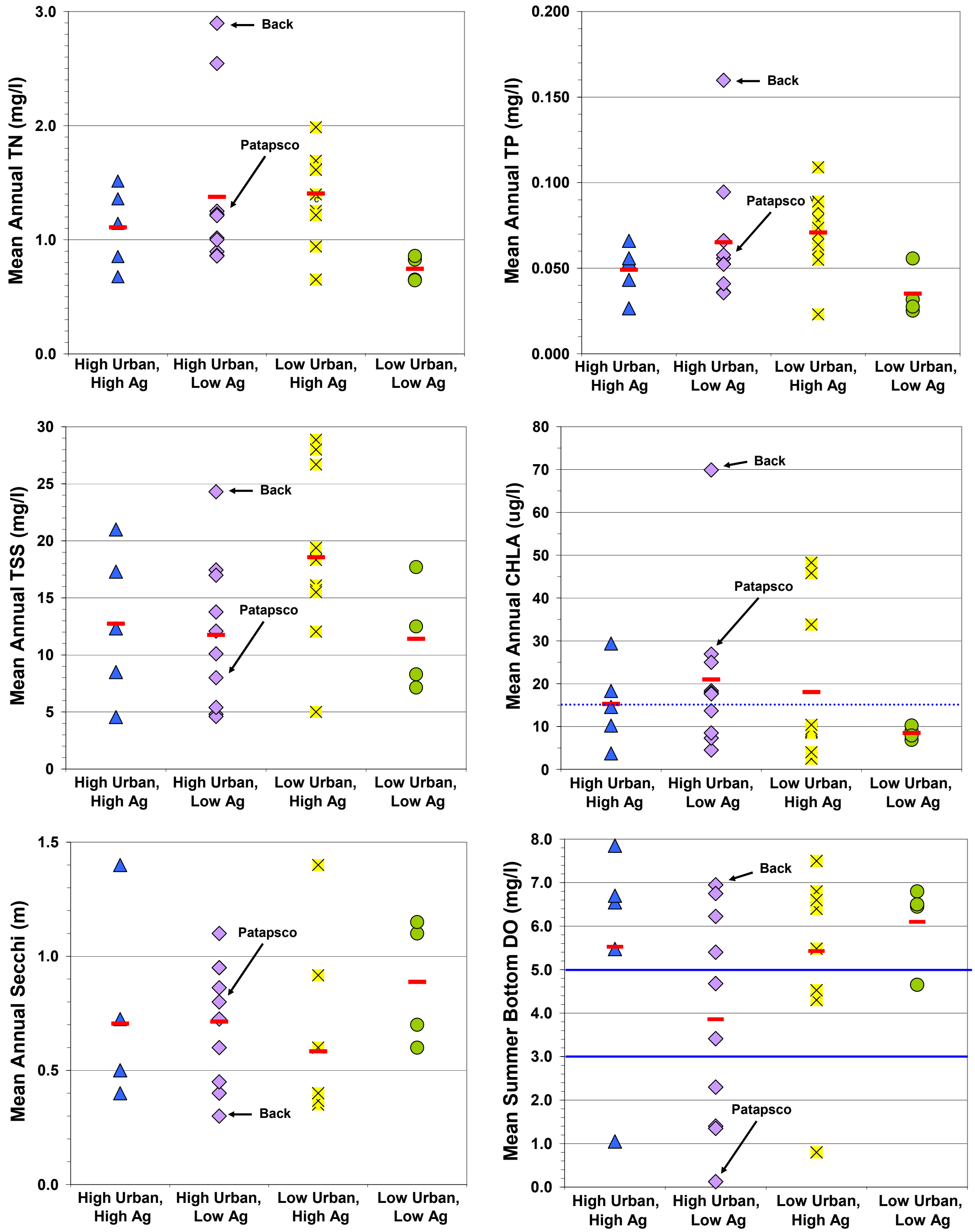

Figure 2. Comparison of the Patapsco and Back Rivers to similar systems.
The mean annual concentration or depth (bottom dissolved oxygen is only summer) for 2008-2010 data. Red bars indicate the mean of all systems within a category. Reference lines are included on the CHLA and BDO graphs.

What needs to be done to make the Patapsco River and the Back River healthy?

The biggest water quality and habitat issues are high nitrogen levels, high algal densities and poor water clarity. Upgrades to wastewater treatment plants will reduce nitrogen and phosphorus loadings to the rivers, and these improvements are already in place or planned. Reducing sediment loadings from urban runoff should also be a priority. Because most of the lower watersheds are heavily developed, retrofitting existing structures with alternatives to conventional building materials and methods should be used to reduce the amount of impervious surfaces and prevent additional degradation of water quality.

An intensive study of the historical loadings to Back River found that non-point sources were important to nutrient loads to the river, in addition to nutrient loads from the wastewater treatment plant. Non-point sources were especially important to phosphorus loads. The study also found that nutrients entering the river are deposited to the sediments, where they accumulate and are available to fuel algal growth at later times. As the result, water quality improvements following loadings reductions will be delayed by as much as 3-6 years. The study recommends management actions that make reductions in non-point source loads.

By lowering nutrients and sediments, water clarity should improve which will improve habitat quality for underwater grasses. Reductions in nutrients will also lead to lower algal densities and further improve habitat quality. Reducing algal densities by reducing nutrients will improve dissolved oxygen conditions, especially in shallow water areas.

What has already been done to improve water and habitat quality in the Patapsco River and the Back River?

A variety of actions have already been taken to lower nitrogen, phosphorus and sediment loadings, and the excessive nitrogen and phosphorus levels in the tidal waters. To reduce nutrient inputs from urban lands, these actions include upgrades to wastewater treatment plants, managing stormwater runoff and retrofitting septic systems. While specific goals have not been set for this basin, improvements are being made. Upgrades to the largest wastewater treatment plants that discharges to the Patapsco River are scheduled to be implemented by 2014. Upgrades to the largest wastewater treatment plant that discharges to the Back River are scheduled to be implemented by 2016. Previous upgrades at the Back River facility cut nitrogen levels in half. Stormwater retrofits have reduced nitrogen loadings and prevented more than 69,700 pounds of nitrogen from entering the rivers since 2003, and roughly 90 septic system retrofits were completed between 2008-2010.

To address nutrient inputs from agricultural lands, additional management actions have been taken. In 2010 there were 4,600 acres of cover crops planted in between growing seasons to absorb excess nutrients and prevent sediment erosion. Fencing on over 6,500 acres of farmland was used to keep livestock out of streams and prevent streambank erosion. Almost 2,500 acres of stream buffers were also in place, allowing areas next to streams to remain in a natural state with grasses, trees and wetlands.

Maryland also has a number of programs in place to reduce the impacts of continued development and increasing amounts of impervious surfaces in the Patapsco and Back rivers watersheds. Program Open Space projects have conserved more than 300 acres of land for outdoor recreation opportunities. Rural Legacy Program projects have protected almost 1,200 acres, with special focus on areas with important cultural sites and natural resources and to ensure large areas of habitat. Maryland Environmental Trust projects have helped individual land owners protect almost 1,600 acres. Maryland Agricultural Land Preservation Program projects have preserved 380 acres of agricultural land from development.

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Introduction

Water quality is measured as the level of nutrients and sediments in the water. Habitat quality is determined by how nutrients and sediments impact water clarity, algal populations and bottom dissolved oxygen levels. Habitat quality is also determined by salinity and water temperatures, but these measures are not changed by nutrients and sediments. Habitat quality determines if and where underwater grasses, fish and bottom dwelling animals can live. Reducing the levels of nutrients and sediments is a major focus of restoration efforts. The goal is to reduce nutrient and sediment levels so that habitat quality is improved and high quality habitat is expanded. Assessing water and habitat quality is an important first step in making decisions on what needs to be done to improve water and habitat quality.

Habitat quality can be assessed by looking at the health of the aquatic plants and animals that remain in the same location, such as underwater grasses and bottom dwelling animals. The health of these organisms depends on habitat that is suitable for growth and survival, so healthy organisms indicate healthy habitats. Changes in the populations of these plants and animals can often be linked to specific parts of habitat quality that are poor, such as water clarity or bottom dissolved oxygen. This additional information helps managers better pinpoint what needs to be changed to improve water and habitat quality.

Land use in a watershed is linked to the human population density. Rivers with high urban land uses have higher population densities and more impervious surfaces. Rivers with high agricultural land uses in rural areas have lower population densities and less impervious surfaces. Higher population densities are often linked to management of human wastes through wastewater treatment plants, while septic systems are more prevalent in areas with lower population density. Pollutant loadings from undeveloped lands such as forests are different from loadings from more developed areas. Information on human population and land use help managers decide the best methods for reducing nutrients and sediments going from the land into the water.

The Patapsco and Back River Water Quality and Habitat Assessment includes a variety of information. Land use data and census data are examined to understand how the watersheds are impacted by human uses. Loadings data is examined to identify how much nutrient and sediment is entering the non-tidal streams from the watershed. Data from long-term non-tidal and tidal water quality monitoring programs are examined for current water and habitat quality and changes over time. Data from monitoring in shallow water habitats are examined to determine water and habitat quality in the areas most important for underwater grasses and the organisms that live there. Data from monitoring of algal populations, underwater grasses and bottom dwelling organisms are examined to determine how well the resulting habitat quality supports healthy plant and animal populations.

Land use and Human population

The Patapsco and Back River basin drains all of Baltimore City and portions of Anne Arundel, Baltimore, Carroll, and Howard Counties (Figure 3). The Patapsco and Back River basin drains approximately 600 square miles in Maryland within eight sub-watersheds. The majority of the basin lies in the Piedmont physiographic province, but the immediate area surrounding Baltimore

Harbor lies in the Coastal Plain province. Major cities include all of Baltimore City and Sykesville and parts of Hampstead, Manchester, Westminster and Mount Airy.

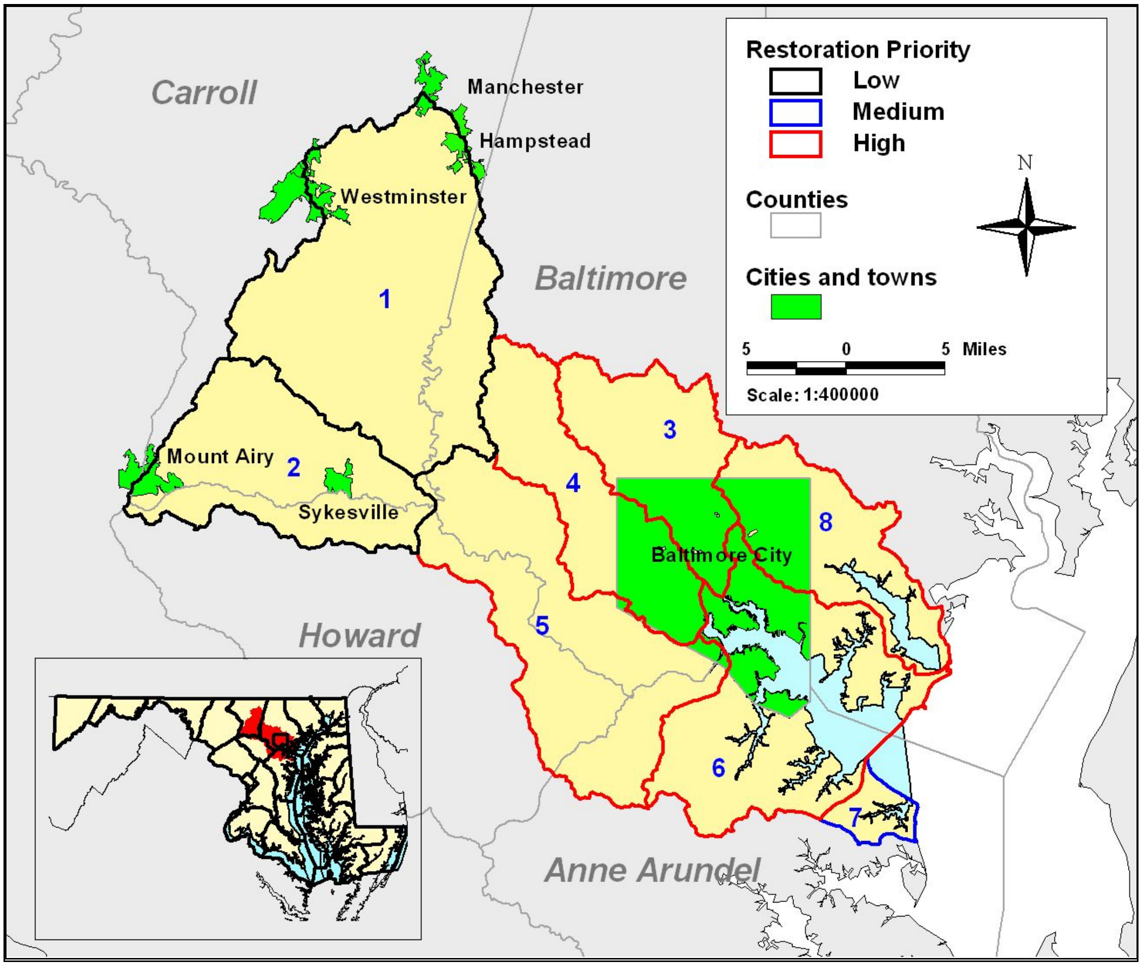

Figure 3. Patapsco and Back Rivers basin.
Trust Fund Restoration Priority designation (high, medium, low), county lines and cities/towns are shown. Sub-watersheds (8-digit) are: 1- Liberty Reservoir, 2- South Branch Patapsco, 3 – Jones Falls, 4- Gwynns Falls, 5- Patapsco River Lower North Branch, 6- Baltimore Harbor, 7- Bodkin Creek, and 8- Back River.

In 2010 there were approximately 1.5 million people living in the basin (Figure 4).[1] Population density was mostly moderate (between 100-1,000 people mi^2) in the upper basin and high (1,000-10,000 people mi^2) in the lower basin, though there were several areas in the lower basin with very high population density (10,000-100,000 people mi^2) within Baltimore City.

[1] 2010 data from the U.S. Census Bureau available online at http://www2.census.gov/census_2010/04-Summary_File_1/

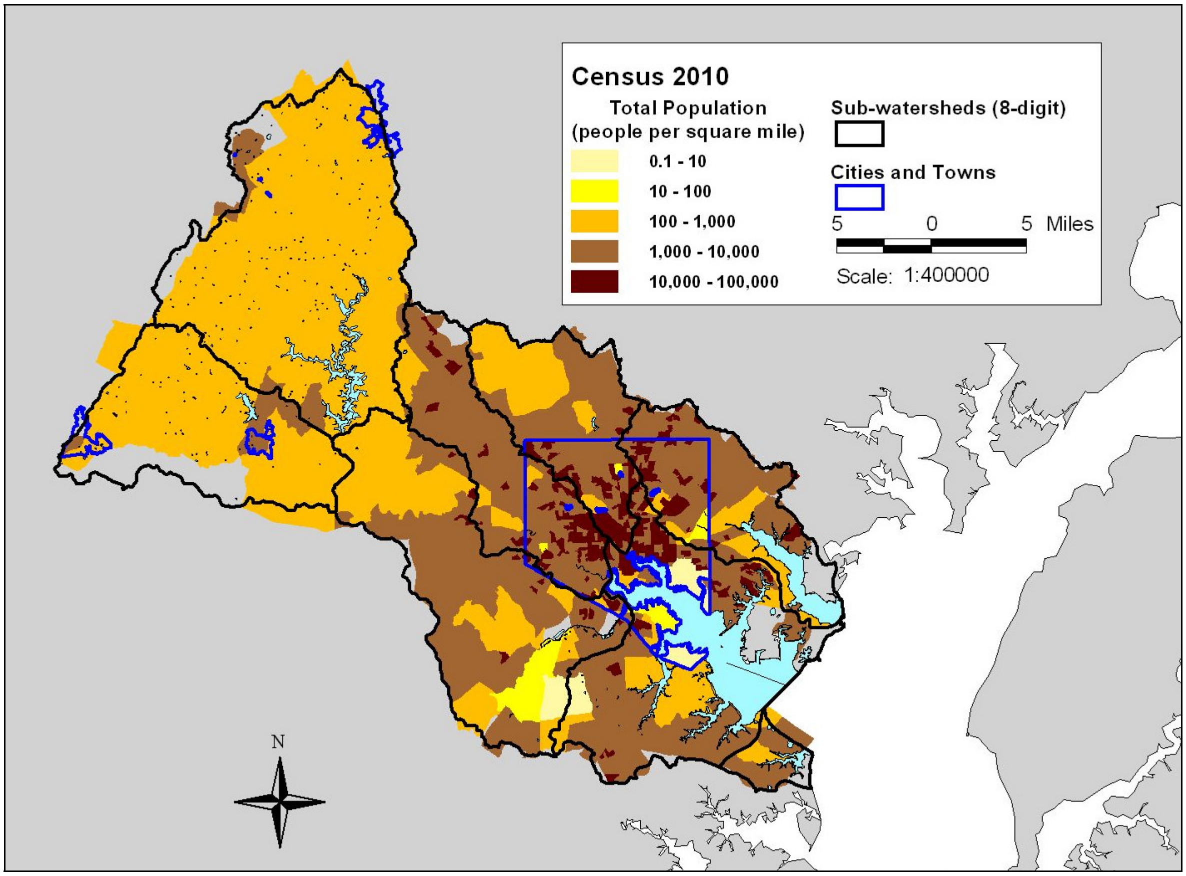

Figure 4. 2010 Census data for total population by block group.
Total population per square mile is shown using a log scale. Differences between the watershed boundaries and the Census bureau block group boundaries result in non-exact matching of the population data to the given watershed.

In 2010, the predominant land use in the entire basin was classified as urban (59%, Figure 5).[2] Forested areas comprised the second largest land use (24%). Less than one-fifth (15%) of the basin was devoted agricultural use. In the upper basin (South Branch Patapsco and Liberty Reservoir sub-watersheds), land use was approximately equally divided between agricultural, forest and urban. Urban land use increased by 12% between 2000 and 2010 in these watersheds, while agricultural lands decreased by a similar amount (Figure 6, Appendix 3). Impervious surfaces covered about 6% of these sub-watersheds.

[2] Maryland Department of Planning data for 2010 available at www.planning.maryland.gov/OurWork/landUse.shtml

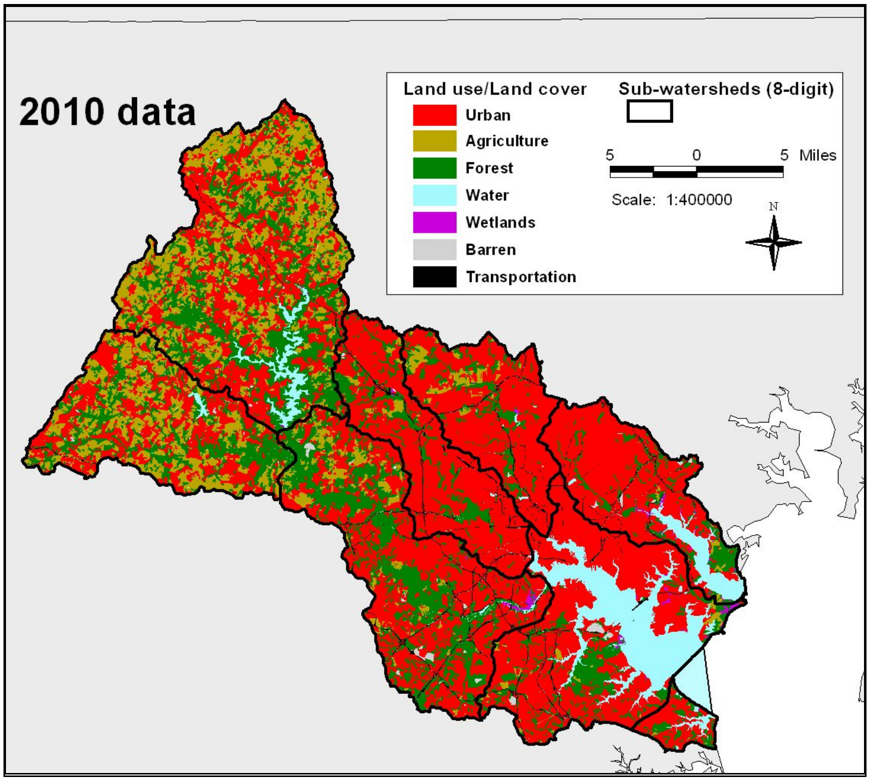

Figure 5. Land use/land cover data for 2010.
See Appendix 1 for detailed land use/land cover information.

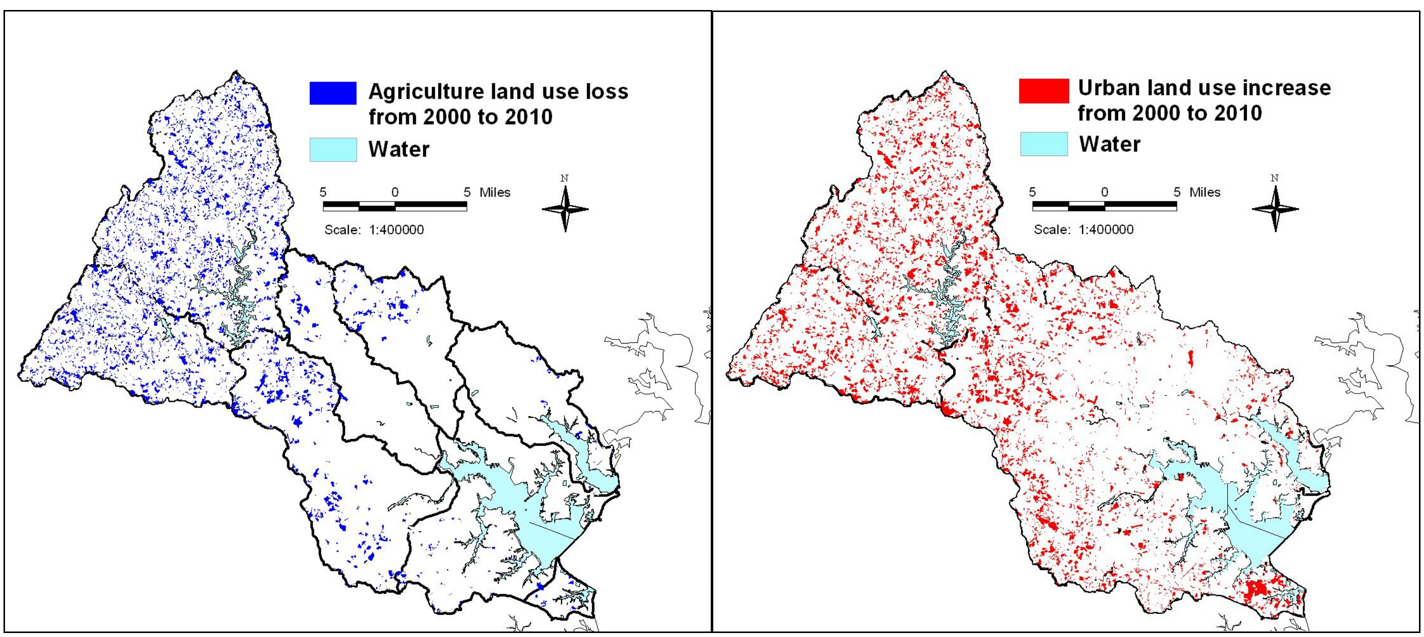

Figure 6. Land use change from 2000 to 2010.
Left panel shows change in agricultural land use in blue. Right panel shows change in urban land use in red.

