Appendix K:
Existing Conditions of the Watershed

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Appendix K
Existing Conditions of the Watershed

The Chesapeake Bay and its watershed are among the most well-studied and best-understood estuaries and watersheds in the world. This section presents information germane to the lower Susquehanna River including the series of dams and reservoirs on the river, as well as the Chesapeake Bay watershed. At times, discussion will focus on the Conowingo Reservoir (and its dam) since it is the largest and most downstream reservoir. Holtwood and Safe Harbor Dams were known to be in dynamic equilibrium at the start of this assessment. Because Conowingo Reservoir was not believed to be in dynamic equilibrium and its reaching that condition could have a potentially large effect on the Bay, more attention is focused on Conowingo Dam than Holtwood or Safe Harbor Dams in this section.

This document summarizes information readily available on the CBP's website accessible at http://www.chesapeakebay.net, and the SRBC website, which is accessible at http://www.srbc.net. References are provided in the text for specific information that is from less readily available sources, such as from primary literature or government agency or privately-funded studies (gray literature). Substantial monitoring has been conducted in the vicinity of Conowingo Dam to meet various permitting requirements over the last several decades under the auspices of the MDNR Power Plant Research Program (Patty et al., 1999).

Several investigations were conducted specifically for this study to obtain additional detailed existing conditions information needed for modeling and plan formulation purposes. Reports from these investigations, conducted by Maryland Geological Survey (MGS), US Geological Survey (USGS), and US Army Corps of Engineers (USACE) Engineer Research and Development Center (ERDC), are presented in other appendices to this report package. Findings of those investigations applicable to sediment and associated nutrient management strategy development are discussed in Chapters 4 and 5 of the main report of this assessment instead of being presented in this section.

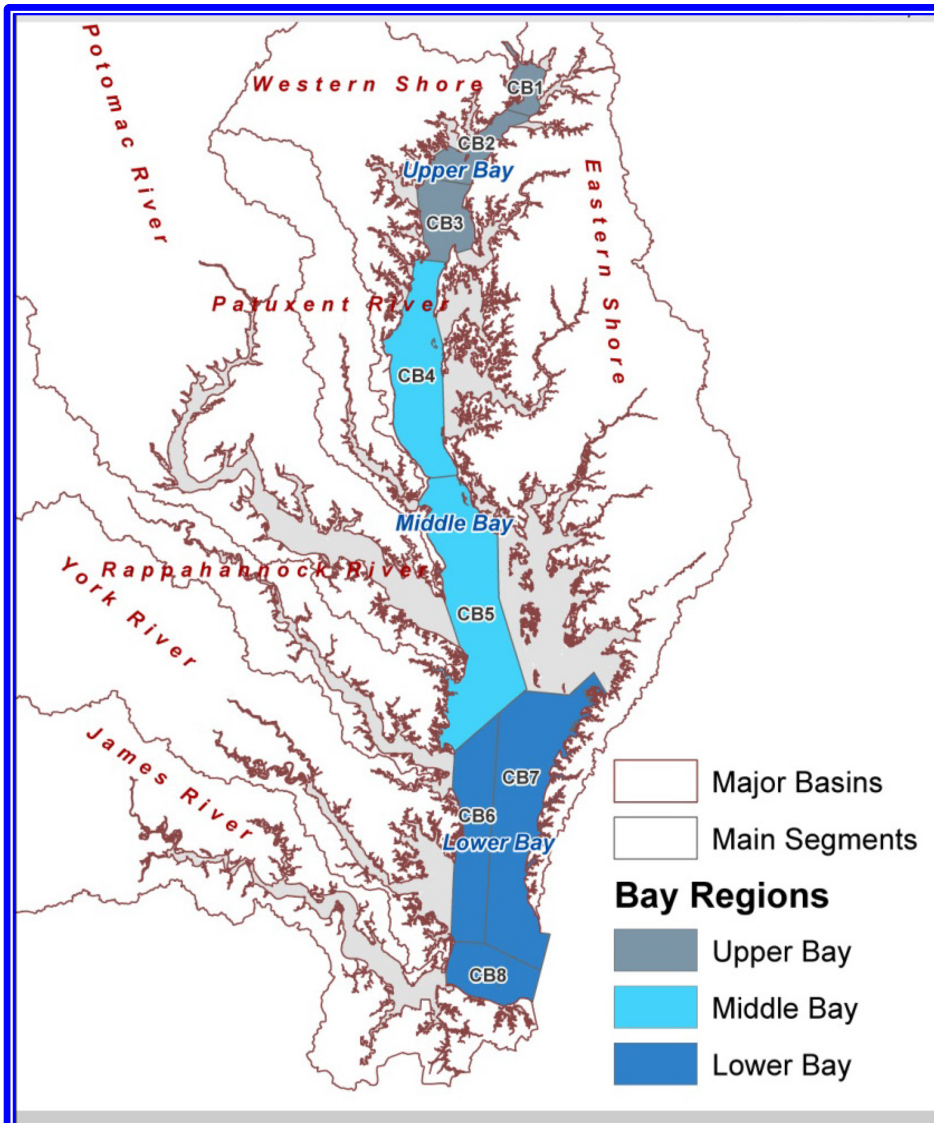
This section presents information on the Bay in terms of upper, middle, and lower Bay, as described in Table K-1 and depicted in Figure K-1. This geographic subdivision correlates with Bay salinity patterns. By this geographic subdivision, the upper Bay lies in Maryland waters, the middle Bay includes waters within Maryland and Virginia, and the lower Bay lies within Virginia.