Patapsco River L N Branch sub-watershed was 56% urban land use in 2010, and the rest of the lower basin had 73%-80% urban land use. Impervious surfaces covered between 19%-29% of the area within the individual sub-watersheds.[3]

Stream health in is categorized as poor for most of the sub-watersheds (Back River, Bodkin Creek, Baltimore Harbor, Gwynns Falls and Patapsco River Lower North Branch sub-watersheds), while in a few (Jones Falls, Liberty Reservoir, South Branch Patapsco), stream health is considered fair.[4] A Watershed Restoration Action Strategy (WRAS) was developed for the Patapsco River Lower North Branch watershed in 2004.[5] All of the smaller watersheds in the lower half of the basin are Maryland Trust Fund high priority watersheds except Bodkin Creek which is medium priority.[6]

Maryland has a number of programs in place to reduce the impacts of continued development and increasing amounts of impervious surfaces in the Patapsco and Back rivers watersheds. Program Open Space projects have conserved more than 300 acres of land for outdoor recreation opportunities. Rural Legacy Program projects have protected almost 1,200 acres, with special focus on areas with important cultural sites and natural resources and to ensure large areas of habitat. Maryland Environmental Trust projects have helped individual land owners protect almost 1,600 acres. Maryland Agricultural Land Preservation Program projects have preserved 380 acres of agricultural land from development.

Nutrient and Sediment Loadings

In accordance with the Chesapeake Bay Total Maximum Daily Load (TMDL), Maryland has developed a Watershed Implementation Plan (WIP) for making reductions in nitrogen, phosphorus and sediment loads to the Chesapeake Bay.[7] Maryland is required to reduce loads to Final Target loads by 2025. Maryland's Interim Target loads are set at 60% of the Final Target loads by 2017. Progress toward these Interim and Final Target loads is further broken into 2-year milestone loads. The first of these 2-year milestones is set for July 1, 2011- June 30, 2013.[8]

The Patapsco and Back rivers are combined with the Upper Western Shore basin and Lower Western Shore basin rivers into a single category- the Western Shore Basin. Final Target Loads for the Western Shore Basin are 9.77 million pounds per year of nitrogen, 0.55 million pounds

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[3] Percent impervious surfaces greater than 10% typically lead to impaired water and habitat quality.
[4] Maryland Department of Natural Resources data available at www.streamhealth.maryland.gov/stream_health.asp
[5] Detailed reports are available at http://dnr.maryland.gov/watersheds/surf/proj/wras.html.
[6] Information on Maryland's Trust Fund is available at http://www.dnr.maryland.gov/ccp/funding/pdfs/TrustFundPriorities.pdf
[7] Maryland's Phase II Watershed Implementation Plan is online at www.mde.state.md.us/programs/Water/TMDL/TMDLImplementation/Pages/FINAL_PhaseII_WIPDocument_Main.aspx
[8] Progress toward meeting the 2011-2013 milestones is available on BayStat at www.baystat.maryland.gov/milestone_information.html

per year of phosphorus and 243 million pounds per year of sediments. The information below is loadings in 2009.

The Patapsco River received approximately 7.6 million lbs/yr of nitrogen, 0.4 million lbs/yr of phosphorus, and 111 million lbs/yr of sediment from the surrounding watershed (Appendix 2). The Back River received approximately 2.2 million lbs/yr of nitrogen, 0.08 million lbs/yr of phosphorus, and 9.4 million lbs/yr of sediment from the surrounding watershed. Point sources are the largest contributor of nitrogen and phosphorus to both rivers (Figure 7). Urban runoff is the largest source of sediment loadings and also a source of phosphorus loadings to Patapsco River.

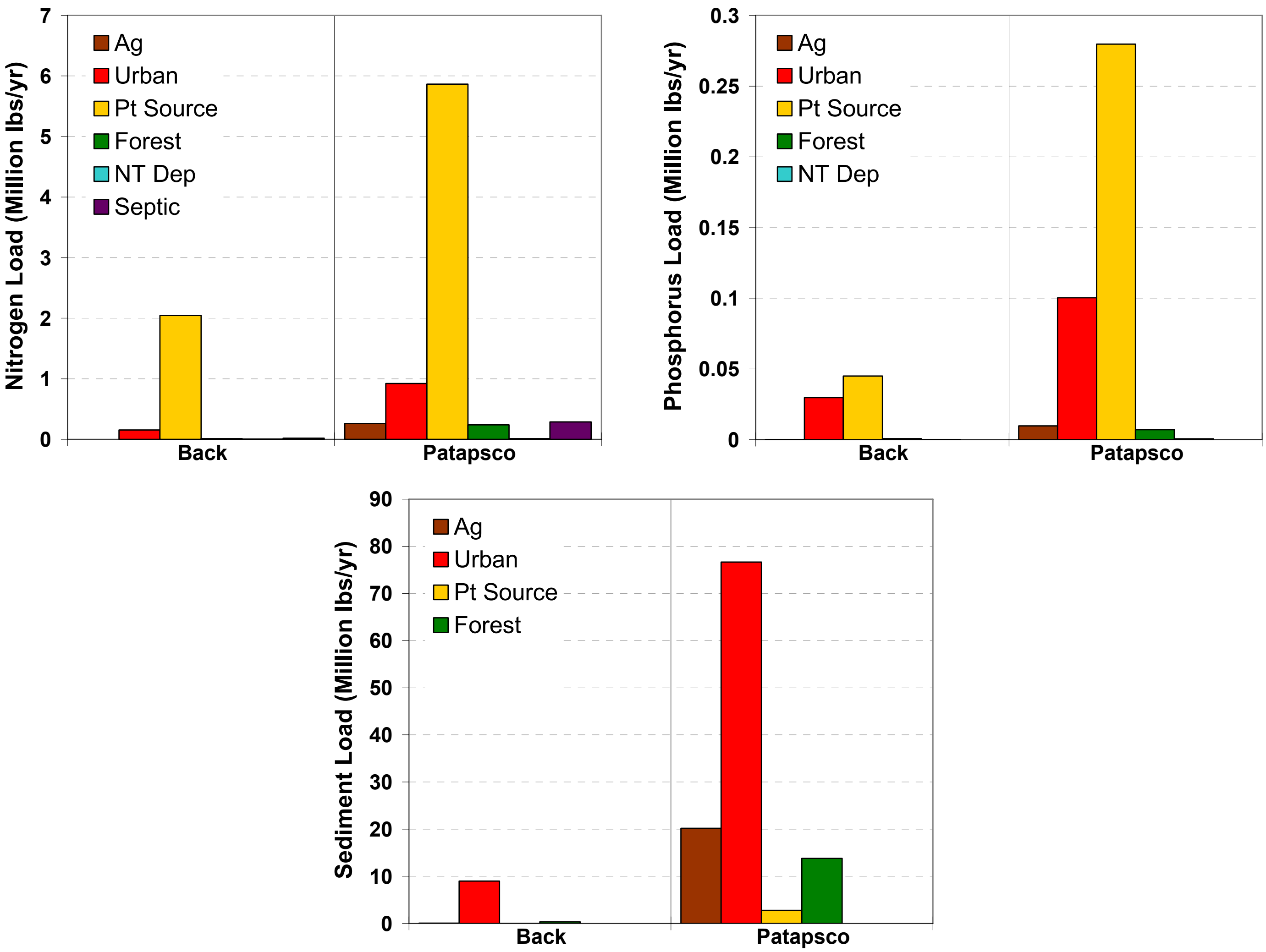

Figure 7. Nitrogen, phosphorus and sediment loadings per year.
Delivered loadings by category in million lbs/yr (see Appendix 2). Septic is not a source of phosphorus or sediment loadings and water deposition (NT Dep) is not a source of sediment loadings.

Point Source Loads

Nutrient loadings from point sources (including wastewater treatment plants, WWTPs) are the easiest to measure. Point source loads are often the most cost-effective to manage. A major focus of management actions to reduce nutrient loads has been upgrades to WWTPs. In 2004 Maryland passed legislation creating the Chesapeake Bay Restoration Fund specifically to fund WWTP upgrades to enhanced nutrient removal (ENR).[9] The program is working to complete ENR upgrades to 67 major WWTPs, including the five major WWTPs in the Patapsco/Back basin.[10]

The Patapsco has four major WWTP that treat sewage. Patapsco River WWTP is the largest (66.7 million gallons per day, MGD). Construction of upgrades at Patapsco WWTP began at the end of 2009. Biological nutrient removal (BNR) was fully implemented in mid 2011 and upgrades to ENR are scheduled to complete by mid 2014.[11]

The other major WWTP plants that discharge to the Patapsco River are:

1. Cox Creek WWTP (15 MGD), which discharges directly to the Patapsco River. BNR was implemented in 2002. ENR construction began in early 2010 and is scheduled for completion by mid-2015.

2. Freedom District WTTP (3.5 MGD), which discharges to the South Branch Patapsco River. BNR was implemented in 1994. ENR construction is scheduled to start in 2013 and be completed in 2015.

3. Mount Airy WTTP (1.2 MGD), which discharges to the South Branch Patapsco River. BNR was implemented in 1999. ENR upgrades were completed in late 2010.

Patapsco WWTP contributes more than 90% of the total nitrogen load and approximately 85% of the total phosphorus load from WWTPs to the Patapsco River. Nitrogen loads from the Patapsco River WWTP have continuously increased since 1985 and are approximately one and a half times higher in 2010 (Figure 8). Phosphorus loads decreased from 1985-2004, but have since begun to increase. Phosphorus loadings since the early 1990s are about one-half those of the mid-1980s. Both nitrogen loads and phosphorus loads are well above the loading caps.

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[9] The Chesapeake Bay Restoration Fund collects fees from wastewater treatment plant users to pay for the upgrades. A similar fee is paid by septic system users to upgrade onsite systems and implement cover crops to reduce nitrogen loading to the Bay. For more information on the Chesapeake Bay Restoration Fund see http://www.mde.state.md.us/programs/Water/BayRestorationFund/Pages/index.aspx.

[10] Major wastewater treatment plants (WWTP) are those with greater than 0.5 million gallons per day (MGD) design flow.

[11] Biological nutrient removal (BNR) technology removes additional nitrogen than traditional methods, bringing nitrogen levels in effluent to below 8 mg/l. Enhanced nutrient removal (ENR) reduces nitrogen levels to below 3 mg/l and phosphorus levels to below 0.3 mg/l in effluent.

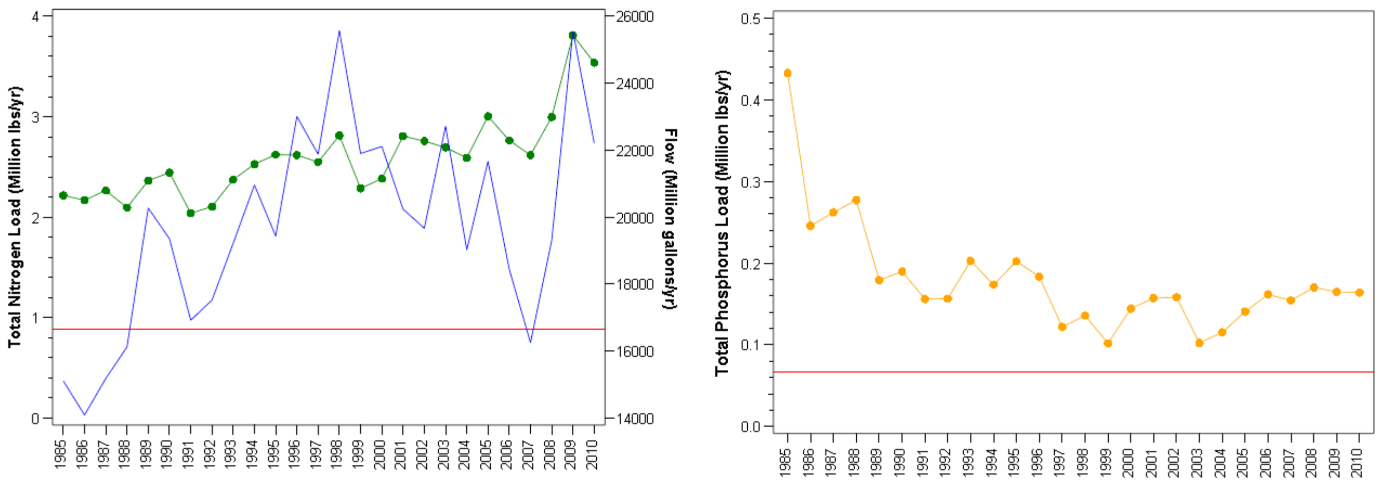

Figure 8. Annual total nitrogen and total phosphorus loadings from Patapsco River WWTP to the Patapsco River.
Blue line on nitrogen graph shows total annual effluent flow. Red horizontal line indicates the loading cap for the facility following implementation of ENR.

Cox Creek WWTP contributes approximately 7% of the total nitrogen load and 13% of the total phosphorus load from WWTPs to the Patapsco River. Nitrogen loads from the Cox Creek WWTP generally decreased since the early 1990s, becoming roughly stable after 2006 following BNR implementation (Figure 9). Phosphorus loads have steadily decreased since 1985. Nitrogen and phosphorus loads in 2010 were almost half the loads in 1985. Both nitrogen and phosphorus loads are approaching loading caps.

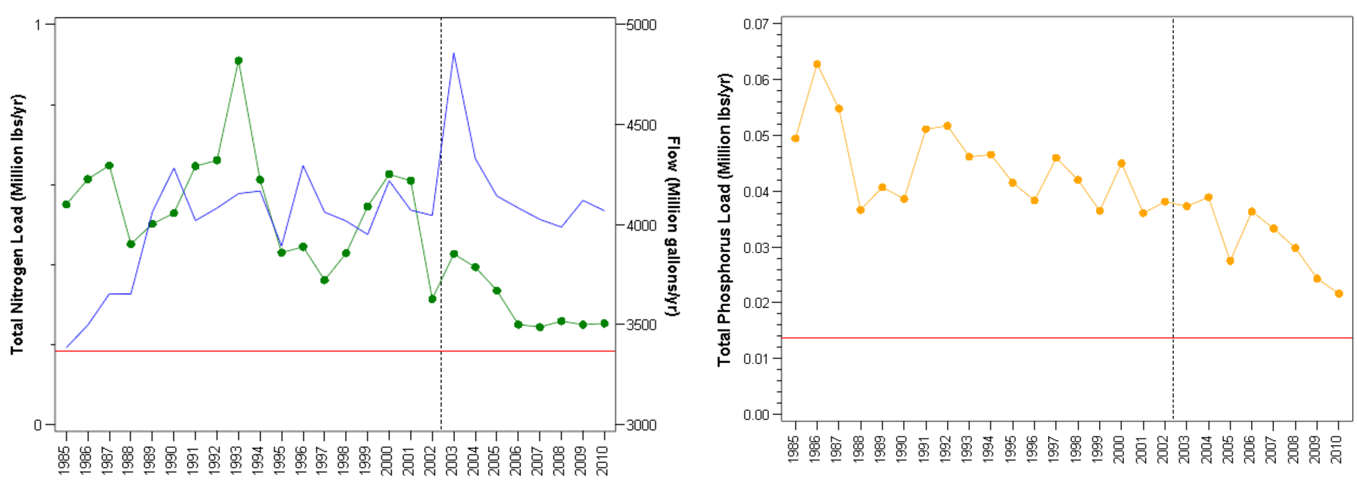

Figure 9. Annual total nitrogen and total phosphorus loadings from Cox Creek WWTP to the Patapsco River.
Blue line on nitrogen graph shows total annual effluent flow. Red horizontal line indicates the loading cap for the facility following implementation of ENR. The dotted vertical line indicates when BNR was implemented.

Nitrogen and phosphorus loadings from Freedom District WWTP and Mount Airy WWTP were less than 2% of the total loads to the Patapsco River.

The Back River basin has one major WWTP, Back River WWTP (180 MGD). BNR was implemented in mid 1998; ENR construction will begin in 2013 and is expected to be complete by 2016. Nitrogen loads from Back River WWTP post-BNR were about one-half of the pre-BNR loads but still well above the loading cap (Figure 10). Phosphorus loads have decreased substantially following the ban on phosphorus in detergents in 1986 and have remained below the loading caps since the early 1990s.

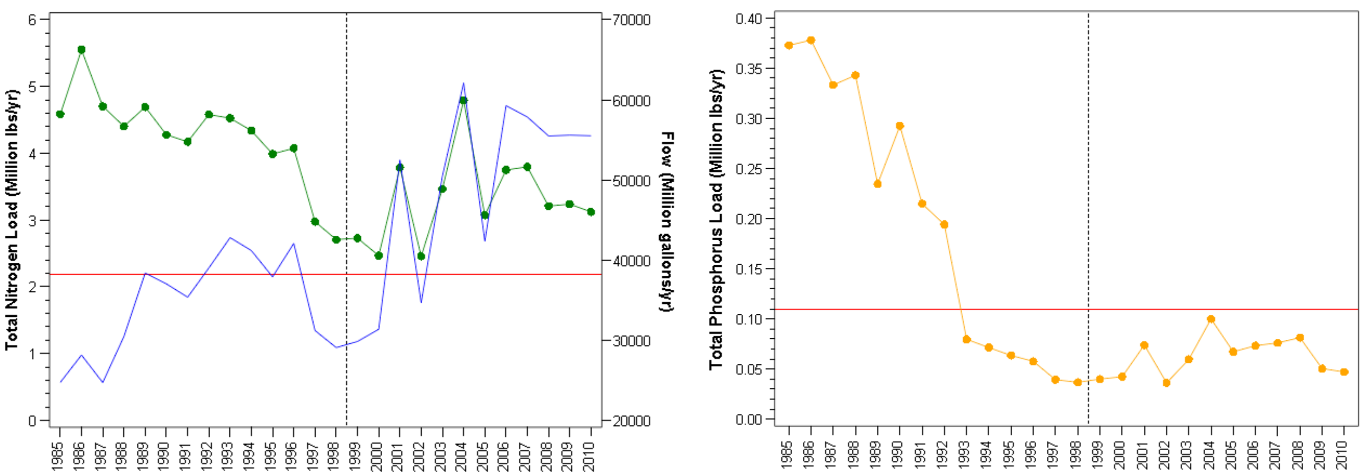

Figure 10. Annual total nitrogen and total phosphorus loadings from Back River WWTP to the Back River.
Blue line on nitrogen graph shows total annual effluent flow. Red horizontal line indicates the loading cap for the facility following implementation of ENR. The dotted vertical line indicates when BNR was implemented.

An intensive study of the historical loadings to Back River noted substantial improvements in nitrogen, phosphorus and sediment loadings since the early 1980s as the result of upgrades to the Back River WWTP.[12] Sediment loads from the WWTP were 15 times lower following upgrades; TN loads were half the earlier loads and TP loads were more than 6 times lower.[13] Several important differences between point source loads from the WWTP and non-point source loads from the watershed were also found: 1) point sources were more consistent throughout the year than non-point source loads; 2) non-point source loads differed widely between seasons and years and were typically very low in summer and fall, following the same pattern as precipitation; 3) TP loads from non-point sources were usually larger than point source loads; and 4) despite the large decreases in point source loads there is no clear reduction in non-point source loads. The study also found that nutrients entering the river were not passed on to the mainstem Chesapeake Bay but were instead either used by biological and chemical processes in

[12] Boynton et al (2011), available online at http://www.gonzo.cbl.umces.edu/documents/water_quality/Level1Report28.pdf
[13] Boynton et. al (2011) note that the P loads dropped drastically after 1983; a P-ban in detergents in 1984 was a driving force in these reductions.

the water or deposited to the sediments. Nutrients deposited to the sediments accumulate and are available to fuel algal growth at later times. As the result, water quality improvements following loadings reductions will be delayed by as much as 3-6 years. The study recommends management actions to make reductions in non-point source loads.

Non Point Source Loads

In 1998, Maryland passed the Water Quality Improvement Act, which requires farmers to reduce nitrogen and phosphorus loadings from agricultural lands.[14] Soil Conservation and Water Quality Plans (SCWQPs) are developed to determine what the appropriate actions, or best management plans (BMPs), are for a given area.[15] Each of Maryland's counties has a Soil Conservation District Office with staff to help farmers develop and implement SCWQPs. The total number of BMPs in place in the basin as a whole (not by individual farm) is used to measure progress.[16] In 2010 there were 4,600 acres of cover crops planted in between growing seasons to absorb excess nutrients and prevent sediment erosion. Fencing on over 6,500 acres of farmland was used to keep livestock out of streams and prevent streambank erosion. Almost 2,500 acres of stream buffers were also in place, allowing areas next to streams to remain in a natural state with grasses, trees and wetlands.

Water and Habitat Quality

Non-tidal water quality monitoring is done year-round at five stations to characterize conditions in free-flowing freshwater (Figure 10, Appendix 3). For these sites, only surface measurements are collected. At two of these stations (NPA0165 and GWN0115) stream gauges are installed which provide flow data. The USGS uses the flow data and the nutrient data to calculate nitrogen, phosphorus and sediment loadings to the streams.[17] For the North Branch Patapsco station (NPA0165) flow data has been collected since 1985. For the Gwynns Falls station, flow data has been collected since 2001. Trends are calculated for the North Branch Patapsco station but not the Gwynns Falls station. Tidal water quality monitoring is done year-round at two stations that have been monitored since 1985 (Figure 10, Appendix 3).

For non-tidal and tidal stations, the following parameters were evaluated: total nitrogen (TN), total phosphorus (TP) and total suspended solids (TSS). For tidal stations, additional parameters were evaluated: dissolved inorganic nitrogen (DIN), dissolved inorganic phosphorus (PO_4), algal abundance (as measured by chlorophyll *a*, CHLA), water clarity (as measured with a Secchi disc and by calculating the percent light through water, PLW), summer bottom dissolved oxygen (BDO), salinity and water temperature.

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[14] For more information, please see the Maryland Department of Agriculture website http://mda2.maryland.gov/resource_conservation/Pages/nutrient_management.aspx
[15] For more information see http://mda.maryland.gov/pdf/scwqplan.pdf
[16] Progress on different BMPs is available at http://www.baystat.maryland.gov/milestone_information.html
[17] For USGS methods see http://md.water.usgs.gov/publications/sir-2006-5178/index.html

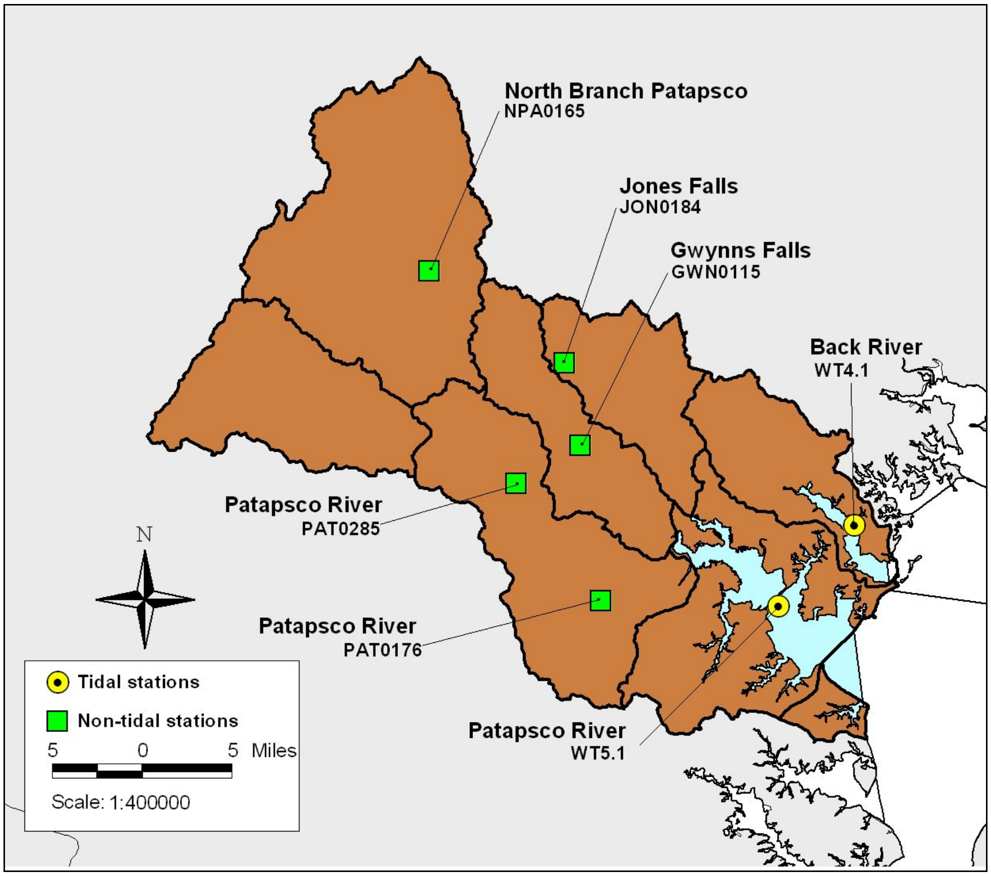

Figure 11. Long-term non-tidal and tidal water quality monitoring stations.
Sub-watersheds (8-digit) also shown.

Assessment methods are described in Appendix 4. Selected graphical results are included with the text. Non-tidal and tidal water quality trends results discussed in the text refer to the 1999-2010 trends. Seasons for 1999-2010 tidal trends are: spring (March-May), summer (July-September)[18] and SAV growing season (Apr-October). Significant trends for 1985-2010 (tidal) or 1986-2010 (non-tidal) are noted in the footnotes. Figure and Appendix references apply to all rivers and are given only the first time referenced. Summary results are presented in Table 1 and Table 2 in the 'Overall Assessment' section. Detailed tabular results tabular results are included in Appendices 6, 7 and 8.

[18] For summer bottom dissolved oxygen analysis, the months used are June-September.

Patapsco River

TN levels in the non-tidal streams are highest in the North Branch Patapsco (NBP0165, Figure 13).[19] TN levels in the tidal portion of the Patapsco River were relatively poor. Substantial reductions in TN have been made since 1985 (Figure 14). DIN levels were relatively poor and summer DIN levels were too high to limit algal growth (Figure 15).

Total phosphorus in non-tidal streams decreased at three stations (PAT0285, GWN0115, PAT0176), and TSS decreased at one (PAT0285). Total phosphorus and sediment loadings at the North Branch Patapsco station decreased from 1985-2010, but sediments also increased from 2001-2010.[20]

TP and PO_4 levels in the tidal portion of the Patapsco River were relatively poor, but PO_4 improved annually, in the summer and in the SAV growing season and maybe in the spring. TSS levels were relatively good and improved annually, in the SAV growing season and maybe in the summer. PO_4 and TSS levels in the SAV growing season were low enough to meet habitat requirements (Figure 16).

Algal density was relatively poor in the Patapsco. Water clarity was also relatively poor, and Secchi depth may have degraded in the spring.[21] Algal densities and water clarity did not meet the SAV habitat requirements. Summer bottom dissolved oxygen was poor and may have degraded.[22] Summer monthly average BDO was almost never above 3 mg/l, clearly indicating poor habitat quality in the bottom waters at the location of the monitoring station (Figure 17).

Back River

TN in Back River was relatively poor and DIN levels were relatively good. TN and DIN improved annually, in the spring and the SAV growing season. The decrease in annual TN levels from 1985-2010 was very substantial. DIN levels followed a similar sharp decline, but DIN levels were rarely low enough to limit algal growth.

TP in Back River was relatively poor but improved annually, in the spring and in the SAV growing season. PO_4 was relatively fair and also improved annually, in spring and in the SAV growing season. PO_4 may also have decreased in the summer. TSS levels were relatively fair and may have improved in the spring. PO_4 levels during the SAV growing season were low enough to meet the habitat requirements in 2008 and 2010, but TSS levels were not.

Algal abundance was relatively poor, and CHLA levels may have increased in the SAV growing season.[23] CHLA levels were too high to meet the habitat requirement. Water clarity was also relatively poor, and degraded in the summer. Water clarity did not meet the SAV habitat requirement. Bottom dissolved oxygen levels in summer were good as an average, but can vary greatly throughout the day and can become extremely low in the summer.[24] Also, the monthly

[19] Total nitrogen, total phosphorus and total suspended solids decreased at all non-tidal stations from 1986-2010.
[20] Non-tidal loadings trends are from USGS (Langland, pers. communication).
[21] Secchi depth degraded from 1985-2010.
[22] Summer bottom dissolved oxygen levels degraded from 1985-2010
[23] However, CHLA levels but may have improved from 1985-2010.
[24] See Boynton et al (2011) available online at available online at http://www.gonzo.cbl.umces.edu/documents/water_quality/Level1Report28.pdf

average BDO were often in excess of 10 mg/l in the summer, an indication of excessive nutrients and algal density fueling high oxygen production by algae.

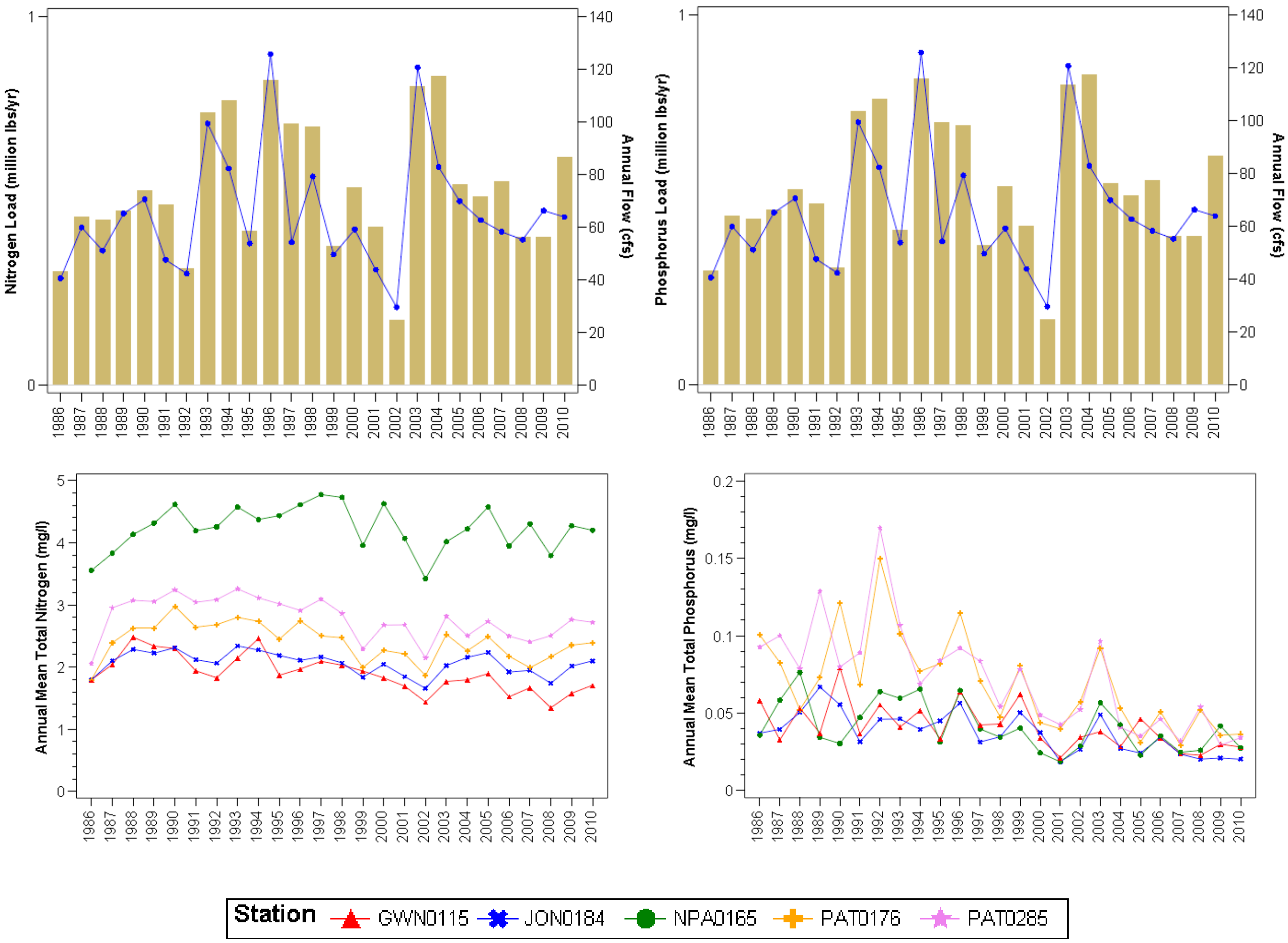

Figure 12. Annual nitrogen and phosphorus load and concentration for non-tidal stations in the Patapsco River basin.
Top graphs show annual nitrogen and phosphorus (tan bars, left axis) and flow (blue line, right axis) for North Branch Patapsco (station NPA0165). Bottom graphs show annual mean concentrations for total nitrogen and total phosphorus for all of the non-tidal stations.

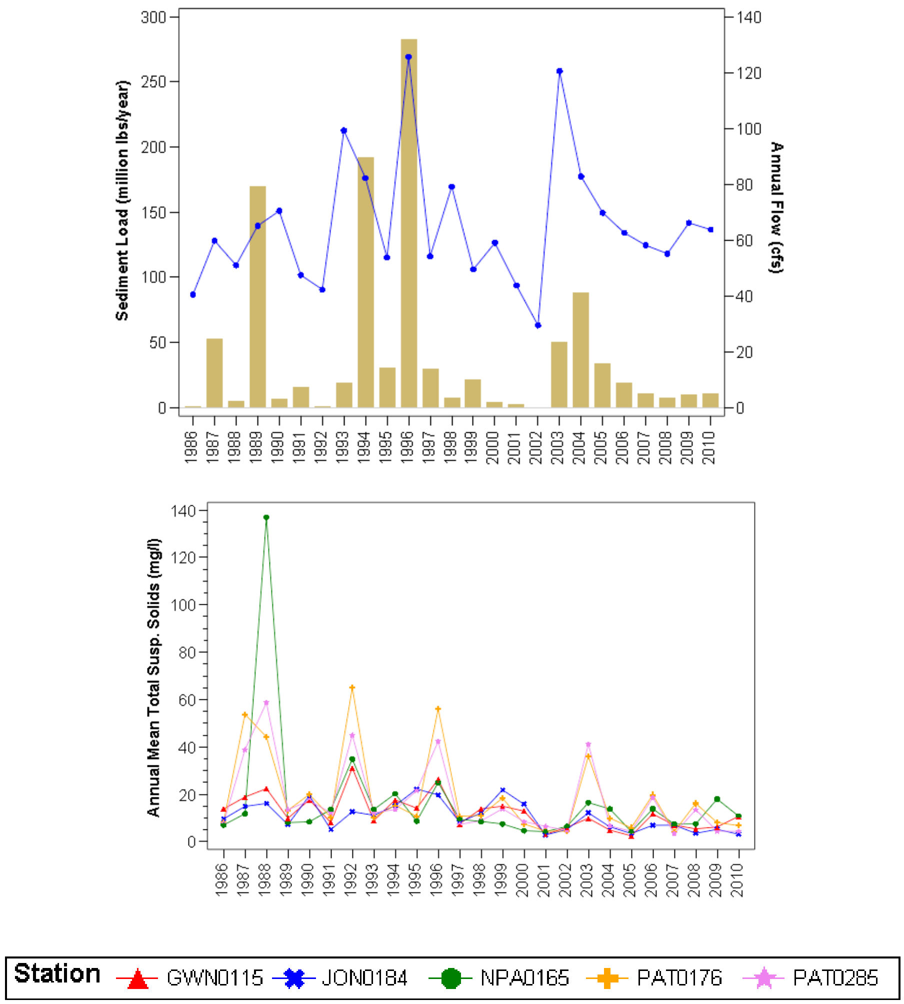

Figure 13. Annual sediment load and concentration for non-tidal stations in the Patapsco River basin.
Top graphs show annual nitrogen and phosphorus (left axis) and flow (right axis) for North Branch Patapsco (station NPA0165). Bottom graphs show annual mean concentrations for total nitrogen and total phosphorus for all of the non-tidal stations. For station NPA0165, 1988 TSS mean is very high due to very high levels on May 18, 1988 (1,502 mg/l). Without this measurement, the 1988 mean TSS level was 12.8 mg/l.

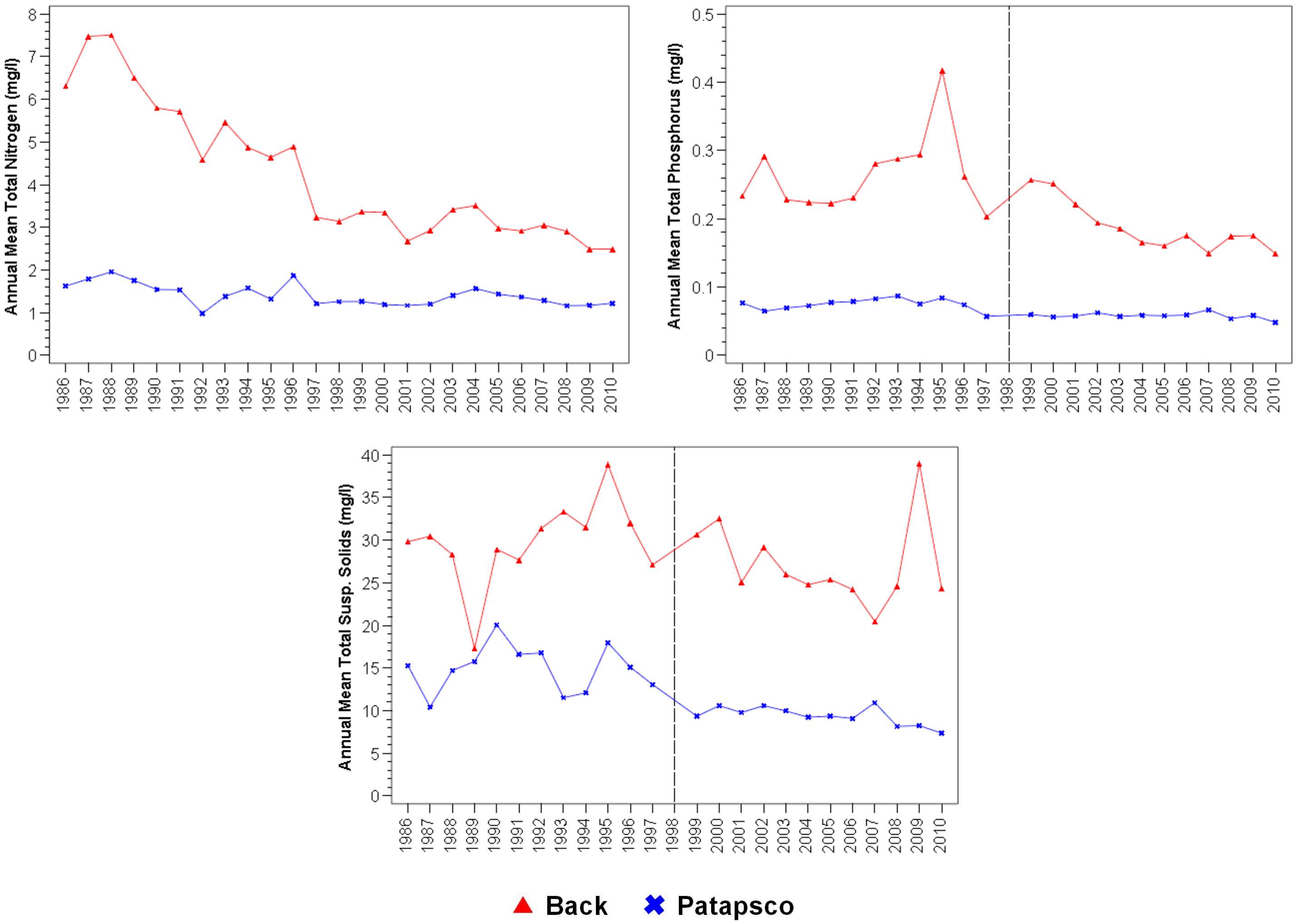

Figure 14. Annual means for total nitrogen, total phosphorus and total suspended solids for the Back and Patapsco rivers.
Dotted line (1998) indicates when the lab change occurred that may have impacted TP and TSS. Caution should be used in making comparisons for TP and TSS from before to after the lab change.

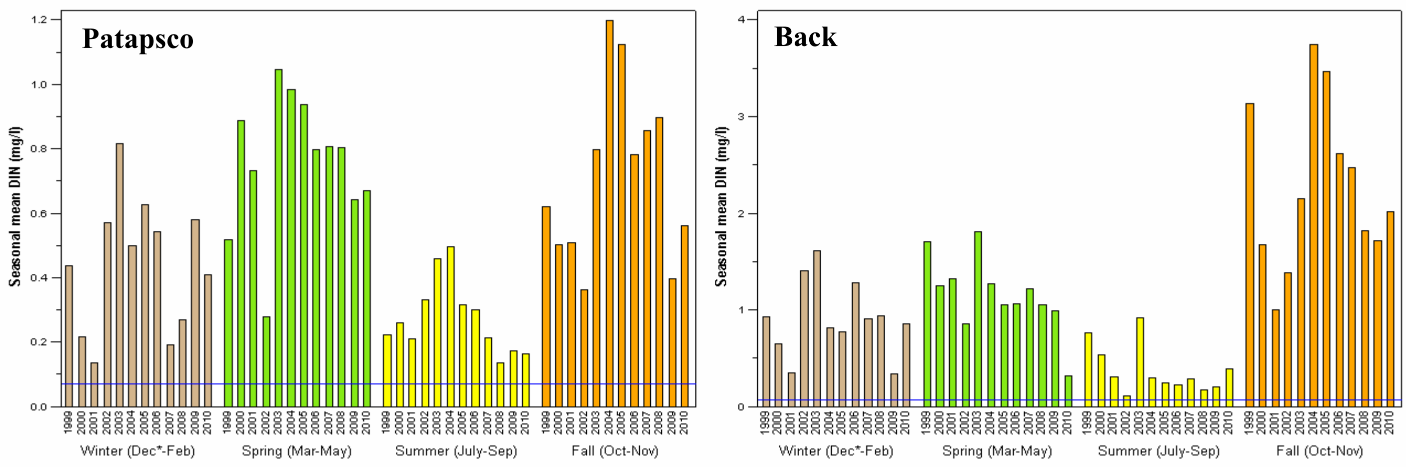

Figure 15. Mean dissolved inorganic nitrogen by season.
The blue line at 0.07 mg/l indicates the DIN level below which nitrogen limitation likely occurs. Winter season includes December (of the previous year), January and February. Spring season includes March-May. Summer season includes July-August (June is a transition month and not included). Fall season includes October and November. Biological nutrient removal of nitrogen at WWTPs is most effective in warmer months, and seasonal changes in phytoplankton populations (blooms in spring and fall) reduce DIN. Note that the y-axis scale differs between graphs.

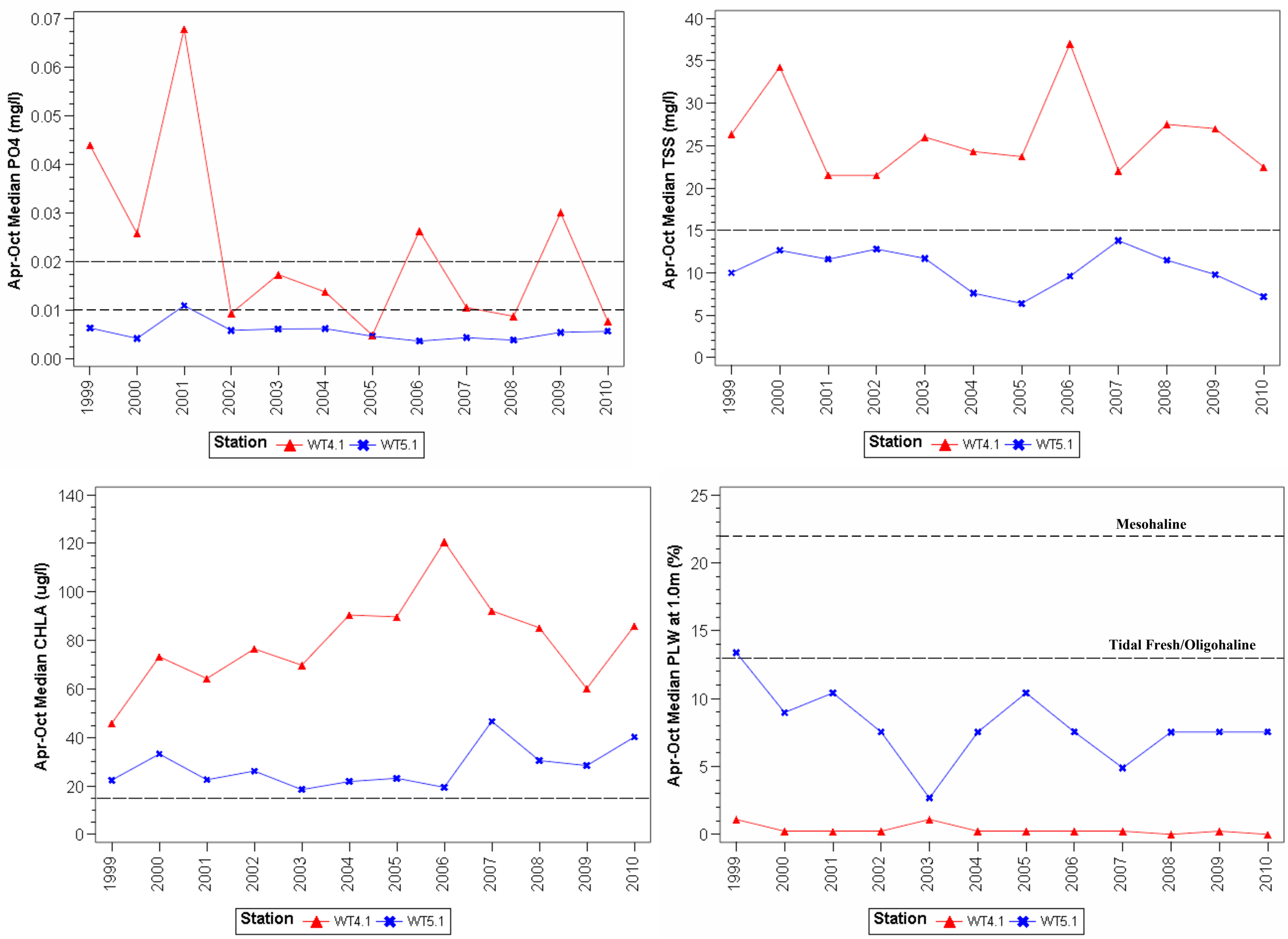

Figure 16. SAV habitat requirement parameters.
SAV growing season (April-October) median values for PO_4, TSS, CHLA, Secchi depth and salinity. Threshold values are shown with dashed lines (Appendix 5). To meet or pass the habitat requirements, levels of PO_4, TSS and CHLA need to be lower than the threshold and Secchi depth needs to be above the threshold. Back River data needs to meet the tidal fresh/oligohaline thresholds. Patapsco River data needs to meet the mesohaline thresholds.