For the Susquehanna River basin, this section presents information based on whether it applies to the lower Susquehanna River subbasin, other subbasins in the basin, or the entire basin, as appropriate. The lower Susquehanna River subbasin is that region of the Susquehanna River basin downstream of Sunbury, PA, to Havre de Grace, MD, excluding the Juniata River subbasin, as shown in Figure 1-1 of the main report of this assessment.

Table K-1. Bay Regions and Geographic Location

Region	Bay and Tributaries
Upper	North of the Chesapeake Bay Bridge to mouth of the Susquehanna River
Middle	Chesapeake Bay Bridge south to the mouth of the Rappahannock River/Tangier Island
Lower	South of the Rappahannock River mouth/Tangier Island to the mouth of Chesapeake Bay

Figure K-1. Major Regions of the Chesapeake Bay Mainstem



Source: Chesapeake Bay Program.

K.1 PHYSIOGRAPHY AND TOPOGRAPHY

K.1.1 Chesapeake Bay

The Chesapeake Bay is oriented north/south lengthwise with much of its interior remote from oceanic influences or flushing seawater. Table K-2 presents a summary of the Bay's physical characteristics. The Bay possesses a large watershed in relation to its surface water area; for every acre of water, there is more than 14 acres of land – a primary reason for the influence that its land use has on Bay water quality. The Bay is predominantly shallow and flat-floored, but possesses a deep axial channel in the mainstem and then other local deep-channel segments in tributary waterways. Additionally, dredged channels merge with these natural deep areas down the Bay mainstem, as well as on many of the tributary rivers (CBP, 2013).

At its northern end from the mouth of the Susquehanna River to about the area of Spesutie Island/Elk Neck, the Bay possesses a broad area of shallow water called Susquehanna Flats, which is depicted in Figure K-2. This area constitutes the delta of the Susquehanna River, and consists of shoals and sandbars extending for several miles in an east-west and north-south direction (Robertson, 1998). Much of this area is vegetated with submerged aquatic vegetation (SAV). Several deeper water channels extend out from the mouth of the Susquehanna River into the upper Bay and flats. Only the navigation channel extending from Havre de Grace to the south fully connects with waters of equivalent depth in the mainstem Bay. Shallow waters of the Susquehanna River delta in the upper Bay expanded substantially in area following European settlement, and the expansive shallow flats that exist today largely derive from anthropogenic sedimentation (Gottschalk, 1945).