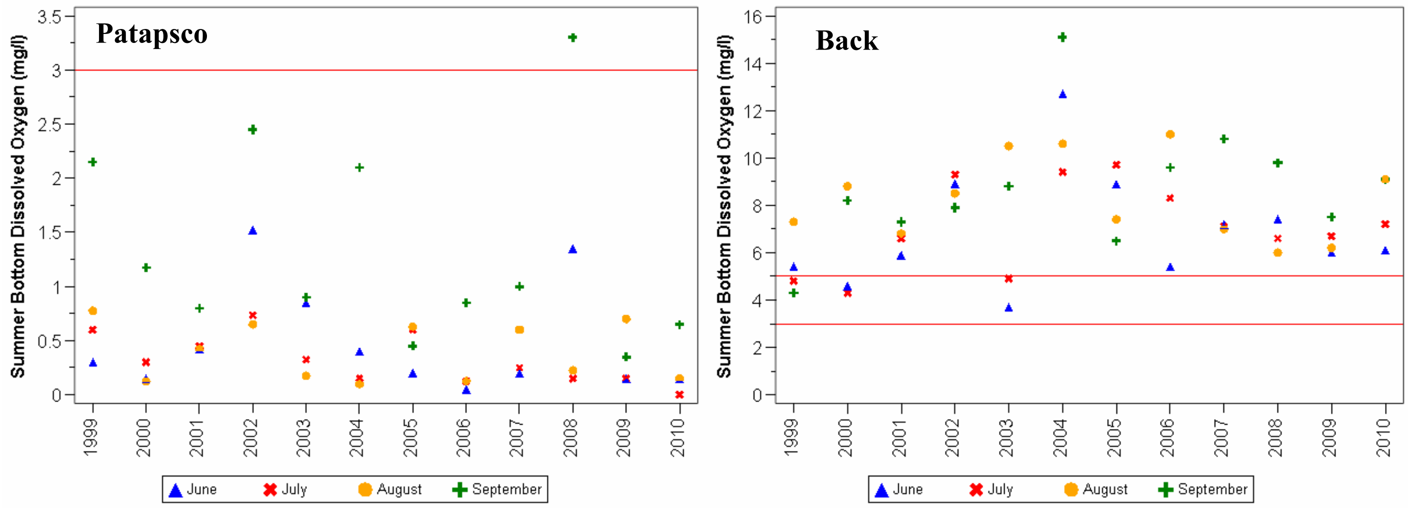

Figure 17. Summer bottom dissolved oxygen levels in Patapsco and Back rivers.
Monthly bottom dissolved oxygen levels with threshold values of 5 mg/l and 3 mg/l shown with red reference lines. Note that the y-axes differ between graphs.

Shallow water

The tidal long-term monitoring program samples at a fixed point that is generally in the center channel and deeper waters of a river. Sampling is usually done once or twice a month. The strength of this type of monitoring is that the repetition of sampling over many years (more than two decades) measures how water quality has changed over time and in response to management actions, land use changes, etc. However, conditions at the long-term monitoring station may not adequately capture water quality conditions in shallow waters, the river as a whole or on short time scales. The shallow water monitoring program is designed to measure conditions in the areas closest to land that are critical habitat areas, especially in the areas with underwater grass beds. Sampling in a river is done for a 3-year period to determine short-term changes in water quality that occur due to weather, such as between a year with very high rainfall and a year with low rainfall. Some shallow water stations have been monitored for longer periods.

The first part of the shallow water monitoring program uses instruments that stay in the water for extended periods (usually April-October) and collect information every 15 minutes; this is called the continuous monitoring program. Instead of the one or two samples a month typical of the long-term monitoring program, the continuous monitoring program can collect more than 2,800 samples a month.[25] This type of monitoring 1) measures water quality changes that occur between night and day, between days and at longer times spans; 2) determines how long water quality problems persist, such as algal blooms or low oxygen water; and 3) measures water quality changes that occur related to weather events such as storms.

[25] Nutrient samples are collected twice a month instead of continuously.

The second part of the monitoring program samples all of the shallow waters of a river (or river segment in larger rivers) once a month from April-October; this is the water quality mapping program. Data is collected nearly constantly as a boat moves along the entire shoreline, so changes in water quality can be measured from one part of the river to another. This data captures water quality in very localized areas and can identify places with better or worse water quality than the river overall. This monitoring is also able to capture changes in water quality related to events that occur in only part of the river such as algal blooms or in response to localized nutrient sources.

A three-year program started in the Patapsco River in 2009 with three continuous monitoring stations in the Patapsco River and two stations at the mouth of the river in the Chesapeake Bay (Figure 18, Appendix 3).[26] Masonville Cove was added (surface monitor) in the summer of 2009 as part of a mitigation agreement for building a dredged material containment facility at the Masonville Marine Terminal. A bottom monitor was added at Masonville Cove in late summer 2010 as part of a research project conducted in conjunction with the Smithsonian Environmental Research Center to quantify the relationship between dissolved oxygen levels and the presence of shellfish. Water quality mapping was also conducted in the Patapsco River during 2009 and 2010.

To date, Back River has not been included as part of the shallow water monitoring program. Continuous monitoring of the Back River is planned to coincide with future upgrades to the Back River wastewater treatment plant. A three-year assessment study of Back River will begin in the year prior to activation of ENR technologies at the plant.

Current Conditions

Results of the 2010 shallow water monitoring program are discussed below. Continuous monitoring results have been grouped based on location (upstream, mid and outer river and the mouth of the river). Water quality mapping results for June through September 2010 are also summarized.

Upper Patapsco

Fort McHenry and Masonville Cove continuous monitoring sites are in the upper reaches of the Patapsco River and closest to Baltimore Harbor. Both Fort McHenry and Masonville Cove showed similar temporal patterns in water quality during 2010, including a large peak in chlorophyll values that occurred in late May (Figures 19-20). Chlorophyll concentrations in excess of 50 µg/l are considered indicative of a significant algal bloom while values above 100 µg/l suggest severe algal bloom conditions. Chlorophyll concentrations close to 500 µg/l at both stations indicated a severe algal bloom. Other measured parameters reflected the bloom as well. For example, both stations showed dissolved oxygen values that peaked at 20 mg/l during the bloom during late May to early June due to photosynthetic activity of the algae. The bloom also marked the onset of dissolved oxygen values that frequently dropped below 5 mg/l, creating conditions that can be detrimental to the survival of living resources. Turbidity at Fort McHenry spiked to near 400 NTU during May, and pH at both stations rose to above 9. At Masonville

[26]Continuous monitoring began in the Patapsco River at Fort McHenry in the Baltimore Harbor in September 2000. An interactive map of all continuous monitoring stations and complete archived data are available at http://mddnr.chesapeakebay.net/newmontech/contmon/archived_results.cfm.

Cove, a slightly smaller, but still severe, bloom occurred during April with a peak chlorophyll value above 350 µg/l. Generally, the bottom waters had higher turbidity and lower dissolved oxygen values than the surface waters at Masonville Cove (Figure 21).

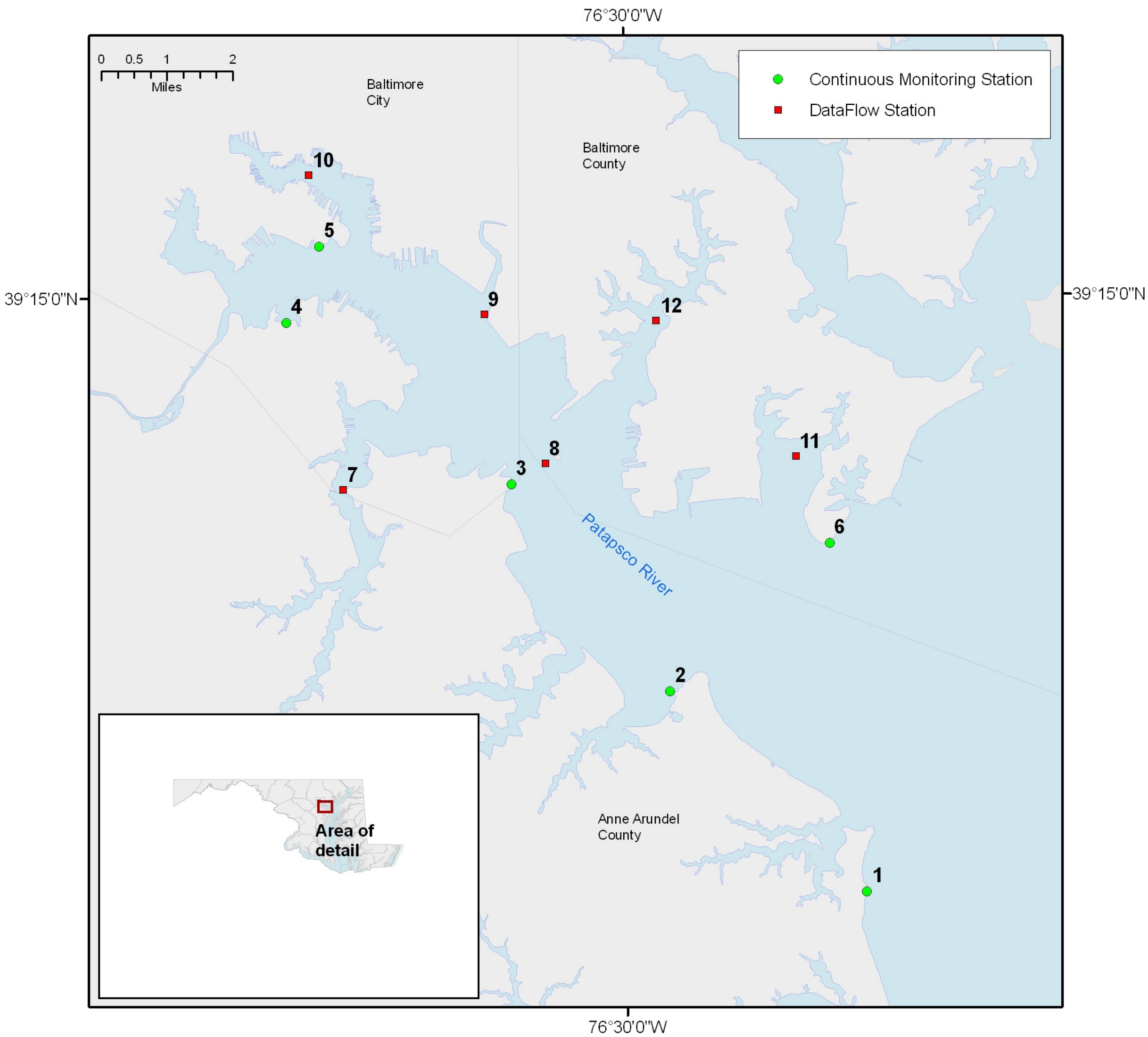

Figure 18. Shallow water calibration stations in the Patapsco River Basin. Green circles show the continuous monitoring locations: Patapsco River- 2. XHF9808 Ft. Smallwood, 3. XIE2581 Fort Armistead, 4. XIE4741 Masonville Cove, 5. XIE5748 Fort McHenry. Chesapeake Bay- 1. XHF6841 Down's Park, 6. XIF1735 Fort Howard. Red squares show water quality mapping calibration stations: Upper Patapsco - 7. CUR0007, 9. XIE4876, 10. XIE6747. Lower Patapsco - 8. WT5.1 (also long-term monitoring station), 11.XIF2929, 12. XIF4705.

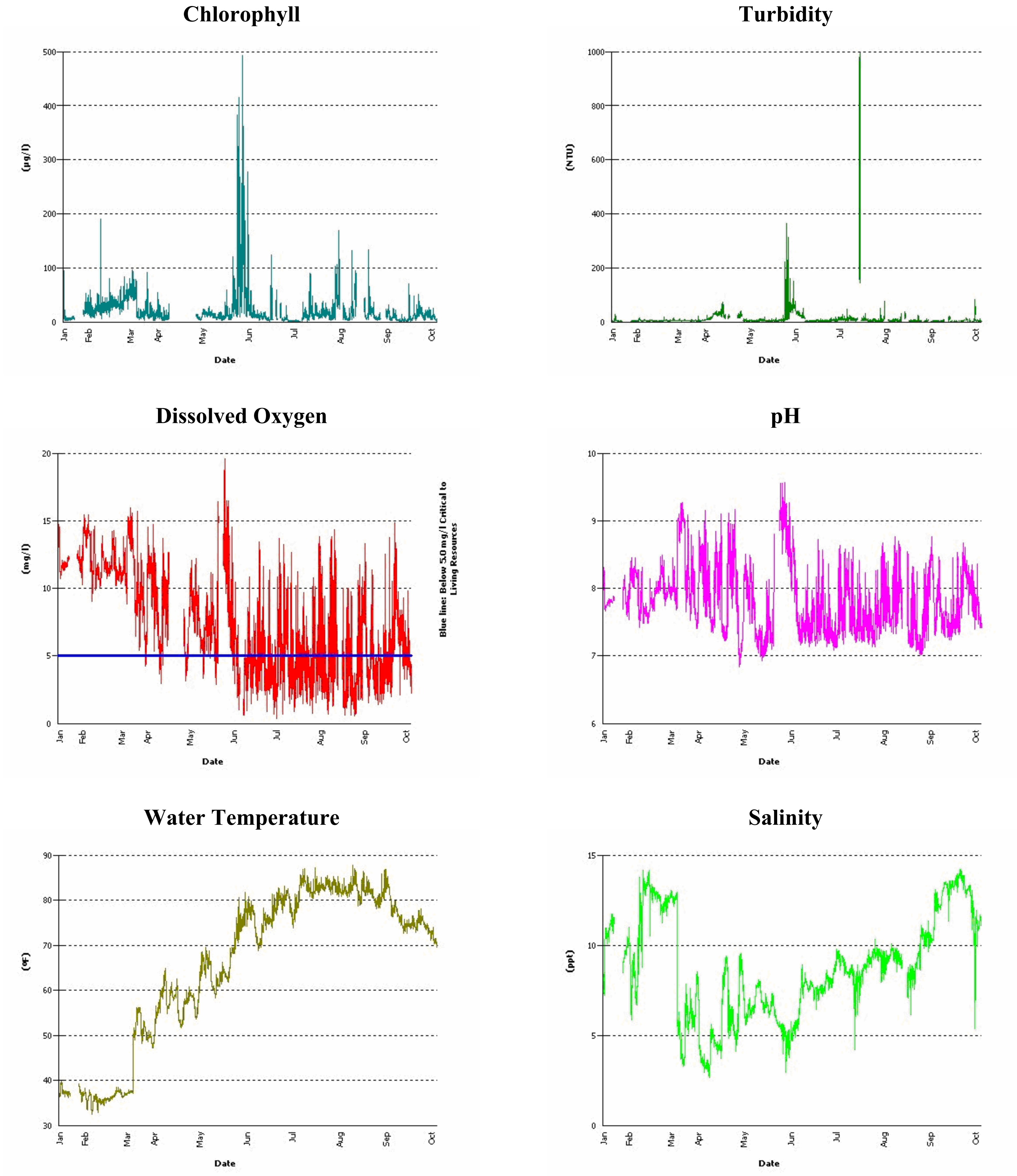

Figure 19. Continuous monitoring results at Baltimore Harbor (Fort McHenry) in 2010.

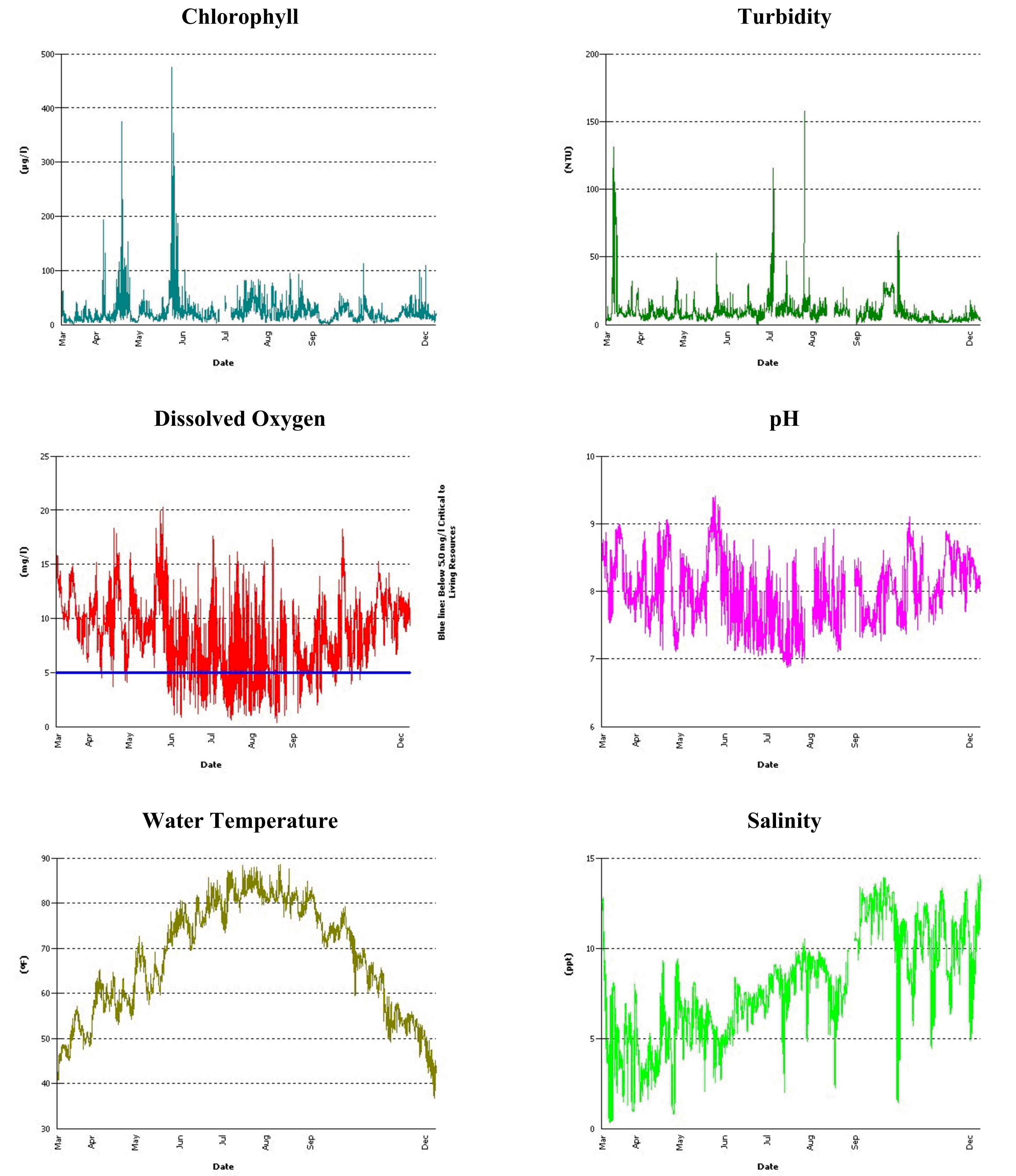

Figure 20. Continuous monitoring results at Masonville Cove (surface) in 2010.

Rainfall and runoff events had a noticeable effect on water quality at Fort McHenry and Masonville Cove in 2010. The Chesapeake Bay region experienced higher than average snowfall in February 2010 with greater than 50 inches of snowfall recorded at BWI airport. Spring runoff was especially large due to the added snowmelt and resulted in lower salinities at both stations. Spring runoff also contributed to turbidity values greater than 100 NTU at Masonville Cove during March. On September 30, 2010 Tropical Storm Nicole passed over the Chesapeake Bay region bringing more than 6 inches of rain to the area. The salinity values for both stations dropped significantly in late September as a result of the storm. Other salinity drops were evident due to storms on May 27 (1.2 inches of rainfall), July 12-14 (2.4 inches of rainfall), and August 12 (2.4 inches of rainfall).[27]

Continuous monitoring chlorophyll data are calculated from measured fluorescence values.[28] Blue-green algal species fluoresce outside of the range of the standard chlorophyll probe deployed with the monitoring instrument. Therefore, this method does not adequately describe the abundance of blue-green algae in the water column. In order to more accurately record the presence of these types of algae, a phycoerythrin probe was installed on the continuous monitoring sonde at Fort McHenry in the Baltimore Harbor during 2010.[29] Phycoerythrin-containing algae are of interest because of their potential toxicity and potential association with other toxic phytoplankton. The data suggest the presence of phycoerythrin-containing algae at Fort McHenry. Peaks of around 20 raw fluorescence units (RFU) occurred occasionally throughout 2010 (Figure 22). Also, a brief spike of approximately 40 RFU was evident in August, and a spike greater than 140 RFU occurred in early June.

Mid and outer Patapsco

Fort Armistead and Fort Smallwood continuous monitoring locations are farther downstream, in the middle and outer Patapsco River. The high chlorophyll concentrations seen upstream at Fort McHenry and Masonville Cove in late May were also evident at the downstream stations. Fort Armistead had a peak in chlorophyll values close to 500 µg/l in late May (Figure 23). Chlorophyll values at Fort Smallwood also peaked in late May, but were lower (approximately 150 µg/l, Figure 24). Although generally below 50 µg/l, chlorophyll values at both stations spiked briefly to greater than 100 µg/l several times during 2010. Dissolved oxygen occasionally dropped below 5 mg/l during the months of June through September, but generally ranged between 5-10 mg/l during the summer months at both stations. Salinity values rose through the summer, and then dropped dramatically in late September due to the influx of fresh water associated with Tropical Storm Nicole.

[27] All rainfall amounts were recorded at BWI by the National Weather Service.

[28] Blue-green algal species fluoresce outside of the range of the standard chlorophyll probe deployed with the monitoring instrument.

[29] Phycoerythrin is a pigment contained in some types of phytoplankton, including cyanobacteria and cryptophytes.

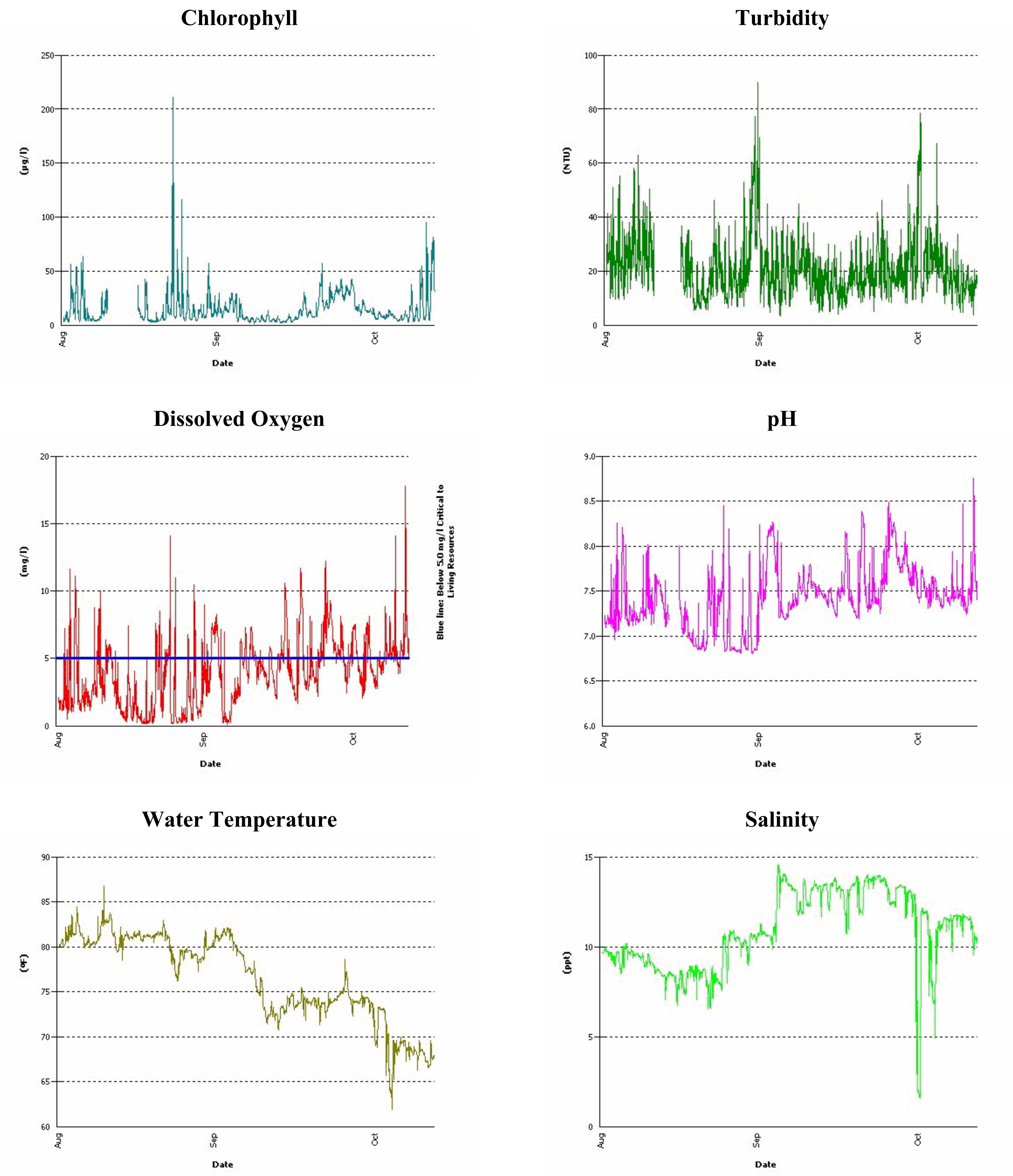

Figure 21. Continuous monitoring results at Masonville Cove (bottom) in 2010.