Susquehanna River

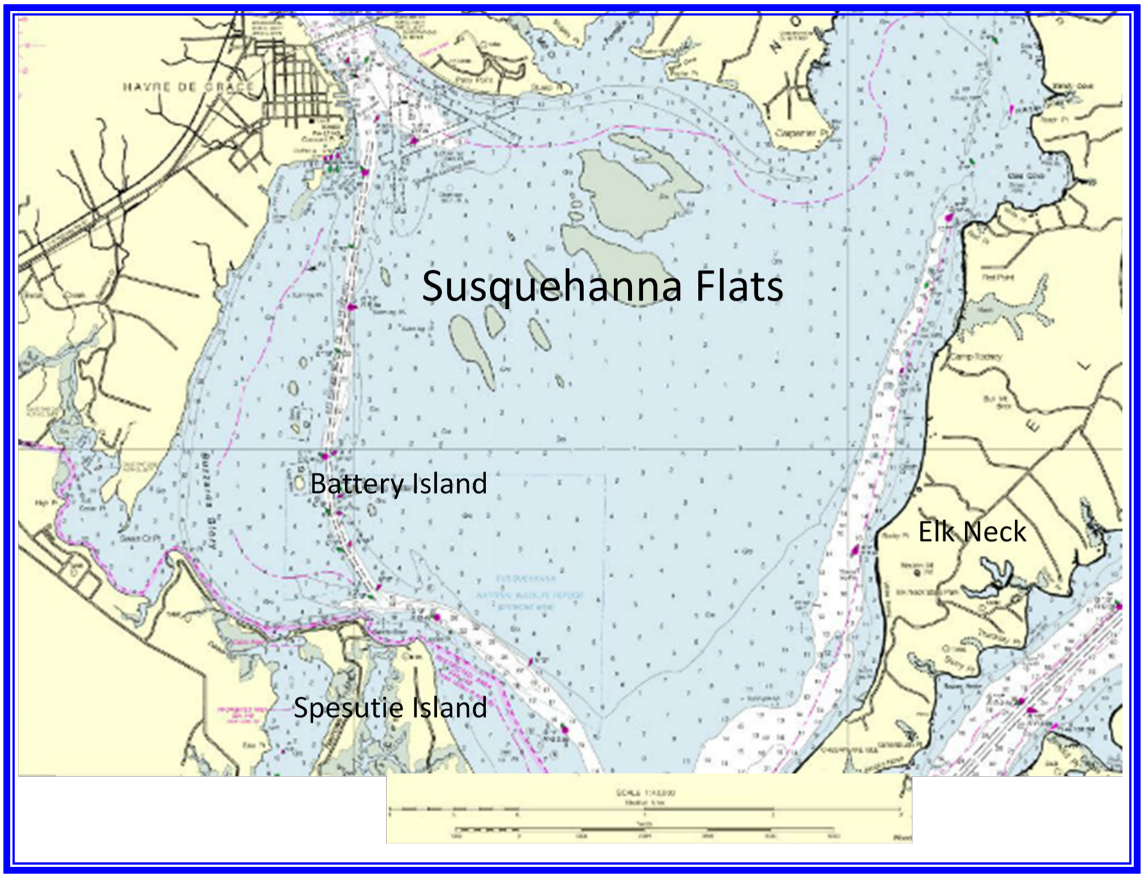
Most of the basin's headwaters originate on the Appalachian Plateau, and the river crosses the Ridge and Valley and Piedmont physiographic provinces before reaching the Bay. The mainstem Susquehanna River has an average gradient of 5 feet per mile, but has many areas of locally steeper gradients through riffles and rapids. The width of the Susquehanna River varies greatly along its length. The river is several hundred feet in width where it enters Pennsylvania from New York,

Table K-2. Chesapeake Bay Metrics

Characteristic	Metric
Length	200 miles
Width	4 miles at Aberdeen, MD, to 30 miles at Cape Charles, VA
Average Depth	21 feet
Maximum Depth	174 feet
Water Surface Area	4,480 square miles
Water Volume	18 trillion gallons
Watershed Area	64,000 square miles

Source: CBP, 2013.

Figure K-2. Susquehanna Flats



<u>Notes</u>: *The light gray-green areas are intertidal; the light blue areas are less than 6 feet deep; and the white areas are greater than 6 feet deep MLLW (mean lower low water).*

Source: NOAA NOS (National Oceanic and Atmospheric Administration National Ocean Service) Nautical Chart 12274.

increasing to about a half mile in width in natural sections of the river below Conowingo Dam. River width is increased greatly in the reservoirs immediately upstream of the Safe Harbor, Holtwood, and Conowingo Dams, to as much as a mile (PFBC, 2011).

K.1.2 <u>Conowingo Reservoir, Lake Aldred, and Lake Clarke</u>

Each of the three lower Susquehanna reservoirs contains islands at its upstream end. Water depths in Lake Clarke and Conowingo Reservoir increase towards the downstream end (where the dam is located). In contrast, Lake Aldred's greatest depths occur in the middle of the lake, and lake depth decreases near the dam.

Lake Clarke is the shallowest, averaging about 15 feet deep. Lake Aldred is the deepest, with greatest depths of 80 to 120 feet. The deepest areas of Conowingo Reservoir are located near the dam, with reservoir depths averaging about 55 feet along the spillway gates and about 70 feet near the turbine gates. Substrate depth near Conowingo Dam is controlled by turbulence from the turbines (Langland and Hainly, 1997).

K.1.3 Upland in Vicinity of Dams

The three dams of interest to this study lie across the Susquehanna River within the valley carved out by the river. Rolling hills of the Piedmont in the vicinity of Conowingo Dam above the river valley range in elevation from 250 to 400 feet maximum. The uplands above the river gorge in the vicinity of Safe Harbor and Holtwood Dams rise to about 750 feet in elevation. The dams flooded lower elevation lands in the river valley.

Conowingo Dam lies about 8 miles upstream of the boundary between the Piedmont and Coastal Plain physiographic provinces on the Susquehanna River. The southern portion of the lower Susquehanna River subbasin lies in the Piedmont physiographic province. The vicinity of the Safe Harbor, Holtwood, and Conowingo Dams is underlain by metamorphosed rock that is resistant to erosion. This material caused the river to carve a deep gorge into the bedrock in a narrow river valley (SRBC, Subbasin Information, 2013). Historic and active quarries produce large topographic depressions in upland areas.

K.2 CLIMATE

The Susquehanna River basin possesses a sub-temperate and humid climate. Continental weather conditions include cold winters with snow events and warm to hot summers. Within the basin, precipitation and temperature are largely influenced by latitude and elevation. Both precipitation and temperature increase from north to south and from west to east. Average annual air temperatures are approximately 44°F in the northern portion of the basin and 53°F in the southern portion. Average annual precipitation in Susquehanna River basin ranges from approximately 33 to 49 inches. An estimated 52 percent of this total precipitation is lost by evapotranspiration; the remaining 48 percent infiltrates to groundwater or results in overland flow and streamflow runoff (SRBC, 2013a).

Across the Susquehanna River basin, precipitation events can be severe, ranging from localized thunderstorms to regional hurricanes. Storms that generate flooding in the study area include northeasters and tropical storms. Northeasters can produce precipitation for a duration of up to several days, and occur most frequently between December and April. Tropical storms produce intense runoff over a shorter period of time, usually occurring between July and October.

Climate trends in the last two decades have shown wetter conditions on average, than in previous decades. Increased precipitation has produced higher annual minimum flows and slightly higher median flows during summer and fall (Najjar et al., 2010). Section 4.1.4 of the main report of this assessment covers the topic of forecast climate change in more detail.