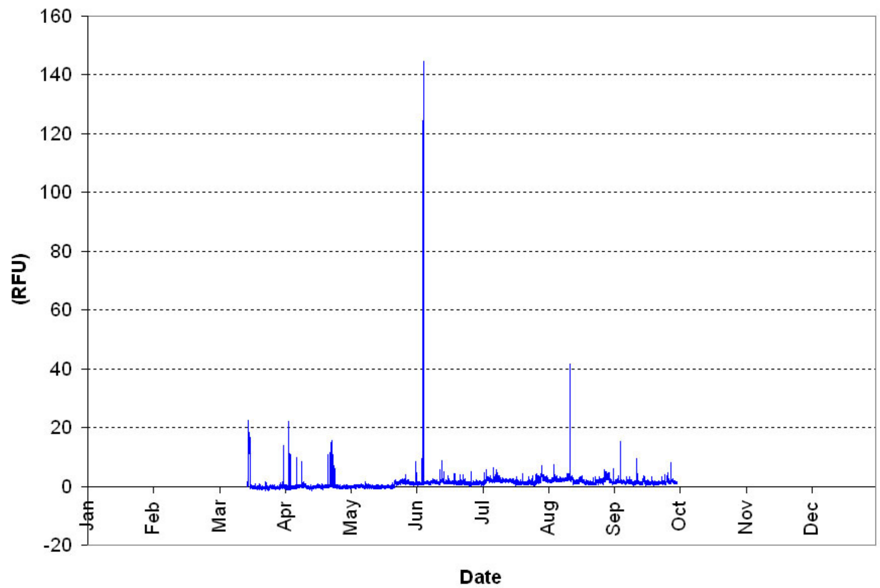

Figure 22. Phycoerythrin levels at Fort McHenry (XIE5748) in the Baltimore Harbor in 2010. (Results are preliminary and have not undergone full QA/QC procedures.)

Mouth of the Patapsco

Fort Howard and Downs Park continuous monitoring sites are located at the mouth of the Patapsco River in Chesapeake Bay Segment 3. Like the stations discussed previously, Downs Park showed elevated chlorophyll concentrations in late May due to a large algal bloom in the river (Figure 25). However, the May bloom did not result in the highest chlorophyll levels observed at Downs Park in 2010. A severe bloom occurred at these stations in March, with peak chlorophyll values over 200 µg/l at Fort Howard (Figure 26) and 150 µg/l at Downs Park. Chlorophyll values above 150 µg/l also occurred in late July and in mid-October at Downs Park.

Turbidity at Downs Park spiked to approximately 350 NTU during early October due to Tropical Storm Nicole, but was otherwise below 100 NTU for most of the year. Turbidity at Fort Howard was generally below 50 NTU with occasional values in the 50-100 NTU range. Both stations showed some values of dissolved oxygen below 5 mg/l throughout the months of June through September, and both stations experienced a drop in salinity in October due to Tropical Storm Nicole.

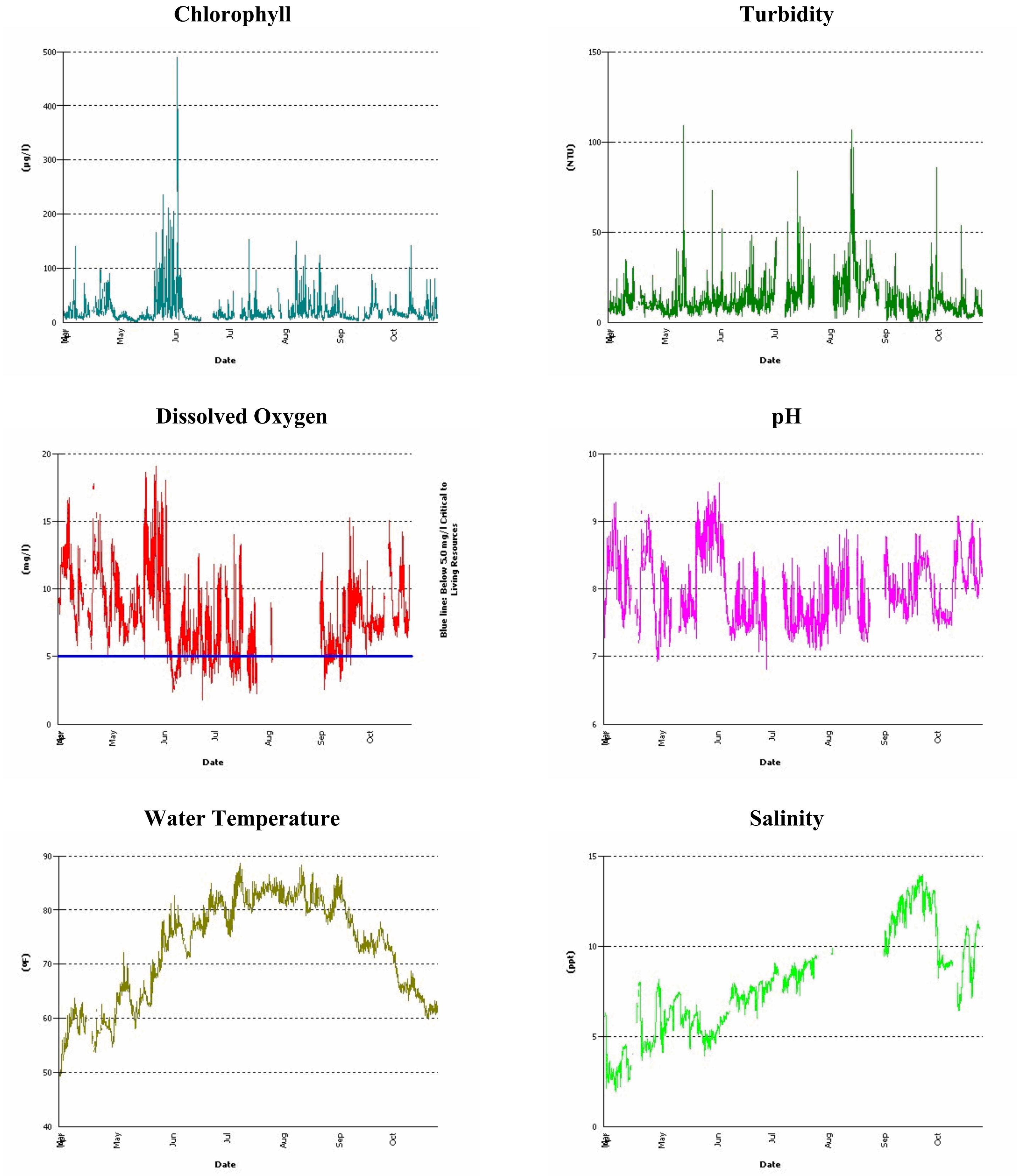

Figure 23. Continuous monitoring results at Fort Armistead in 2010.

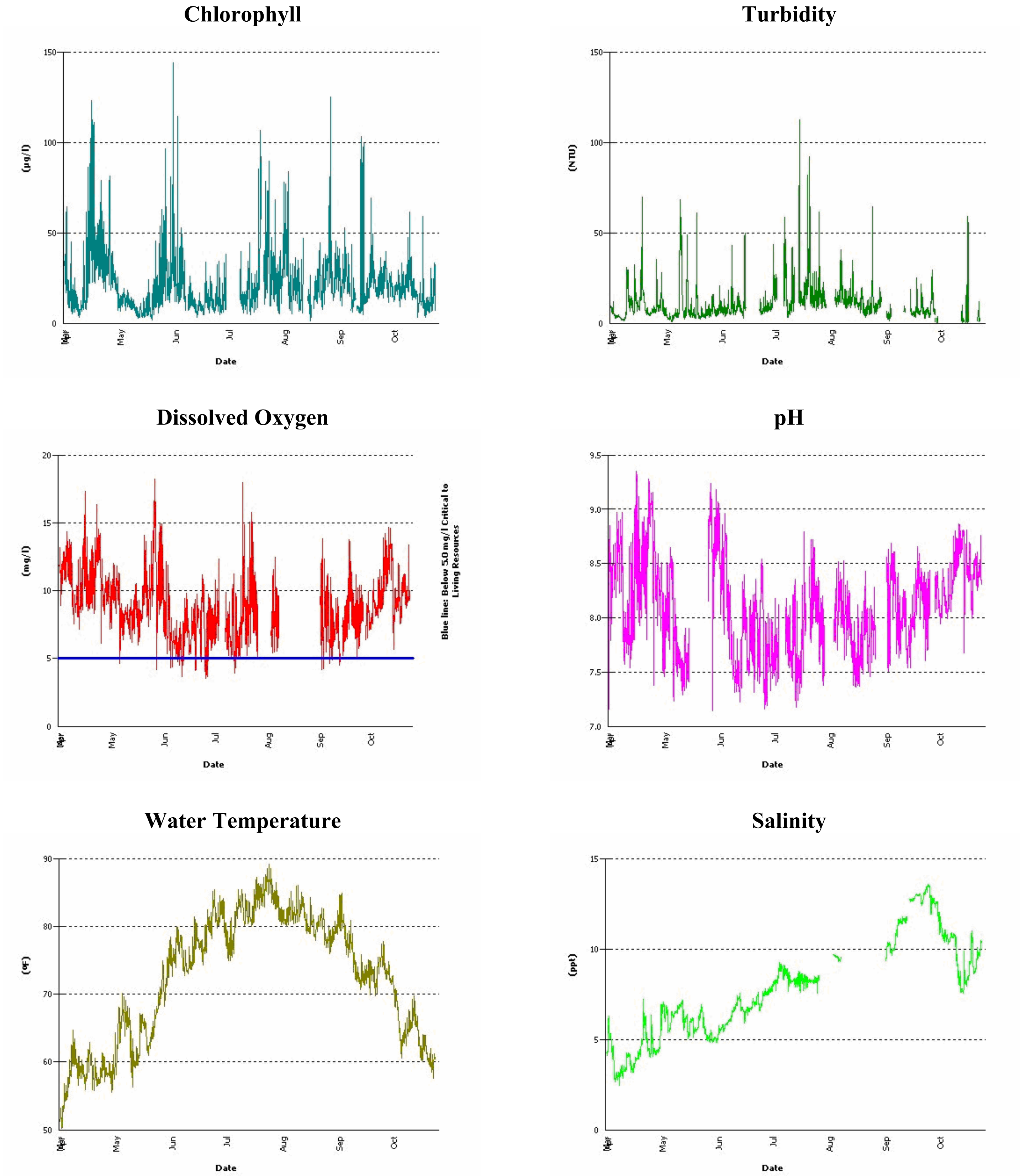

Figure 24. Continuous monitoring results at Fort Smallwood in 2010.

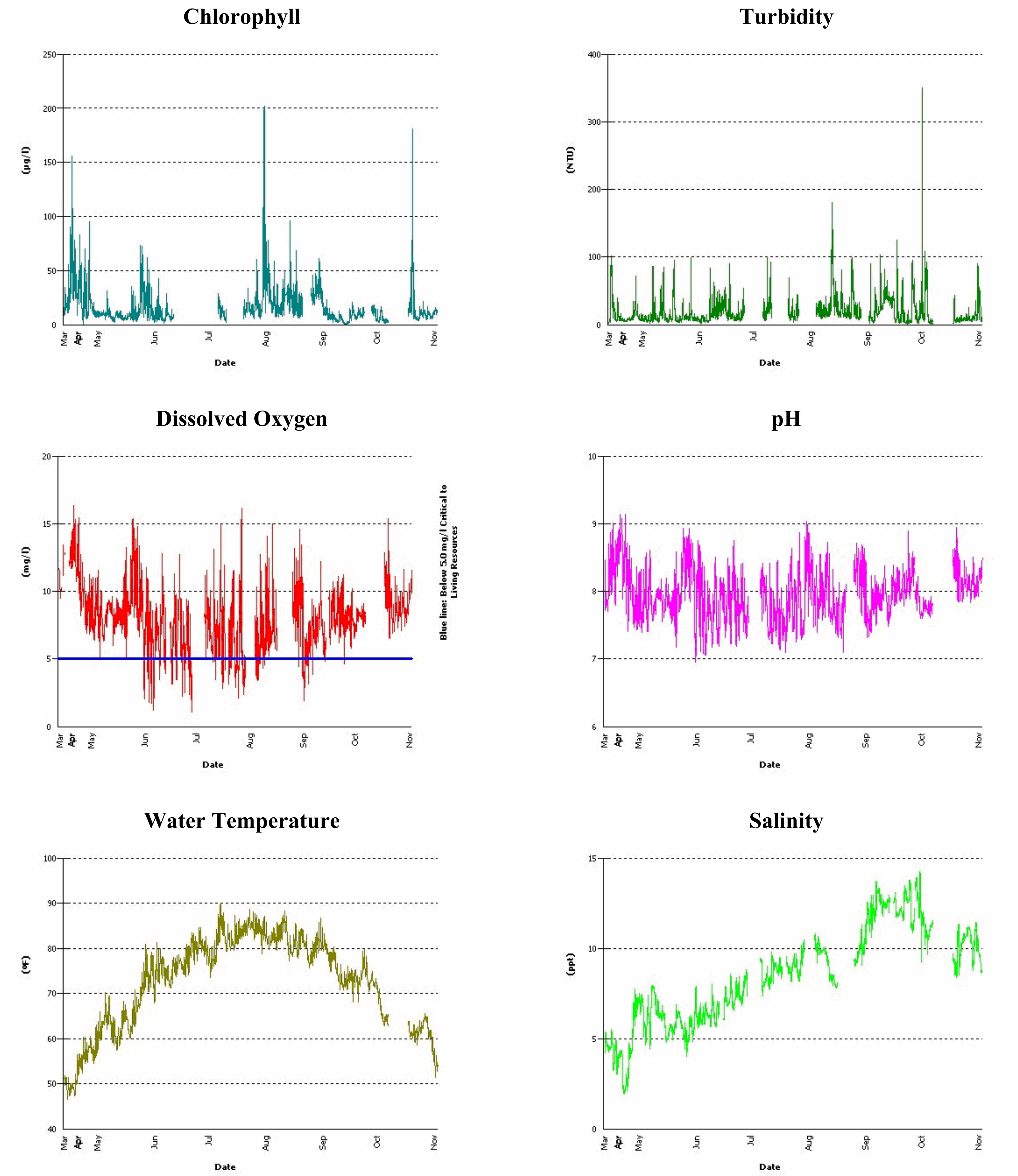

Figure 25. Continuous monitoring results at Downs Park in 2010.

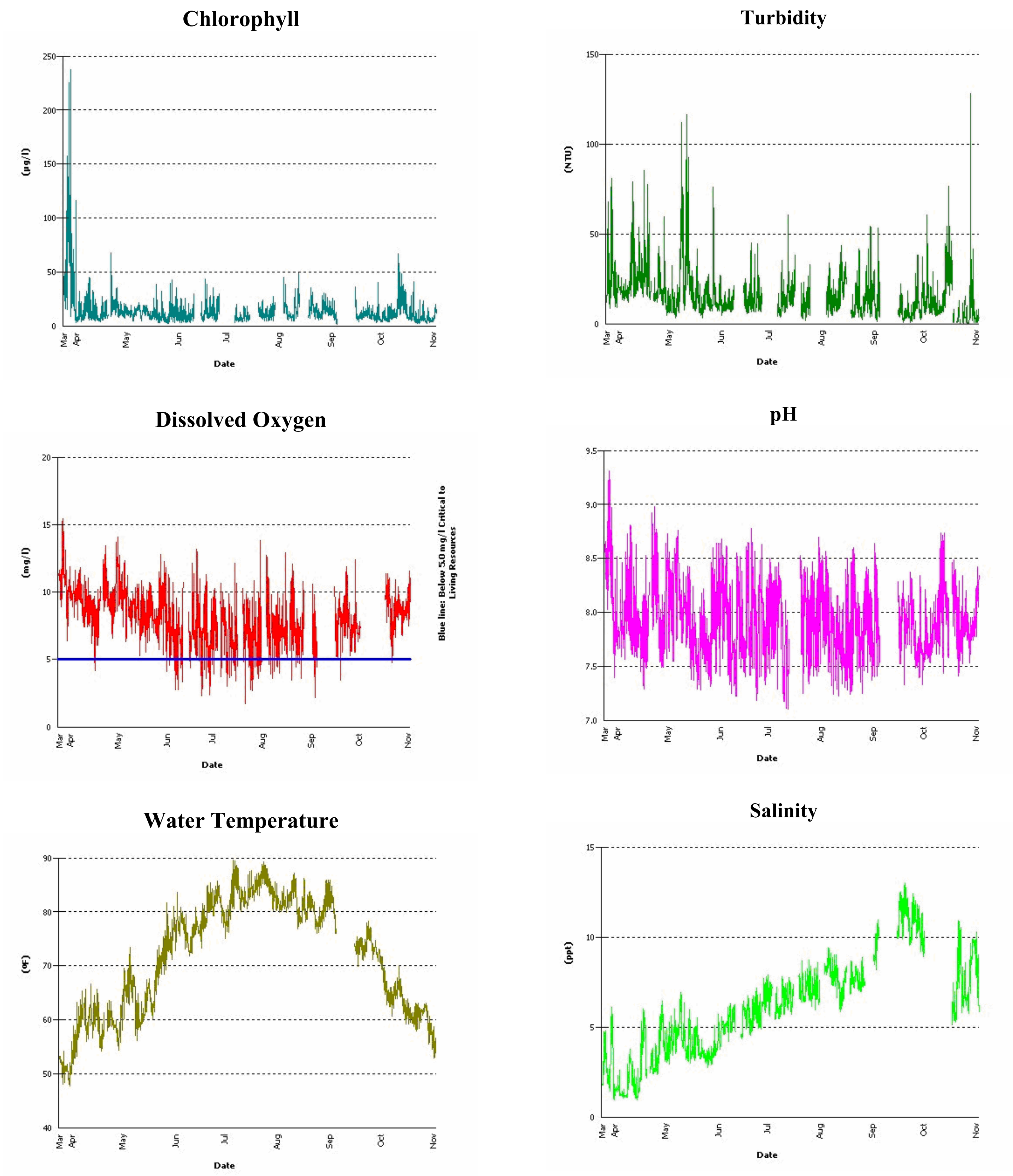

Figure 26. Continuous monitoring results at Fort Howard in 2010.

Overall Patapsco River

The 2010 water quality mapping results for June through September in the Patapsco River are shown in Figures 27-30.[30] These four months show the progression of water quality conditions through the summer. The 2010 continuous monitoring data presented earlier showed high chlorophyll concentrations at several Patapsco River stations in late May and early June due to severe algal blooms. The June water quality mapping results (Figure 27) agree with the continuous monitoring data, with high chlorophyll concentrations evident in the upper reaches of the tidal Patapsco River near Baltimore's Inner Harbor. The bloom persisted into July (Figure 28), with slightly lower chlorophyll concentrations. During August (Figure 29), areas of high chlorophyll concentrations were more dispersed throughout the map area; and in September (Figure 30), much lower chlorophyll concentrations were measured as the bloom conditions subsided. It is also interesting to note the salinity map for September 2010. Typically, salinity levels increase toward the mouth of the river due to mixing with the more saline waters of the Chesapeake Bay. However, in September 2010 higher salinity waters were located in the upstream reaches of the Patapsco River. This may have been the result of increased freshwater discharge from the Susquehanna River diluting Bay waters during Tropical Storm Nicole.

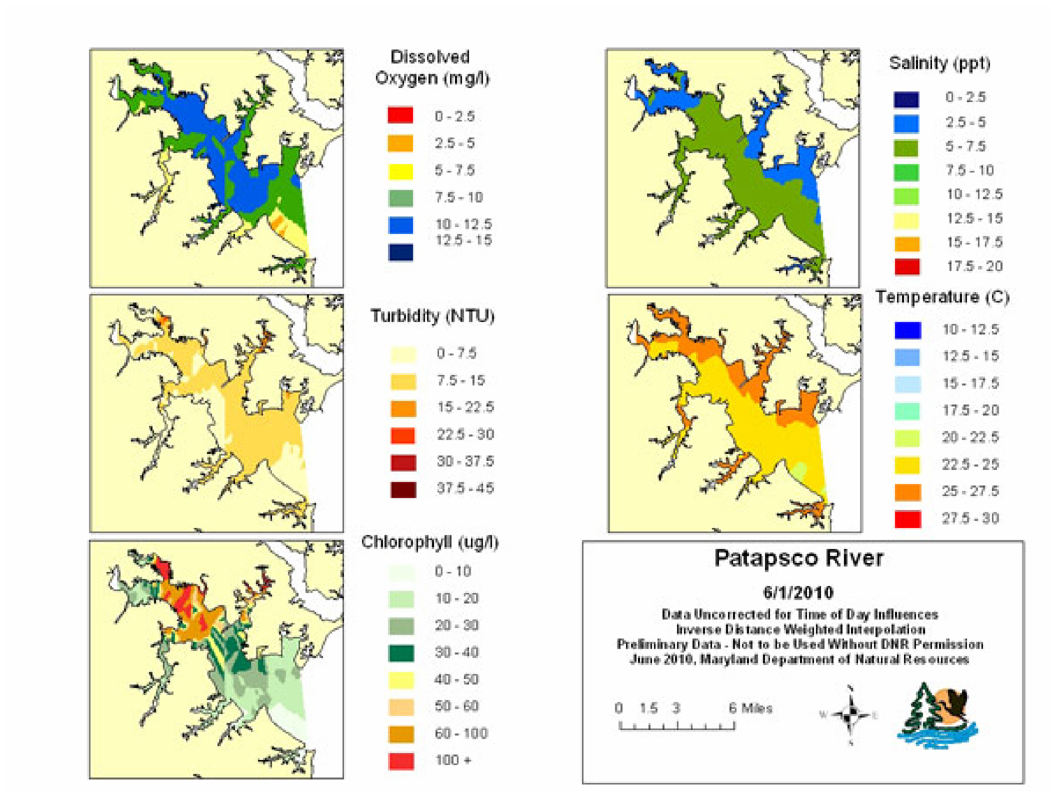

Figure 27. Water quality mapping survey results for the Patapsco River, June 2010.

[30] Interpolated maps for all cruises are available on the Maryland Department of Natural Resources "Eyes on the Bay" website http://mddnr.chesapeakebay.net/sim/dataflow_data.cfm

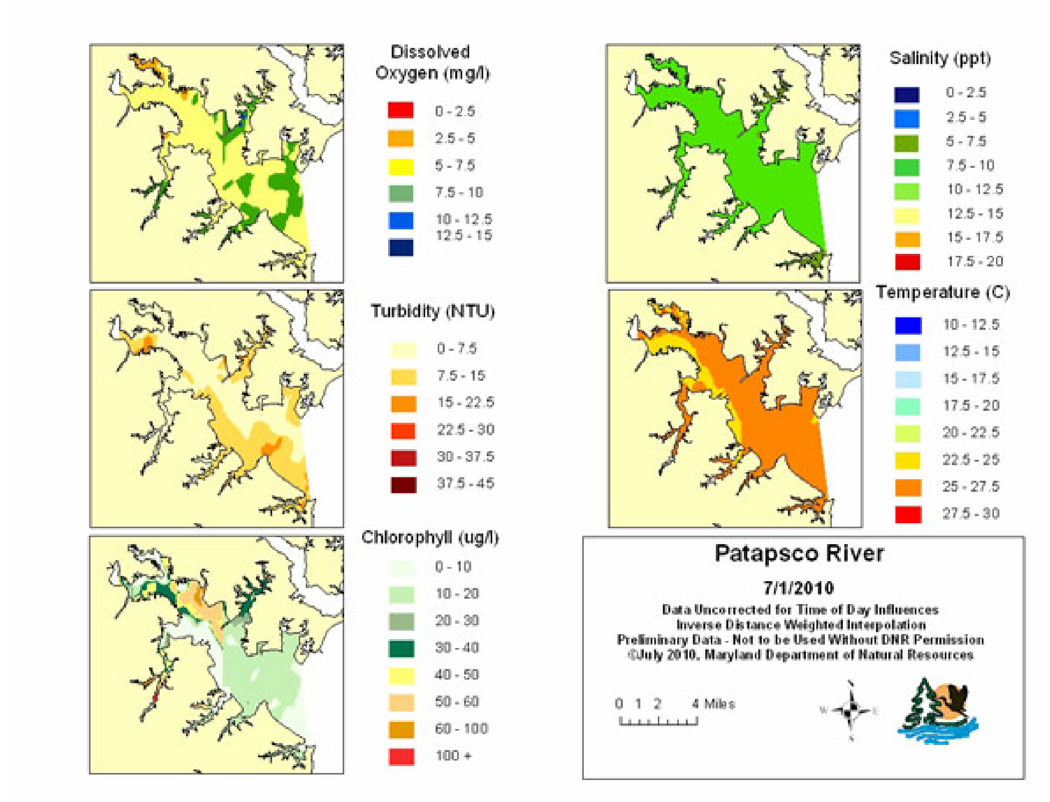

Figure 28. Water quality mapping survey results for the Patapsco River, July 2010.

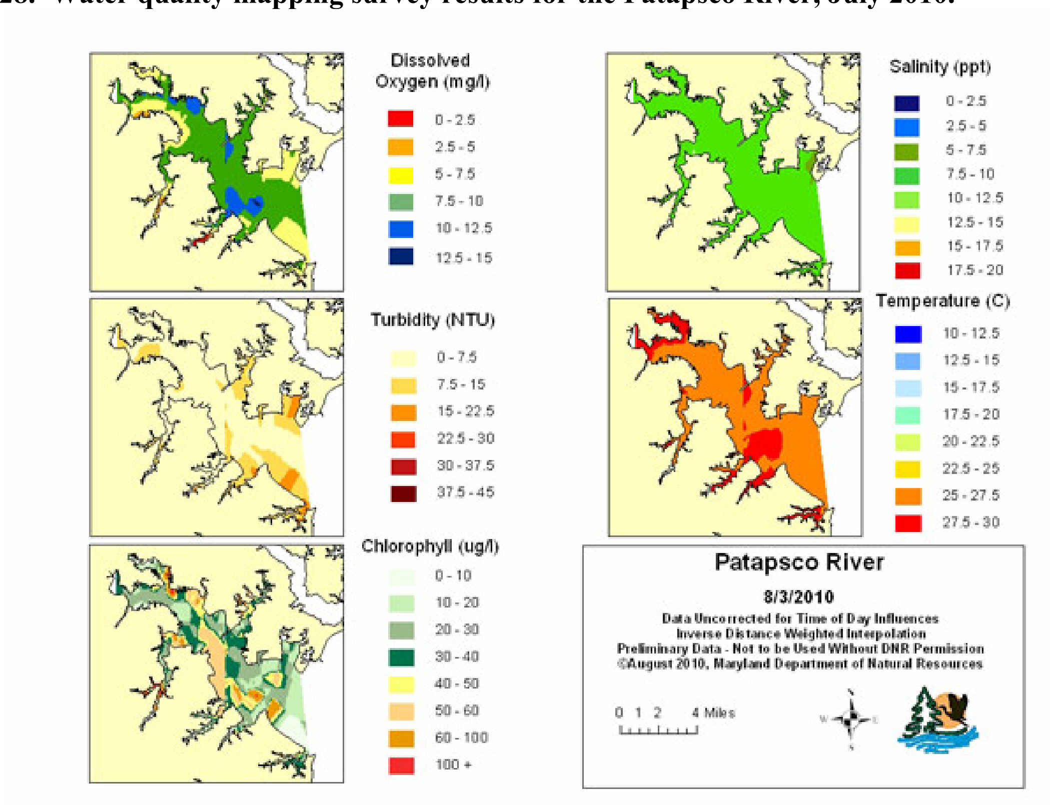

Figure 29. Water quality mapping survey results for the Patapsco River, August 2010.

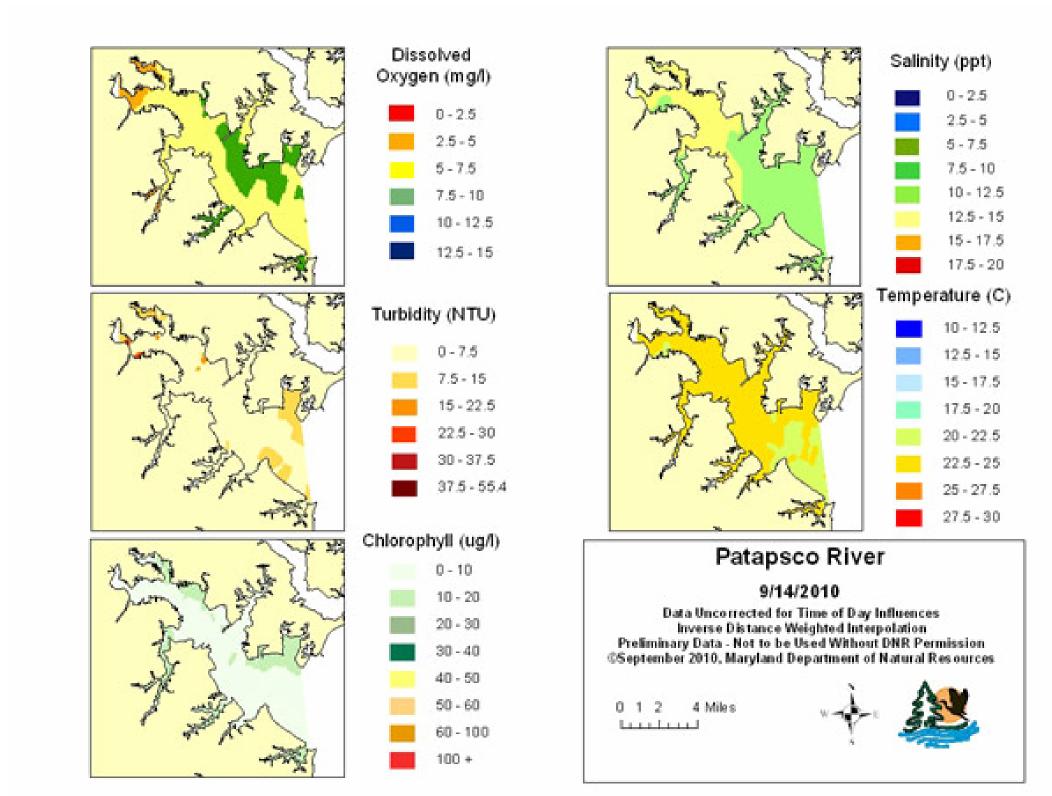

Figure 30. Water quality mapping survey results for the Patapsco River, September 2010.

Temporal and Spatial conditions

Water and habitat quality in the shallow water was evaluated in two ways. The first was a temporal assessment. High temporal frequency data from the continuous monitoring program were used to determine how often water quality met conditions needed for healthy habitats. Percent failures are defined as the percent of values in each year that did not meet the water quality thresholds (see Appendix 4 for methods). Data for the years 2000-2010 were used. Chlorophyll and turbidity measurements collected during the SAV growing season (April through October) and summer dissolved oxygen values (June through September) were included in the analysis. The percent failures for all stations are shown in Appendix 9.

The second method was a spatial assessment. The nutrient data collected at continuous monitoring and water quality mapping calibration stations for April-October were compared to the SAV habitat requirements (Appendix 9). Water quality and habitat conditions were also compared between the shallow water stations and the long-term station.

Turbidity thresholds were frequently exceeded at Fort Armistead, Fort Howard, Downs Park, and in the bottom waters of Masonville Cove. All of these stations had greater than 70% failure of the 7 NTU turbidity threshold. Fort Smallwood and Masonville Cove (surface) generally had a 50-70% failure rate for turbidity. During the years 2001-2003 at Fort McHenry, turbidity failures were between 55% and 65%. However, during the years 2004-2010, percent failures of the 7 NTU turbidity threshold were just 10-35% at Fort McHenry. Throughout the Patapsco River, between 24% and 63% of chlorophyll records exceeded the 15 µg/l chlorophyll threshold.

Among Patapsco River Basin stations, Fort McHenry exceeded the dissolved oxygen criteria most often. Most years at Fort McHenry failed the 3.2 mg/l dissolved oxygen threshold 20-30% of the time. The years 2004-2006 were slightly better, with approximately 10% failure of the 3.2 mg/l threshold. Fort Armistead and Masonville Cove (surface) had similar percent failures of the dissolved oxygen threshold. Both stations failed the 3.2 mg/l threshold less than 17% of the time. Fort Smallwood in the Patapsco River, and Fort Howard and Downs Park at the mouth had comparatively few failures of the dissolved oxygen thresholds. Generally, less than 4% of the dissolved oxygen values at these stations dropped below 3.2 mg/l.

The percent failure analysis determines how often dissolved oxygen levels were below healthy levels, but not how long at any one time dissolved oxygen levels are dangerously low. This is important because most benthic animals and fish can survive in low dissolved oxygen for short periods but not extended periods. A special study of the continuous monitoring data from Maryland rivers, including the Fort McHenry data for 2004-2008, found that periods of dissolved oxygen levels below 3.2 mg/l at different locations lasted from as little as 15 minutes to as long as 2.5 days.[31] The longest continuous period of extremely low dissolved oxygen at Fort McHenry was 52 hours (in 2007), or just over 2 days, the second worst site among the 21 river locations analyzed. Also, the total amount of time in a sample year with extremely low dissolved oxygen levels ranged from 184 hours (in 2005) to 986 hours (in 2008).

Shallow waters in the Patapsco generally failed to meet the habitat requirement for CHLA (the exceptions were borderline, Table 3) and DIN levels and Secchi depths failed in the entire river. TSS and PO_4 levels generally met the requirements (again, the exceptions were borderline).

Secchi depths were similar throughout the river. CHLA levels were significantly lower at the mouth of the river (Fort Howard) than levels in the middle river (long-term station and Fort Armistead), upper Bear Creek (XIF4705) and the outer portion of Baltimore Harbor (XIE6747). TSS levels at Fort Armistead were significantly higher than at the long-term station even though these stations were very close to each other. TSS levels at Fort Armistead were also significantly higher that at Fort McHenry. In 2009, PO_4 levels at Fort Smallwood were significantly lower than in the outer Baltimore Harbor, but DIN levels were similar throughout the river.

[31] Boynton et al (2011) available online at http://www.gonzo.cbl.umces.edu/documents/water_quality/Level1Report28.pdf

Table 3. Shallow water monitoring data compared to SAV habitat requirements. All calibration data for a station (water quality mapping and continuous monitoring) were used to calculate a monthly median. Monthly medians for April-October were used to calculate the SAV growing season median, which was compared to habitat requirements (Appendix 5). The long-term station (WT5.1) includes data from long-term and water quality mapping sampling. DIN and PO_4 were only measured at Masonville Cove and the long-term station in 2010. Station names in **bold** are continuous monitoring stations. Stations in regular font are water quality mapping calibration stations. The long-term station is in *italics*.

Station			map #	year	Chla mg/l		TSS mg/l		DIN mg/l		PO4 mg/l		Secchi Depth	
Upper	XIE6747	Outer Baltimore Harbor	10	2009	30.7	FAIL	10.0	MEET	0.291	FAIL	0.0137	FAIL	0.60	FAIL
				2010	15.0	MEET	4.6	MEET					0.80	FAIL
	XIE5748	**Fort McHenry**	5	2009	17.4	FAIL	11.3	MEET	0.454	FAIL	0.0088	MEET	0.70	FAIL
				2010	23.1	FAIL	6.6	MEET					0.60	FAIL
	XIE4741	**Masonville Cove**	4	2009	19.6	FAIL	10.5	MEET	0.412	FAIL	0.0045	MEET	0.50	FAIL
				2010	20.8	FAIL	10.7	MEET	0.857	FAIL	0.0036	MEET	0.70	FAIL
Middle	XIE4876		9	2009	26.9	FAIL	7.3	MEET	0.171	FAIL	0.0055	MEET	0.60	FAIL
				2010	29.7	FAIL	8.8	MEET					0.80	FAIL
	CUR0007	Curtis Creek	7	2009	26.4	FAIL	6.0	MEET	0.329	FAIL	0.0067	MEET	0.70	FAIL
				2010	25.6	FAIL	5.7	MEET					0.70	FAIL
	XIE2581	**Fort Armistead**	3	2009	24.6	FAIL	16.4	FAIL	0.324	FAIL	0.0042	MEET	0.55	FAIL
				2010	20.3	FAIL	10.3	MEET					0.55	FAIL
	WT5.1	***Long-term***	8	2009	32.9	FAIL	9.8	MEET	0.162	FAIL	0.0048	MEET	0.60	FAIL
				2010	30.5	FAIL	7.2	MEET	0.351	FAIL	0.0057	MEET	0.70	FAIL
	XIF4705	Bear Creek	12	2009	41.9	FAIL	14.7	MEET	0.117	FAIL	0.0043	MEET	0.50	FAIL
				2010	29.9	FAIL	5.2	MEET					0.80	FAIL
Outer	**XHF9808**	**Fort Smallwood**	2	2009	29.0	FAIL	14.6	MEET	0.162	FAIL	0.0034	MEET	0.50	FAIL
				2010	22.5	FAIL	11.4	MEET					0.60	FAIL
	XIF2929	Old Round Bay	11	2009	19.5	FAIL	14.0	MEET	0.133	FAIL	0.0038	MEET	0.50	FAIL
				2010	32.3	FAIL	13.3	MEET					0.40	FAIL
Mouth	**XIF1735**	**Fort Howard**	6	2009	15.2	FAIL	14.7	MEET	0.260	FAIL	0.0047	MEET	0.5	FAIL
				2010	14.0	MEET	13.3	MEET					0.6	FAIL
	XHF6841	**Down's Park**	1	2009	24.9	FAIL	15.9	FAIL	0.171	FAIL	0.0046	MEET	0.6	FAIL
				2010	14.2	MEET	13.6	MEET					0.7	FAIL

Health of Key Plants and Animals

Phytoplankton

Phytoplankton (generally algae) are the primary producers in the Chesapeake Bay and rivers and the base of the food chain. Routine samples collected in the long-term tidal and shallow water monitoring programs estimate the abundance of algae but can not determine the health of the population overall. As part of a supplemental program, since 1985 the overall phytoplankton community was sampled at the long-term tidal water quality station in the Patapsco River in spring and summer. The phytoplankton index of biotic integrity (PIBI) assesses the health of the community.[32] A PIBI score of ≥ 3 is considered meeting the goal for phytoplankton community health. PIBI scores in the Patapsco were generally higher in the spring than in the summer, but failed to meet goals in both seasons (Figure 32).[33] Spring PIBI scores degraded from 1985-2010, but may be improving from 1999-2010.

[32] Methods for calculation of the PIBI are available at www.chesapeakebay.net/.../indicator_survey_phyto_ibi_2011_final.docx

[33] P-IBI scores calculated by J. Johnson, Interstate Commission on the Potomac River Basin/Chesapeake Bay Program.

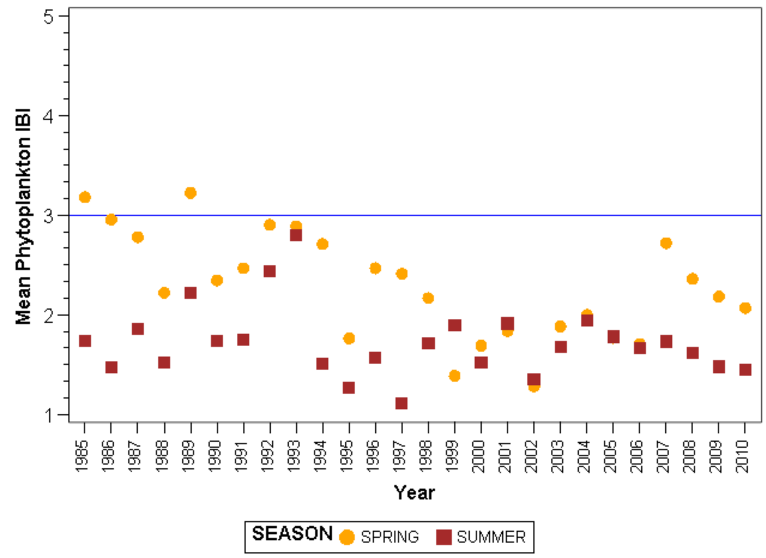

Figure 31. Spring and summer Phytoplankton Index of Biotic Integrity (PIBI) scores 1985-2010.

Harmful Algal Blooms (HABs)

High algal density (algal blooms) can degrade habitat quality. Blooms of certain species of phytoplankton (harmful algae) can also degrade habitat quality. Routine samples collected in the long-term tidal and shallow water monitoring programs can not distinguish between good and harmful algae. Additional samples are taken at some locations to determine what algal species are present and in what densities. When a bloom occurs, samples are taken to test for the presence and levels of toxins, which can be released by some types of harmful algae. Fortunately, of the more than 700 species of algae in Chesapeake Bay, less than 2% of them are believed to have the ability to produce toxic substances.[34]

Blue-green algae are generally smaller cells and not as nutritious and edible to small animals (zooplankton). Blooms of blue-green algae look like blue-green paint floating at or near the water surface (Figure 32). Blue-green algae can only live in low salinity waters. Some species of blue-green algae (*Microcystis* and *Anabaena*) can produce a toxin that is released into the water. Contact with or ingestion of water containing high toxin levels can cause human health impacts (skin irritation, gastrointestinal discomfort), and can be harmful or even fatal to livestock and pets.

Blooms of some species of dinoflagellates are known as 'mahogany tides' because the color of the algae and the density of algae in the bloom make the water appear brown or reddish-brown (Figure 32). These conditions are most often caused by blooms of *Prorocentrum minimum*. While *Prorocentrum* frequently blooms in the spring, blooms have been observed in Maryland waters in all seasons. These algae do not produce a toxin, but the magnitude of the bloom can harm fish and shellfish by replacing more nutritious algae, depleting oxygen in the water column or clogging gills. The darkened waters can also reduce the light reaching underwater grasses.

[34] Information on Harmful Algal Blooms is available at http://mddnr.chesapeakebay.net/eyesonthebay/habs.cfm

Other harmful algal species can lead to fish kills. *Karlodinium venificum* can release a toxin that harms fish, and densities above 20,000 cells/ml can be acutely toxic to fish. Extremely low dissolved oxygen is often the result of the abrupt die off of a bloom, when the process of decomposing the large amount of plant material uses up the oxygen in the water. The combination of the toxin and low dissolved oxygen can lead to fish kills.

Figure 32. Harmful algal blooms.
Left panel: Blue-green algae bloom. Right panel: 'Mahogany tide' bloom.

HABs are a recurring issue in the Back and Patapsco rivers. Blooms of the blue-green algae *Microcystis aeruginosa* have occurred in the Back River when salinities were low (such as in 2001) due to freshwater flow that was higher than normal. In the Patapsco, higher salinity waters have 'mahogany tide' blooms in most years. *Karlodinium* is also found in the Patapsco River and has caused or contributed to fish kills.

Underwater grasses

Water quality determines the distribution and abundance of underwater grasses (submerged aquatic vegetation, SAV). For this reason, SAV communities are good barometers of the health of the tidal rivers and bays. SAV is also a critical nursery habitat for many bay animals. Similarly, several species of waterfowl are dependant on SAV as food when they over-winter in the Chesapeake region. SAV distribution is determined through the compilation of aerial photography directed by the Virginia Institute of Marine Science (VIMS).[35]

Patapsco River
Until 2004, VIMS identified only very small amounts of SAV in the Patapsco River. Although this mesohaline river showed promise of an SAV resurgence in 2005 with a phenomenal 278 acres identified (71% of its goal), SAV has steadily declined since then (Figure 33). In 2008, 18 acres of SAV were identified by aerial surveys. In 2009 that number fell to12 acres. Finally in 2010, for the first time in several years, there was no SAV identified in the Patapsco (Figure 34).

Back River
The Back River had no substantial SAV beds in 2010. While a tiny patch (0.02 acres) of SAV was identified, 2004 was the first and only year that a substantial amount of SAV was observed (30 acres of wild celery). There is no restoration goal for this system. However, a restoration effort (1999-2006) where wild celery transplants were grown from seed by students and planted in Long Creek has survived.

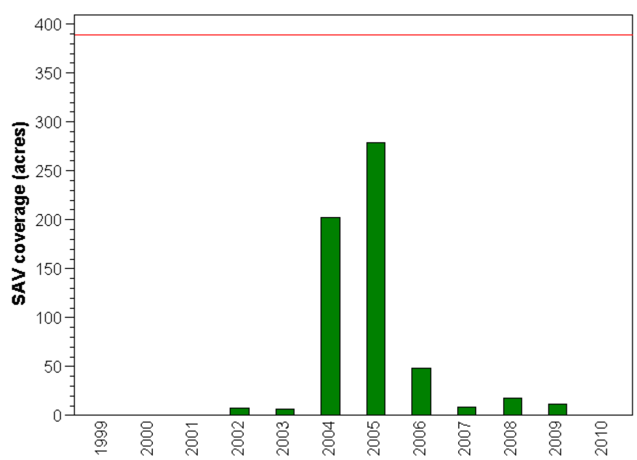

Figure 33. SAV coverages in the Patapsco River 1999-2010.
SAV data provided by the Virginia Institute of Marine Science. Red line shows the restoration goal for the river.