K.3 LAND USE

Land use is the human use of land – the natural and built environment features covering the earth's surface that comprise land cover. As of 2003, 23 percent of the Chesapeake Bay watershed is used for agriculture and almost 12 percent has been developed. Developed lands are concentrated in the vicinity of the cities of Baltimore, Norfolk, Richmond, Harrisburg, Scranton, Binghamton, and Washington, DC, and their respective suburbs and radiating development corridors. Most of the remaining land is forested. Agricultural land use shows a downward trend over the last several decades, while developed land use shows an increasing trend over the same time period (CBP, 2013).

Land use patterns vary greatly within the Susquehanna River watershed, but range generally from primarily forested in the upstream portions of the basin, to primarily agricultural and urban in the downstream portions of the basin. These land use patterns specific to Susquehanna River watershed are illustrated further in Table K-3 and Figure K-3.

Of the six subbasins in the Susquehanna River watershed, the lower Susquehanna subbasin is the most developed. The lower Susquehanna subbasin is a major production area for hydroelectricity by virtue of the geomorphic conditions, history, and proximity to human population favoring its development there. Some of the most productive agricultural lands and largest population centers of the Susquehanna River basin are located in the lower Susquehanna subbasin. Intense agricultural activity occurs in many of the fertile soils throughout the subbasin. Significant urban areas include York, Lancaster, and Harrisburg, all in Pennsylvania (SRBC, 2013a).

Land use affects anthropogenic nutrient inputs to the Bay and streams of the Susquehanna River watershed. Excess nutrient inputs to the Bay are the principal stressor to the Bay ecosystem. Agricultural and urban land uses generate nitrogen and phosphorus nutrient pollution, while forests tend to retain most of the atmospherically deposited pollution they receive. Fertilized soils yield more phosphorus nutrient pollutants when eroded than non-fertilized soils. Even though forest is the largest single land cover in the Bay watershed, runoff from agricultural and urban lands often bypasses forests and is substantial enough to overwhelm the mitigating effects of forests on water quality, and Bay health is compromised as a result.

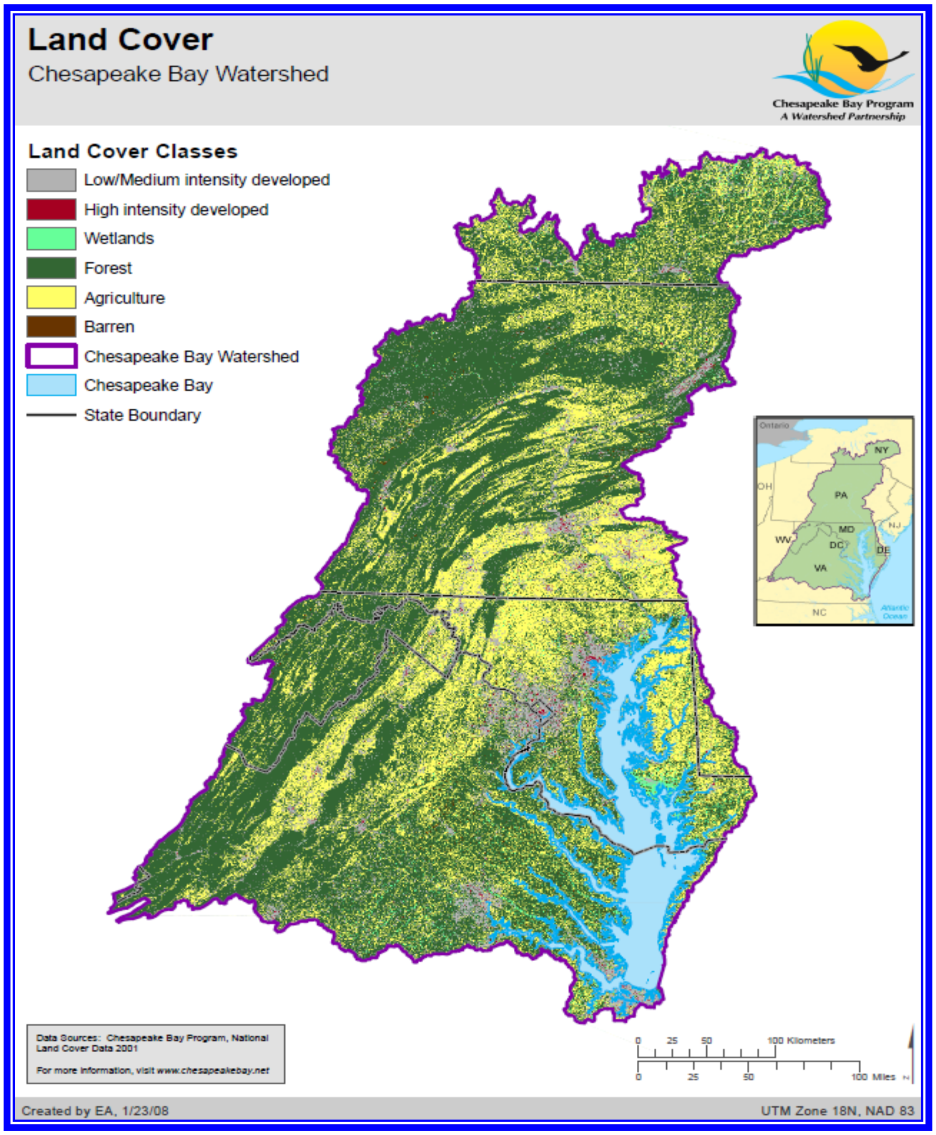
Land use also affects sediment transport processes. Agriculture and timber production can cause increased upland erosion and delivery of sediments to streams. Urbanization promotes increased runoff, which exacerbates streambank and channel erosion. Delivery of excess sediments to the Bay is of concern because of environmental and navigational impacts.