[35] Reports detailing methodology and annual SAV coverage are available at www.vims.edu/bio/sav . Details on species of SAV discussed in this report can be found at www.dnr.maryland.gov/bay/sav/key

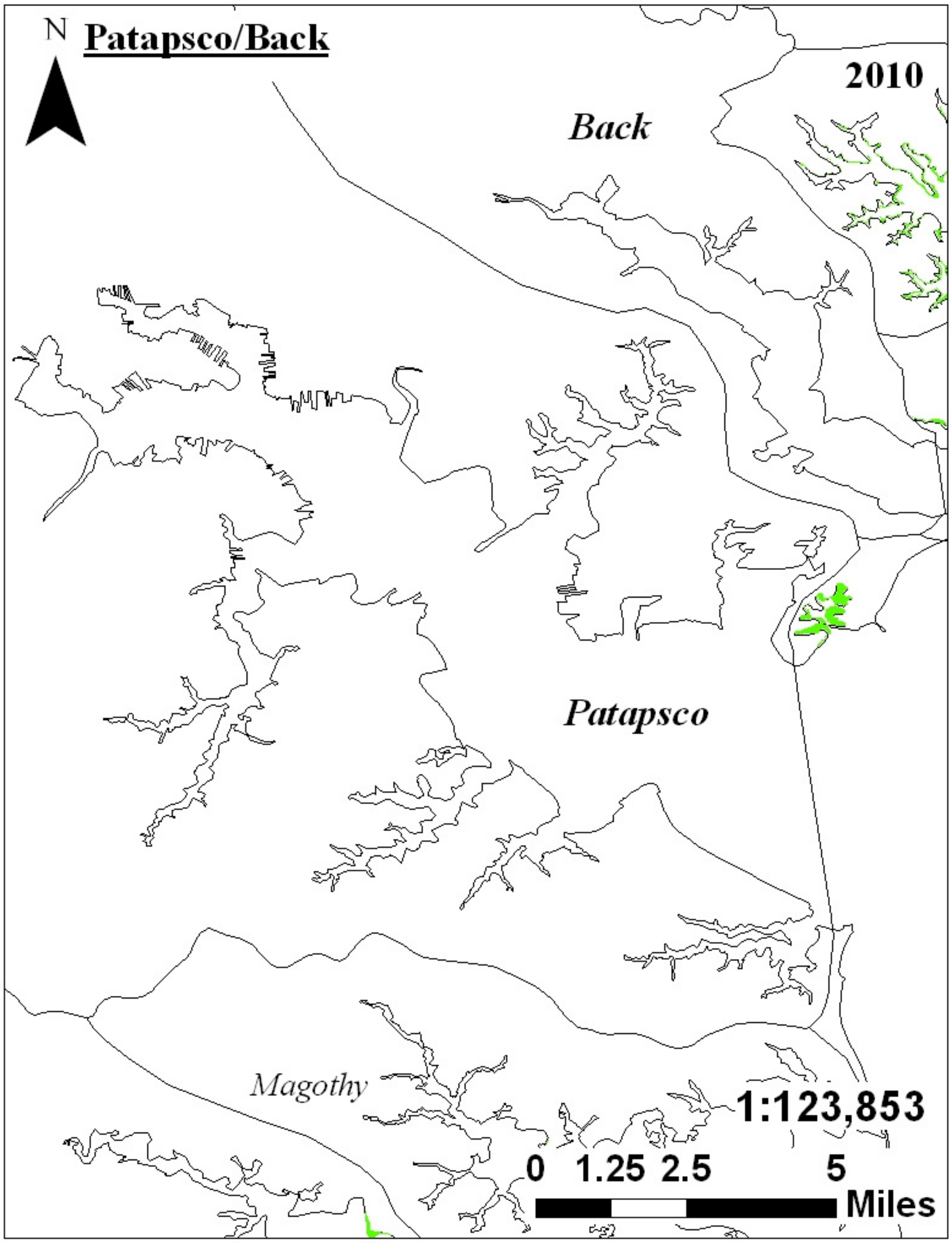

Figure 34. SAV beds (in green) in the Patapsco and Back Rivers in 2010.
SAV data provided by the Virginia Institute of Marine Science.

Benthic animals

Benthic animals are the animals that live in or on the bottom of the bay. To determine the health of benthic communities, samples are collected in the summer at one long-term benthic monitoring station in the Back River and four stations in the Patapsco. The Back River station has been monitored since 1995. Patapsco River stations include two sampled since 1984 (main river and Middle Branch) and two sampled since 1989 (Bear Creek and Curtis Bay). Trends are calculated for these long-term monitoring stations. Starting in 1994, samples were also collected from all of the rivers and mainstem Bay each year from randomly selected locations. Within the smaller western shore rivers (excludes the Patuxent and Potomac), there are not a fixed number of samples each year in any particular river and each river is not sampled in every year. Larger rivers end up with more samples collected over time. The benthic index of biotic integrity (BIBI) assesses the health of the benthic community.[36] A BIBI score of greater than 3 is considered meeting the goal for benthic community health.

In 2008-2010, benthic animal community health was degraded or severely degraded in the Back River, Middle Branch, Bear Creek, and Curtis Bay long-term stations; conditions were marginal in the Patapsco main river. Conditions have degraded in Middle Branch (1985-2010), Curtis Bay (1989-2010), and Back River (1995-2010). During this time period, 30 random samples were collected in the Patapsco River (Figure 35). Degraded conditions were found at about half of sites (16 of 30 samples). The majority of the degraded sites were in the upper Patapsco River and in the creeks, while the mouth of the river had healthy benthic populations. Back River was not randomly chosen to be sampled in 2008 or 2010. In 2009, 3 samples were collected, 2 met goals and 1 was degraded. Overall, the results for 2008-2010 for the Patapsco and Back rivers indicated 45-55% of total benthic habitat was degraded.[37]

Benthic community health in the Patapsco and Back rivers is degraded due to the combined effects of low dissolved oxygen, high nutrient loadings and sediment contamination with toxic chemicals.[38] In the western shore rivers as a group, overall benthic community health was worse in 2005-2010 than in previous years. Fewer organisms (reduced abundance) and fewer species have been found and indicate very poor habitat quality due to low dissolved oxygen. Degrading trends in benthic community health at the long-term stations in Middle Branch, Curtis Bay and Back River are likely indicative of increased low dissolved oxygen stress on the benthic community. Worsening low dissolved oxygen conditions may have resulted from higher spring flows in recent years compared to earlier years. Higher flows cause higher nutrient loadings and contribute to earlier and more extensive areas of low dissolved oxygen conditions.

[36] Methods for calculation of the BIBI are available at http://www.baybenthos.versar.com/DsgnMeth/Analysis.htm#BIBI.
[37] Annual reports for 2008, 2009 and 2010 are available online at http://www.baybenthos.versar.com/referenc.htm.
[38] See Annual reports, section 4.

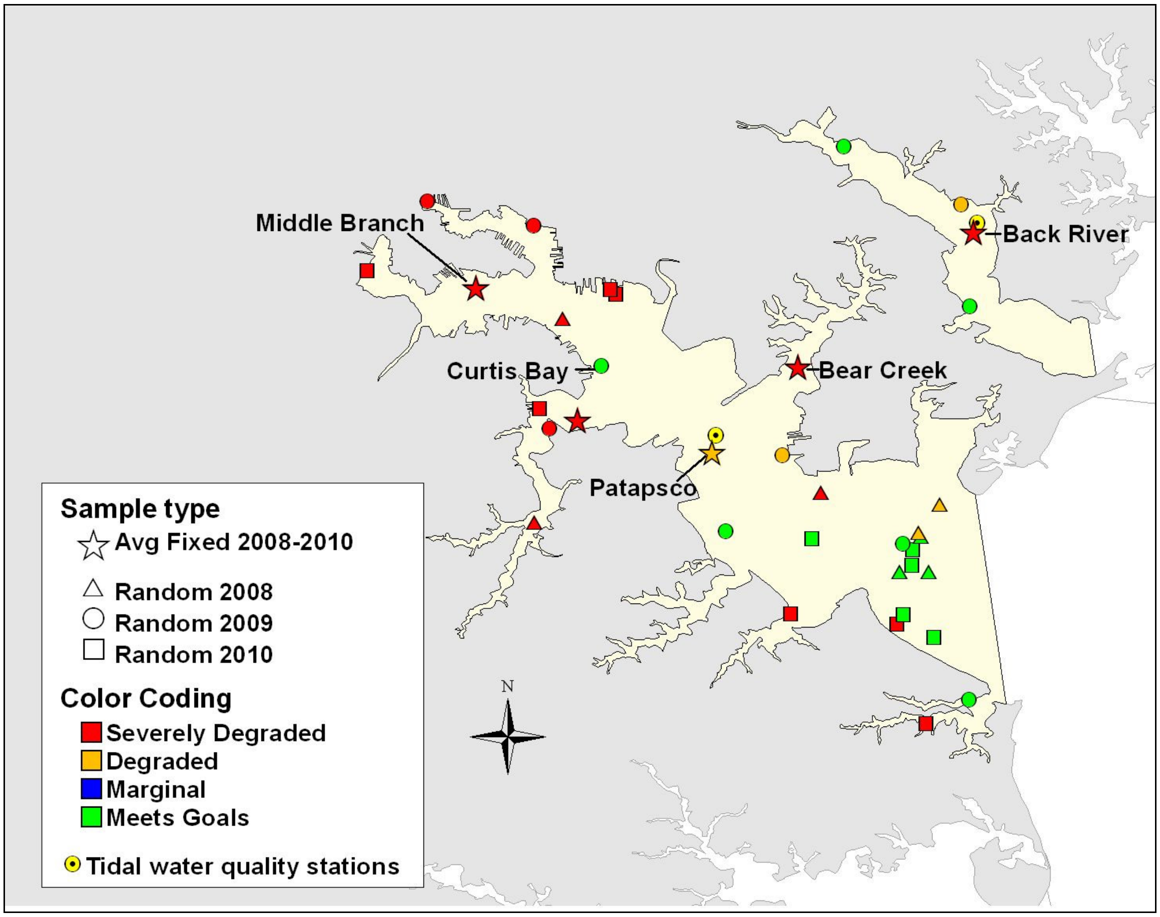

Figure 35. Benthic Index of Biotic Integrity results for 2008-2010.
Random samples were collected in 30 locations in 2008-2010. Yellow circles show locations of long-term tidal water quality monitoring stations. A BIBI score of 3 or greater Meets Goals. BIBI scores of 2.7-2.9 are Marginal, 2.1-2.6 are Degraded and less than 2.1 are Severely Degraded.

Summary of Water Quality and Habitat Conditions

Information on current water and habitat quality and the changes through time is needed to assess the health of a river. Many types of information are needed to most completely understand the current conditions. In some instances the assessment is straight forward and all of the information indicates both good water quality and healthy habitats. Most often, some aspects of the overall picture indicate good conditions and other aspects indicate poor conditions. The summary presented here is intended to best represent an overall condition. This is a simplified version and can not capture all the detail presented in the previous sections of this report. Informing the public about the overall health of a river is often best done with a summary of all of the data. Management decisions can benefit from both the summarized and the detailed information.

The Patapsco River and Back River basin has high to very high human population densities and intense urban land use (more than 50% of the watershed area). These characteristics set these rivers apart from the other western shore rivers, and lead to different management needs and strategies for these systems. Point sources are the largest sources of nitrogen and phosphorus loadings, and urban run-off is the largest source of sediment loadings. Stream health is poor in five of the seven sub-watersheds, and five of these sub-watersheds are designated as a high priority for restoration efforts.

Patapsco River

Water quality has improved in the non-tidal and tidal portions of the Patapsco River. Nitrogen (N), phosphorus (P) and sediment (S) levels have decreased in non-tidal streams in the Patapsco River sub-watersheds. P and S loadings to the North Branch Patapsco decreased from 1985-2010, but S increased from 2001-2010. In the tidal waters of the middle Patapsco River, N levels decreased since 1985 but are still too high to allow for nitrogen limitation of algal growth. P and S levels improved in the main river. Habitat requirements for submerged aquatic vegetation (SAV) were met for P and S, but habitat quality was impaired due to poor algal densities and water clarity. Bottom dissolved oxygen levels were very poor and habitat quality for benthic animals was degraded. Dissolve oxygen and water clarity have degraded.

Shallow water monitoring indicated turbidity failed to meet good habitat quality requirements at least 50% and by more than 70% of the time in some areas. Chlorophyll levels exceeded the criteria from 20-60% of the time. Summer dissolved oxygen levels in the shallow waters were impaired at the Fort McHenry location, falling below the 3.2 mg/l criteria 20-30% of the time. Summer dissolved oxygen levels passed the 3.2 mg/l criteria more than 80% of the time at Fort Armistead and Masonville Cove, and at least 95% of the time at Fort Smallwood.

Underwater grasses were limited prior to 2004, but covered 278 acres (71% of restoration goal) in 2005. Since 2008 underwater grass beds have been greatly reduced and by 2010 no beds were measured. Benthic animal populations are impaired in Bear Creek, Curtis Bay and Middle Branch and have degraded. Benthic animal populations in the main river are marginal. Phytoplankton populations are also impaired and have degraded.

Back River

The Back River WWTP is the dominant source of nitrogen and phosphorus to the Back River. Upgrades to the wastewater treatment plant in 1998 improved N loadings but they remain above loadings caps. Further upgrades are planned for completion by 2017. An intensive study of the historical loadings to Back River found that non-point sources were also important, especially to phosphorus loads. The study also found that nutrients entering the river are deposited to the sediments, where they accumulate and are available to fuel algal growth at later times. As the result, water quality improvements following loadings reductions will be delayed by as much as 3-6 years. The study recommends management actions that make reductions in non-point source loads.

Water quality improved with substantial decreases in N levels in the tidal main river, but N levels are still too high to allow for nitrogen limitation of algal growth. P levels also improved. Habitat requirements for underwater grasses were met for P but habitat quality was impaired due to poor sediment levels, algal densities and water clarity. Water clarity degraded. Algal densities may have degraded from 1999-2010, but may also have improved from 1985-2010. Bottom dissolved oxygen levels were good on average, but habitat quality for benthic animals was impaired in summer months. Also, the very high summer dissolved oxygen levels are more indicative of poor than good habitat quality due to high nutrients fueling high algal production.

Virtually no underwater grass beds have been measured in the Back River. Benthic animal populations at the long-term tidal water quality station in the main river are impaired and have degraded, though other locations have healthy benthic animal communities.

Appendix 1

Land use/Land cover for 2000 and 2010 and Amount of Impervious Surface

Land-use/Land-cover 2000 and 2010 from the Maryland Department of Planning. 2010 data available at www.planning.maryland.gov/OurWork/landUse.shtml. 2000 data available from Maryland Department of Planning, Planning Data Services, (410) 767-4450. Use codes from the Maryland Department of Planning Land Use/ Land Cover Classification Definitions (http://www.planning.maryland.gov/PDF/OurWork/LandUse/AppendixA_LandUseCategories.pdf). Impervious surface calculated from definitions in Cappiella and Brown, Urban Cover and Land Use in the Chesapeake Bay watershed, Center for Watershed Protection, 2001, as referenced in Table 4.1 of a User's Guide to Watershed Planning in Maryland, http://dnr.maryland.gov/watersheds/pubs/userguide.html

Sub-watershed	Land use/ Land cover	Area in 2000 (sqr miles)	%Total in 2000	Area in 2010 (sqr miles)	%Total in 2010	Area Change (sqr miles)	%Total Area change
Back River	AGRICULTURE	1.01	2%	0.64	1%	0.37	1%
	BARREN LAND	0.11	0%	0.31	1%	-0.21	0%
	FOREST	9.59	18%	8.07	15%	1.52	3%
	TRANSPORTATION	0.38	1%	1.32	2%	-0.94	-2%
	URBAN	42.86	**78%**	43.69	**80%**	-0.83	-2%
	WETLANDS	0.63	1%	0.55	1%	0.08	0%
	IMPERVIOUS SURFACE	13.25	**24%**	13.87	**25%**	-0.62	0%
Bodkin Creek	AGRICULTURE	0.42	5%	0.10	1%	0.32	4%
	BARREN LAND	0.00	0%	0.00	0%	0.00	0%
	FOREST	4.43	**49%**	2.35	**26%**	2.08	**23%**
	TRANSPORTATION	0.00	0%	0.00	0%	0.00	0%
	URBAN	4.14	**46%**	6.55	**73%**	-2.41	**-27%**
	WETLANDS	0.03	0%	0.02	0%	0.01	0%
	IMPERVIOUS SURFACE	1.06	12%	1.17	13%	-0.11	0%
Baltimore Harbor	AGRICULTURE	1.82	2%	1.58	2%	0.24	0%
	BARREN LAND	0.62	1%	0.73	1%	-0.11	0%
	FOREST	15.12	17%	13.36	15%	1.76	2%
	TRANSPORTATION	1.84	2%	2.14	2%	-0.30	0%
	URBAN	66.85	**77%**	68.40	**79%**	-1.55	-2%
	WETLANDS	0.78	1%	0.81	1%	-0.04	0%
	IMPERVIOUS SURFACE	25.19	**29%**	25.26	**29%**	-0.07	0%
Jones Falls	AGRICULTURE	5.24	9%	3.42	6%	1.82	3%
	BARREN LAND	0.11	0%	0.08	0%	0.03	0%
	FOREST	9.62	17%	7.72	13%	1.89	3%
	TRANSPORTATION	0.50	1%	1.02	2%	-0.52	-1%
	URBAN	42.76	**73%**	45.99	**79%**	-3.24	-6%
	WETLANDS	0.05	0%	0.06	0%	-0.01	0%
	IMPERVIOUS SURFACE	10.43	18%	11.08	19%	-0.65	0%
Gwynns Falls	AGRICULTURE	2.80	4%	1.49	2%	1.31	2%
	BARREN LAND	0.23	0%	0.04	0%	0.19	0%
	FOREST	11.33	17%	10.17	16%	1.16	2%
	TRANSPORTATION	1.01	2%	1.95	3%	-0.94	-1%
	URBAN	49.74	**76%**	51.56	**79%**	-1.82	-3%
	WETLANDS	0.05	0%	0.05	0%	0.00	0%
	IMPERVIOUS SURFACE	14.84	**23%**	16.11	**25%**	-1.27	0%

Sub-watershed	Land use/ Land cover	Area in 2000 (sqr miles)	%Total in 2000	Area in 2010 (sqr miles)	%Total in 2010	Area Change (sqr miles)	%Total Area change
Patapsco River L N Br	AGRICULTURE	14.52	12%	8.07	7%	6.44	5%
	BARREN LAND	0.74	1%	1.00	1%	-0.26	0%
	FOREST	45.92	**39%**	39.78	**34%**	6.14	5%
	TRANSPORTATION	0.62	1%	2.76	2%	-2.14	-2%
	URBAN	55.85	**47%**	66.13	**56%**	-10.28	-9%
	WETLANDS	0.75	1%	0.60	1%	0.15	0%
	IMPERVIOUS SURFACE	17.48	15%	21.04	18%	-3.55	-1%
Liberty Reservoir	AGRICULTURE	67.75	**43%**	51.85	**33%**	15.90	**10%**
	BARREN LAND	0.01	0%	0.24	0%	-0.23	0%
	FOREST	50.34	**32%**	47.32	**30%**	3.02	2%
	TRANSPORTATION	0.00	0%	0.41	0%	-0.41	0%
	URBAN	40.95	**26%**	58.93	**37%**	-17.99	**-11%**
	WETLANDS	0.08	0%	0.09	0%	-0.01	0%
	IMPERVIOUS SURFACE	8.74	5%	11.01	7%	-2.28	0%
S Branch Patapsco	AGRICULTURE	37.50	**44%**	28.56	**33%**	8.94	**10%**
	BARREN LAND	0.04	0%	0.18	0%	-0.15	0%
	FOREST	24.71	**29%**	23.12	**27%**	1.58	2%
	TRANSPORTATION	0.12	0%	0.19	0%	-0.07	0%
	URBAN	23.26	**27%**	33.41	**39%**	-10.15	**-12%**
	WETLANDS	0.08	0%	0.01	0%	0.07	0%
	IMPERVIOUS SURFACE	4.66	5%	5.37	6%	-0.72	0%
Entire Basin	AGRICULTURE	131.05	**21%**	95.71	15%	35.34	6%
	BARREN LAND	1.85	0%	2.58	0%	-0.72	0%
	FOREST	171.05	**27%**	151.91	**24%**	19.15	3%
	TRANSPORTATION	4.48	1%	9.79	2%	-5.32	-1%
	URBAN	326.40	**51%**	374.67	**59%**	-48.27	-8%
	WETLANDS	2.44	0%	2.19	0%	0.25	0%
	IMPERVIOUS SURFACE	95.66	15%	104.92	16%	-9.26	-1%

Appendix 2

Delivered Loads to the Back and Patapsco Rivers

Phase 5.3 2009 Progress Run 8/25/2010

Chesapeake Bay Program. Accessed January 10, 2012 from
http://www.chesapeakebay.net/watershedimplementationplantools.aspx?menuitem=52044
File
(ftp://ftp.chesapeakebay.net/Modeling/phase5/Phase53_Loads-Acres-BMPs/MD/
Load_Acres_MDWIP_08252010.xls)

Loadings by Land Use and Segment
Loadings > 20% are in **bold** typeface

River	River/CBP segment	Category	N load (Million lbs per yr)	% Total N Load	P load (Million lbs per yr)	% Total P Load	Sed load (Million lbs per yr)	% Total Sed Load
Back	Back/ BACOH	Agriculture	0.001	0%	0.0001	0%	0.07	1%
		Forest	0.011	1%	0.0006	1%	0.35	4%
		Non-tidal Water Deposition	0.002	0%	0.0001	0%		
		Septic	0.018	1%				
		Urban Runoff	0.154	7%	0.0298	**39%**	8.98	**95%**
		Point Source	2.045	**92%**	0.0450	**60%**	0.03	0%
		Total Load	**2.231**		**0.0756**		**9.43**	
Patapsco	Patapsco/ PATMH	Agriculture	0.261	3%	0.0097	2%	20.18	18%
		Forest	0.239	3%	0.0070	2%	13.79	12%
		Non-tidal Water Deposition	0.010	0%	0.0006	0%		
		Septic	0.288	4%				
		Urban Runoff	0.921	12%	0.1003	**25%**	76.68	**68%**
		Point Source	5.865	**77%**	0.2797	**70%**	2.74	2%
		Total Load	**7.584**		**0.3973**		**113.39**	

Appendix 3

Station names, locations and descriptions.

Long-term non-tidal and tidal water quality.