Table K-3. Land Use as Percentage of Basin Area

River Basin	Open Water	Developed	Natural Vegetation	Cultivated	Vegetated Wetland	Barren
Susquehanna	1	4	65	27	1	0
Lower Susquehanna	2	9	45	42	1	0

<u>Notes</u>: Numbers do not add up to 100 percent due to rounding.
Source: USGS, 2006.

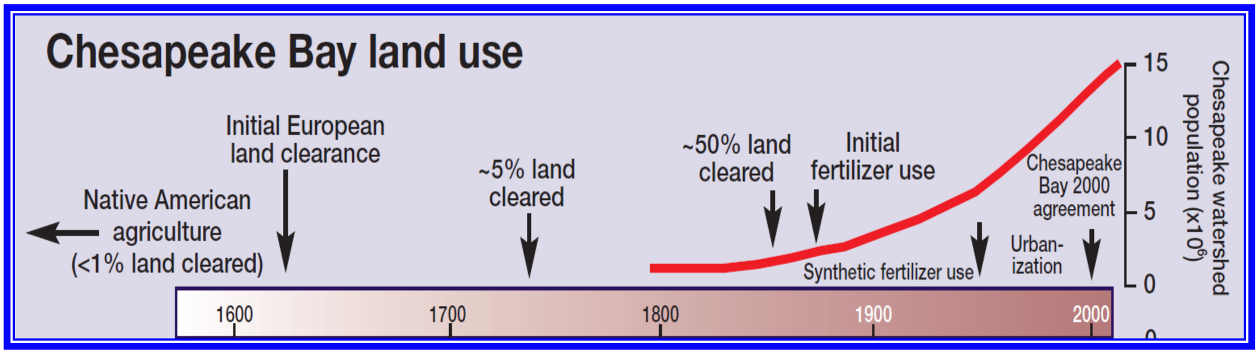
Figure K-3. Land Cover in the Chesapeake Bay Watershed in 2001



Source: Susquehanna River Basin Commission (SRBC).