Station Name	Location/Depth	Latitude/ Longitude (NAD83 DMS)	Characterizes
PAT0176	Patapsco River at Bridge on Washington Boulevard	39° 13.069'N 76° 42.320'W	Non-tidal:Free-flowing freshwater
NPA0165	North Branch Patapsco Bridge at Maryland Route 91 gage	39° 28.967' N 76° 52.925' W	Non-tidal:Free-flowing freshwater
JON0184	John Falls near Bridge Falls Road (MD Route 25)	39° 24.523' N 76° 44.566' W	Non-tidal:Free-flowing freshwater
GWN0115	Gwynns Falls Bridge on Essex Road in Villa Nova near gage station	39° 20.567' N 76° 43.583'W	Non-tidal:Free-flowing freshwater
PAT0285	Patapsco River at Bridge on MD Route 99 near Hollofield gage	39° 18.746' N 76° 47.534' W	Non-tidal:Free-flowing freshwater
WT4.1	Back River, East of Stansbury Point at day beacon 12, depth 2m	39° 16.652' N 76° 26.620' W	Tidal: Lower Estuarine
WT5.1	Patapsco River, East of Hawkins Point at buoy 5M, depth 17m	39° 12.785' N 76° 31.352' W	Tidal: Lower Estuarine

Shallow water monitoring locations and dates

Waterbody/ Segment	Station Name	Map #	Station	Years deployed	LAT (NAD83)	LONG (NAD83)
Patapsco River (PATMH)	Masonville Cove	4	XIE4741	(surface) 2009- present (bottom)2010- present	39° 14.718' N	76° 35.868' W
	Baltimore Harbor at Fort McHenry	5	XIE5748	2000-present	39° 15.678' N	76° 35.178' W
	Fort Armistead	3	XIE2581	2009-present	39° 12.511' N	76° 31.929' W
	Fort Smallwood	2	XHF9808	2009-present	39° 09.762' N	76° 29.248' W
	Additional water quality mapping calibration stations	7	CUR0007	2009-present	39° 12.453' N	76° 34.785' W
		8	WT5.1	2009-present	39° 12.786' N	76° 31.352' W
		9	XIE4876	2009-present	39° 14.767' N	76° 32.377' W
		10	XIE6747	2009-present	39° 16.623' N	76° 35.353' W
		11	XIF2929	2009-present	39° 12.866' N	76° 27.095' W
		12	XIF4705	2009-present	39° 14.672' N	76° 29 454' W
Chesapeake Bay (CB3MH)	Fort Howard	2	XIF1735	2009-present	39° 11.718' N	76° 26.526' W
	Down's Park	1	XHF6841	2009-present	39° 07.095' N	76° 25.930' W

Appendix 4

Water and Habitat Quality Data Assessment Methods

Loadings
For USGS methods see http://md.water.usgs.gov/publications/sir-2006-5178/index.html

Current condition- Status
Tidal station nutrient concentrations and physical properties were evaluated to determine the current health of the rivers (status). Relative status was determined for total nitrogen (TN), dissolved inorganic nitrogen (DIN), total phosphorus (TP), dissolved inorganic phosphorus (PO_4), total suspended solids (TSS), algal abundance (as measured by chlorophyll *a*, CHLA) and water clarity (as measured with a Secchi disc) for the 2008-2010 period. For status calculation methods see
http://mddnr.chesapeakebay.net/eyesonthebay/documents/ICPRB09-4_StatusMethodPaperMolson2009.pdf.

Results for some parameters are compared with established threshold values to evaluate habitat quality. Summer bottom dissolved oxygen (BDO) is compared to US EPA Chesapeake Bay dissolved oxygen criteria for deep-water seasonal (June- September). Summer dissolved oxygen is considered healthy if levels are 5 mg/l or greater and impaired if levels are less than 3 mg/l. For more details see www.chesapeakebay.net/content/publications/cbp_13142.pdf. DIN is compared to a nitrogen limitation threshold value of less than 0.07 mg/l (Fisher and Gustafson 2002, available online at
http://www.hpl.umces.edu/gis_group/Resource%20Limitation/2002_report_27Oct03.htm#es).
Submerged aquatic vegetation (SAV) growing season median concentrations for 2008-2010 for PO_4, TSS, CHLA and percent-light through water (PLW) are compared to SAV habitat requirements (Appendix 5) using the methods of Kemp et al. (2004) available online at
http://archive.chesapeakebay.net/pubs/sav/savreport.pdf

Change over time- Trends
Nutrient levels and physical properties were evaluated to determine progress toward improved water quality (trends). For trends calculation methods see
http://mddnr.chesapeakebay.net/eyesonthebay/documents/stat_trend_hist.pdf. For non-tidal water quality stations, concentrations of TN, TP and TSS were evaluated. For tidal water quality stations, the following parameters were evaluated: TN, DIN, TP, PO_4, TSS, algal abundance (as measured by chlorophyll *a*, CHLA), water clarity (as measured with a Secchi disc), summer BDO, salinity and water temperature. In order to understand results in the primary parameters, additional parameters were examined including nitrate-nitrite (NO_{23}), ammonium (NH_4) and ratios of nutrient concentrations (TN:TP, DIN:PO_4) that may explain more about nutrient use by aquatic plants and limitations of available nutrients.

Non-tidal water quality data was tested for linear trends for 1999-2010 and 1986-2010. Tidal water quality data were tested for linear trends for 1985-1997, 1999-2010 and 1985-2010. Tests for non-linear trends were also done for 1985-2010 with the tidal water quality data. Trends are significant if $p \leq 0.01$; also included in the discussion are trends that 'may be' significant when $0.01 < p < 0.05$. Due to a laboratory change in 1998 that affects the tidal water quality data, a step trend may occur for TP, PO_4 and TSS. For these parameters, trends are determined for

1985-1997 and 1999-2010 only.

In addition to annual trends for the various time ranges above, tidal water quality data was tested for seasonal trends for 1999-2010. Seasons tested were spring (March-May), summer (July-September) and SAV growing season (April-October).

Shallow water Temporal Assessment (Percent failure analysis)

Continuous monitoring data were compared to water quality thresholds. Measurements of dissolved oxygen taken during the months of June through September were compared to the US EPA threshold value of 3.2 mg/l for shallow water bay grass use (instantaneous minimum). This time period was used because the summer months typically experience the lowest dissolved oxygen levels and are the most critical for living resources. Chlorophyll and turbidity measurements collected during the SAV growing season of April through October were compared to threshold levels of 15 µg/l and 7 NTU, respectively. Values above these levels can inhibit light penetration through the water column and impact growth of underwater grasses. Percent failures are defined as the percent of values in each year that did not meet the water quality thresholds.

Shallow water Spatial Assessment

Algal density, sediment and nutrient samples were collected from calibration sites on water quality mapping cruises, some of which were also at continuous monitoring sites. In addition, samples were collected at the continuous monitoring sites when the equipment was serviced (approximately every two weeks). All data for a station (water quality mapping calibration and continuous monitoring calibration) were used to calculate a monthly median. Monthly medians for April-October were used to calculate the SAV growing season median. Note that the long-term stations include data from long-term and water quality mapping sampling. The median CHLA, TSS, PO_4 and DIN levels and Secchi depths for the April-October SAV growing season were compared to the habitat requirements in the same manner as the long-term tidal data (Appendix 5).

Non-parametric one-way ANOVAs were used to determine if there were differences between stations (SAS Institute software). Where a significant difference was present, a Tukey's Studentized Range (HSD) test was performed to determine which stations were different from each other. Tests were considered significant at $p < 0.05$.

Appendix 5

Submerged Aquatic Vegetation Habitat Requirements

Submerged Aquatic Vegetation (SAV) habitat requirements by salinity regime (from Habitat Requirements for Submerged Aquatic Vegetation in Chesapeake Bay: Water Quality, Light Regime, and Physical-Chemical Factors. W. M. Kemp, R. Batiuk, R. Bartleson, P. Bergstrom, V. Carter, C. L. Gallegos, W. Hunley, L. Karrh, E. W. Koch, J. M. Landwehr, K. A. Moore, L. Murray, M. Naylor, N. B. Rybicki, J. C. Stevenson and D. J. Wilcox. Estuaries. 2004. 27:363–377 available online at http://archive.chesapeakebay.net/pubs/sav/savreport.pdf.).

SAV growing season for all three regimes in Maryland is from April-October. Median seasonal values are compared to the listed habitat requirement to determine if water quality is suitable for SAV growth and survival. Note that the dissolved inorganic nitrogen (DIN) requirement for mesohaline waters exceeds the 0.07 mg/l level where nitrogen limitation of algal growth likely occurs. The more stringent nitrogen limitation DIN level is used for interpretation of habitat quality instead. Due to issues with the model calibration, instead of Percent light at leaf (PLL) water clarity is assessed with percent light through water (PLW) at 1.0 meter depth (L. Karrh, personal communication). PLW can be calculated for the long-term stations that were sampled from 1985-2010. For all stations, Secchi depth can also be used to estimate PLW (L. Karrh, personal communication).

Salinity Regime (ppt)	**Water Column Light Requirement (PLW) (%) or Secchi Depth (m)**	**Total Suspended Solids (mg/l)**	**Plankton Chlorophyll-*a* (µg/l)**	**Dissolved Inorganic Nitrogen (mg/l)**	**Dissolved Inorganic Phosphorus (mg/l)**
Tidal Fresh <0.5 ppt	>13% or 0.725 m	< 15	< 15	Not applicable	< 0.02
Oligohaline 0.5-5 ppt	>13% or 0.725 m	< 15	< 15	Not applicable	< 0.02
Mesohaline 5-18 ppt	>22% or 0.97 m	< 15	< 15	< 0.15 (Nitrogen Limitation < 0.07)	< 0.01

Appendix 6

Long-term annual trends results from non-tidal water quality stations.
Trend results from 1999-2010 and 1986-2010.

Grey shading of the 1985-2010 Linear Trend results indicates the non-linear trend is significant and the linear trend results should not be reported. For trends significant at $p \leq 0.01$, results are abbreviated as INC (increasing), DEC (decreasing), U (u-shaped non-linear trend) and INV-U (inverse u-shaped non-linear trend). NT alone indicates trend is not significant at $p < 0.05$.

PARAM	STATION	1999-2010 Linear	1986-2010 Linear	1986-2010 non-linear	Non-linear date
TN	PAT0176	NT	DEC	INV-U	Sep-91
	NPA0165	NT	NT	INV-U	Dec-98
	JON0184	NT	DEC		
	GWN0115	NT	DEC		
	PAT0285	NT	DEC		
TP	PAT0176	DEC	DEC		
	NPA0165	NT	DEC		
	JON0184	NT	DEC		
	GWN0115	DEC	DEC		
	PAT0285	DEC	DEC		
TSS	PAT0176	NT	DEC		
	NPA0165	NT	DEC		
	JON0184	NT	DEC		
	GWN0115	NT	DEC		
	PAT0285	DEC	DEC		

Appendix 7

Current status and long-term tidal water quality trends
1985-1997, 1999-2010 and 1985-2010

Data is from the surface layer with the exception of dissolved oxygen, which is from the bottom. Bottom dissolved oxygen trends are for summer only (June-September). Red colored status and trends results indicate poor or degrading conditions. Green colored status and trends results indicate good or improving conditions. Blue colored status indicates fair status. Blue colored trends indicate decreasing trends where a qualitative assessment (improving or degrading) is not applicable; purple colored trends indicate increasing trends in the same parameters. Grey shading of the 1985-2010 Linear Trend results indicates the non-linear trend is significant and the linear trend results should not be reported. For trends significant at $p \leq 0.01$, results are abbreviated as IMP (improving), DEG (degrading), INC (increasing), DEC (decreasing), U (u-shaped non-linear trend) and INV-U (inverse u-shaped non-linear trend). For trends significant at $0.01 < p < 0.05$, NT (no trend) precedes the abbreviation. NT alone indicates trend is not significant at $p < 0.05$.

Param	Station	Initial 2-yr Median	2008-2010 Median	2008-2010 Status	1985-1997 Linear Trend	1999-2010 Linear Trend	1985-2010 Linear Trend	1985-2010 Non-Lin Trend	Non-linear inflection
TN	Back R	6.145	2.545	**POOR**	**IMP**	**IMP**	**IMP**	**INC to ASYMPTOPE**	28-Feb-12
	Patapsco R	1.663	1.224	**POOR**	**IMP**	NT	**IMP**	**U**	29-Mar-06
DIN	Back R	3.349	0.534	**GOOD**	**IMP**	**IMP**	Not evaluated due to lab change		
	Patapsco R	0.809	0.421	**POOR**	**IMP**	NT			
TP	Back R	0.247	0.160	**POOR**	NT	**IMP**	Not evaluated due to lab change		
	Patapsco R	0.077	0.052	**POOR**	NT	NT			
PO4	Back R	0.005	0.006	**FAIR**	**DEG**	**IMP**	Not evaluated due to lab change		
	Patapsco R	0.012	0.004	**POOR**	NT	**IMP**			
TSS	Back R	24.0	24.3	**FAIR**	NT	NT	Not evaluated due to lab change		
	Patapsco R	11.9	8.0	**GOOD**	NT	**IMP**			
CHLA	Back R	92.8	69.9	**POOR**	NT	NT	NTIMP		
	Patapsco R	22.5	26.9	**POOR**	NT	NT	NT		
SECCHI	Back R	0.3	0.3	**POOR**	NT	SLOPE=0	SLOPE=0		
	Patapsco R	0.9	0.8	**POOR**	NT	NT	**DEG**		
DO	Back R	7.3	7.0	**GOOD**	**IMP**	NT	NT		
	Patapsco R	0.6	0.1	**POOR**	**DEG**	NTDEG	**DEG**		
WTEMP	Back R	18.7	14.4	**INC**	NT	NT	NT		
	Patapsco R	16.7	14.6	**INC**	NT	NT	NT		
SALINITY	Back R	2.8	2.4	**INC**	**DEC**	NT	NT		
	Patapsco R	9.2	7.7	**DEC**	**DEC**	NT	NT		
NH4	Back R	2.775	0.012	**GOOD**	**IMP**	**IMP**	Not evaluated due to lab change		
	Patapsco R	0.356	0.031	**FAIR**	**IMP**	NTIMP			
NO23	Back R	1.000	0.518	**FAIR**	NT	NT	Not evaluated due to lab change		
	Patapsco R	0.415	0.338	**POOR**	NT	NT			
TN:TP	Back R	45	38	**DEC**	**DEC**	NT	Not evaluated due to lab change		
	Patapsco R	50	50	NOD	NT DEC	NT			
DIN:PO4	Back R	1194	156	**DEC**	**DEC**	NT	Not evaluated due to lab change		
	Patapsco R	185	246	**INC**	**DEC**	NTINC			

Appendix 8

Seasonal trends results for long-term tidal water quality data

Seasonal trends results for surface data from 1999-2010. Color codes and abbreviations are the same as used in Appendix 7.

station	param	ANNUAL Jan-Dec	SPRING Mar-May	SUMMER Jun-Sep	SAV Apr-Oct
TN	Back R	**IMP**	**IMP**	NT	**IMP**
	Patapsco R	NT	NT	NT	NT
DIN	Back R	**IMP**	**IMP**	NT	**IMP**
	Patapsco R	NT	NT	NT	NT
TP	Back R	**IMP**	**IMP**	NT	**IMP**
	Patapsco R	NT	NT	NT	NT
PO4	Back R	**IMP**	**IMP**	NTIMP	**IMP**
	Patapsco R	**IMP**	NTIMP	**IMP**	**IMP**
TSS	Back R	NT	NTIMP	NT	NT
	Patapsco R	**IMP**	NT	NTIMP	**IMP**
CHLA	Back R	NT	NT	NT	NTDEG
	Patapsco R	NT	NT	NT	NT
SECCHI	Back R	SLOPE=0	NT	**DEG**	SLOPE=0
	Patapsco R	NT	NTDEG	NT	NT
WTEMP	Back R	NT	NT	NT	NT
	Patapsco R	NT	NT	NT	NT
SALINITY	Back R	NT	NT	NT	NT
	Patapsco R	NT	NT	NT	NT

Appendix 9

Shallow water monitoring water and habitat quality

Temporal Assessment- Percent failures

Continuous monitoring data for the years 2000-2010. Instantaneous measurements of dissolved oxygen taken during June through September were compared to threshold value 3.2 mg/l. Chlorophyll and turbidity measurements collected during the SAV growing were compared to threshold levels of 15 µg/l and 7 NTU, respectively. The percent of values in each year that did not meet the water quality thresholds are presented as “percent failures”.

The bottom monitor at Masonville Cove had only 10 weeks of data (August 3-October 12, 2010). Even though a subset of the annual data record is selected for the determination of percent failures (June-September for dissolved oxygen and April-October for chlorophyll and turbidity), the number of available observations for Masonville Cove (bottom) was much less than for the other stations. Similarly, the station at Fort McHenry was first established on September 22, 2000, so only nine days were available for 2000 for the dissolved oxygen analysis and only forty days were available for the turbidity and chlorophyll analyses. Data for the years 2000 to 2003 at Fort McHenry were not quality assured by DNR and may be unreliable. Also, there were no valid data records for dissolved oxygen at Fort McHenry in 2002. In 2005, the Fort McHenry continuous monitoring equipment incurred damage and was removed on July 13, 2005, resulting in a limited data set. Finally, in 2010, the pier at Fort McHenry (to which the monitoring instrument was anchored) was washed away during Tropical Storm Nicole, and the data record ends on October 5, 2010.

Station	Location	Year	Dissolved Oxygen Thresholds % < 3 mg/l	Dissolved Oxygen Thresholds % < 5 mg/l	Chlorophyll Thresholds % > 30 ug/l	Turbidity Thresholds % > 7 NTU
XIE4741	*Patapsco River*	2009	8.15	27.25	10.88	55.57
	Masonville Cove (surface)	2010	14.52	36.00	24.88	57.58
	Masonville Cove (bottom)	2010	45.3 [a]	71.3 [a]	11.46 [a]	96.46 [a]
XIE5748	*Patapsco River*	2000	2.67 [ab]	79.15 [ab]	13.81 [ab]	13.97 [ab]
	Baltimore Harbor	2001	31.72 [b]	63.47 [b]	26.38 [b]	55.89 [b]
	Fort McHenry	2002	No data	No data	26.84 [b]	59.53 [b]
		2003	25.64 [b]	57.70 [b]	8.10 [b]	63.75 [b]
		2004	8.19	33.50	8.98	18.63
		2005	15.34 [a]	35.68 [a]	10.70 [a]	33.21 [a]
		2006	9.21	36.80	20.25	21.49
		2007	19.22	52.79	29.68	26.78
		2008	26.23	56.80	19.24	18.45
		2009	21.46	50.54	12.89	11.79
		2010	22.58 [c]	57.43 [c]	11.84 [c]	35.42 [c]
XIE2581	*Patapsco River*	2009	10.70	38.85	19.26	71.30
	Fort Armistead	2010	1.76	28.28	17.16	73.93
XHF9808	*Patapsco River*	2009	2.19	11.40	19.53	57.26
	Fort Smallwood	2010	0.00	5.10	18.53	55.21
XIF1735	*Chesapeake Bay*	2009	0.81	7.97	9.98	88.58
	Fort Howard	2010	0.75	10.00	2.26	78.67
XHF6841	*Chesapeake Bay*	2009	0.25	4.25	21.77	67.80
	Downs Park	2010	3.18	16.58	12.61	77.99

< 10 % failure	40 - 70 % failure
10 - 40 % failure	> 70 % failure

[a] Data not available for more than half of the analysis period
[b] Data have not undergone complete QA/QC procedures by DNR
[c] Data not available for less than half of the analysis period

Spatial Assessment

Shallow water monitoring data for 2009-2010 compared to SAV habitat requirements in the Patapsco River.
All data for a station (water quality mapping and continuous monitoring) were used to calculate a monthly median. Monthly medians for April-October were used to calculate the SAV growing season median, which was compared to habitat requirements (Appendix 5). Note that the long-term stations include data from long-term and water quality mapping sampling. In 2010, DIN and PO_4 was not measured at some stations.

	Station		map #	year	Chla mg/l		TSS mg/l		DIN mg/l		PO4 mg/l		Secchi Depth		DO mg/l		Salinity	Salinity Zone	TN mg/l	TP mg/l	Wtemp °C
Upper	XIE6747	Outer Baltimore Harbor	10	2009	30.7	FAIL	10.0	MEET	0.291	FAIL	0.0137	FAIL	0.60	FAIL	6.7	MEET	7.1	MH	1.499	0.0835	23.1
				2010	15.0	MEET	4.6	MEET					0.80	FAIL	5.5	MEET	8.7	MH			24.6
	XIE5748	**Fort McHenry**	5	2009	17.4	FAIL	11.3	MEET	0.454	FAIL	0.0088	MEET	0.70	FAIL	7.6	MEET	7.6	MH	1.333	0.0640	23.7
				2010	23.1	FAIL	6.6	MEET					0.60	FAIL	6.5	MEET	8.6	MH			25.2
	XIE4741	**Masonville Cove**	4	2009	19.6	FAIL	10.5	MEET	0.412	FAIL	0.0045	MEET	0.50	FAIL	7.4	MEET	6.3	MH	1.247	0.0601	23.8
				2010	20.8	FAIL	10.7	MEET	0.857	FAIL	0.0036	MEET	0.70	FAIL	8.4	MEET	7.3	MH	1.643	0.0615	22.6
Middle	XIE4876		9	2009	26.9	FAIL	7.3	MEET	0.171	FAIL	0.0055	MEET	0.60	FAIL	9.8	MEET	7.8	MH	1.388	0.0807	22.9
				2010	29.7	FAIL	8.8	MEET					0.80	FAIL	8.7	MEET	8.9	MH			23.5
	CUR0007	Curtis Creek	7	2009	26.4	FAIL	6.0	MEET	0.329	FAIL	0.0067	MEET	0.70	FAIL	9.0	MEET	7.2	MH	1.350	0.0724	22.9
				2010	25.6	FAIL	5.7	MEET					0.70	FAIL	7.7	MEET	5.5	MH			23.7
	XIE2581	**Fort Armistead**	3	2009	24.6	FAIL	16.4	FAIL	0.324	FAIL	0.0042	MEET	0.55	FAIL	9.1	MEET	7.5	MH	1.229	0.0677	24.0
				2010	20.3	FAIL	10.3	MEET					0.55	FAIL	8.1	MEET	7.5	MH			23.0
	WT5.1	***Long-term***	8	2009	32.9	FAIL	9.8	MEET	0.162	FAIL	0.0048	MEET	0.60	FAIL	10.4	MEET	7.5	MH	1.238	0.0751	23.3
				2010	30.5	FAIL	7.2	MEET	0.351	FAIL	0.0057	MEET	0.70	FAIL	10.5	MEET	8.5	MH	1.176	0.0520	22.9
	XIF4705	Bear Creek	12	2009	41.9	FAIL	14.7	MEET	0.117	FAIL	0.0043	MEET	0.50	FAIL	10.9	MEET	6.4	MH	1.411	0.0943	23.1
				2010	29.9	FAIL	5.2	MEET					0.80	FAIL	7.9	MEET	7.4	MH			23.3
Outer	**XHF9808**	**Fort Smallwood**	2	2009	29.0	FAIL	14.6	MEET	0.162	FAIL	0.0034	MEET	0.50	FAIL	8.9	MEET	6.5	MH	1.120	0.0672	22.8
				2010	22.5	FAIL	11.4	MEET					0.60	FAIL	8.0	MEET	8.1	MH			22.8
	XIF2929	Old Round Bay	11	2009	19.5	FAIL	14.0	MEET	0.133	FAIL	0.0038	MEET	0.50	FAIL	9.0	MEET	6.7	MH	1.349	0.0746	24.8
				2010	32.3	FAIL	13.3	MEET					0.40	FAIL	7.8	MEET	7.4	MH			22.9
Mouth	**XIF1735**	**Fort Howard**	6	2009	15.2	FAIL	14.7	MEET	0.260	FAIL	0.0047	MEET	0.5	FAIL	7.9	MEET	4.9	OH	0.995	0.0634	21.8
				2010	14.0	MEET	13.3	MEET					0.6	FAIL	8.4	MEET	5.5	MH			23.5
	XHF6841	**Down's Park**	1	2009	24.9	FAIL	15.9	FAIL	0.171	FAIL	0.0046	MEET	0.6	FAIL	8.2	MEET	6.8	MH	1.106	0.0596	22.0
				2010	14.2	MEET	13.6	MEET					0.7	FAIL	7.9	MEET	9.1	MH			22.7