The Susquehanna River basin was almost entirely forested prior to European settlement. After European settlement, large-scale deforestation and land use conversion occurred due to increased agriculture, energy demands (charcoal made from wood), and industrial logging. Deforestation peaked in the early 1900s when only 30-percent forest cover remained in the basin. Since then, forest cover has increased substantially from natural afforestation of abandoned agricultural lands, as well as the institution of modern forestry and soil conservation practices, which include planting trees (TNC, 2010). Figure K-4 illustrates these land use historical changes.

Figure K-4. Timeline of Land Use Activities from European Settlement to Present



Source: Modified from Willard and Cronin, 2007.

K.4 HYDROLOGY

K.4.1 Bay and Tidal Waters

The Chesapeake Bay is the largest estuary in the United States, and the watershed discharging into the Bay includes parts of six states (Delaware, Maryland, New York, Pennsylvania, Virginia, and West Virginia) and all of the District of Columbia. Approximately one-half of the water in the Chesapeake Bay comes from the 150 major rivers and streams in the Chesapeake drainage basin, with the Susquehanna River being the principal source of fresh water to the Bay. Atlantic Ocean water entering through the Bay mouth comprises the other half (CBP, 2013).

Bay Circulation from Rivers to Ocean

Water circulation in the Bay is primarily driven by the downstream movement of fresh water in from rivers and upstream movement of salt water from the ocean. A gradient of increasing salinity is produced proceeding oceanward. Tides pump water into and out of the Bay. In addition to salinity differences, the earth's rotation affects Bay circulation. Inflowing ocean water hugs the Eastern Shore, while outflowing Bay water hugs the Western Shore. Wind can mix the Bay's waters and occasionally reverse the direction of the flows. Major storm and flood events cause the general circulation patterns to break down (CBP, 2013).

Currents in the open waters of the middle and upper Bay are typically less than about 1 knot (1 knot is 1 nautical mile per hour, or about 1.7 feet per second). Currents through narrows and natural or dredged channels through shallow water can have velocities of up to several feet/second during ebb and flood tides. Currents in the broad shallows of the Susquehanna Flats area of the upper Bay during the SAV-growing season are typically very sluggish, and even during the non-growing season are often less than about 0.3 knots because water movement tends to be slowed by frictional forces in shallow water. Water exchange driven by tides and wind in the vicinity of the Susquehanna Flats is focused into distinct channels. Within these channels, current velocities on the order of up to several feet per second occur. Currents in the upper Bay during major Susquehanna River flow events were modeled for this study; information on this effort is presented in Appendix B of this assessment report.

Water Column

In response to regional climate variation and its relatively shallow water depths, Bay surface water temperatures fluctuate through the year, ranging from about 34°F in winter to 84°F in summer (CBP, 2013). The variation in Bay annual surface water temperatures is among the widest of any estuary in the world (Murdy, 1997, cited in Buccheister et al., 2013) due to the relatively shallow average water depths.

Less dense, fresher surface water layers are seasonally separated from saltier and denser water below by a zone of rapid vertical change in salinity known as the pycnocline (CBP, 2013). The pycnocline plays an important role in Bay water quality acting to prevent deeper water from being reoxygenated from above (Kemp et al., 1999). Pycnocline depth varies in the Bay as a function of several factors. It shows general long-term geographic patterns as summarized in Table K-4, but varies over shorter time periods as a function of precipitation and winds. When substantial freshwater inflow occurs during warm weather months it promotes stronger stratification that can last for extended periods during a year. Conversely, sustained winds in a single direction for several days can cause the pycnocline to tilt, bringing deeper water up into shallows on the margins of the Bay.

Table K-4. Pycnocline Depth by Bay Region

Bay Region	Pycnocline Depth Below Surface (feet)
Upper	9 to 12
Middle	18 to 36
Lower	12 to 30

Source: Kemp et al., 1999.

Because of this partial seasonal separation into layers, or strata, the Bay is classified as a partially stratified estuary. Division of surface from deeper waters varies depending on the season, temperature, precipitation, and winds. In late winter and early spring, melting snow and high streamflow increase the amount of fresh water flowing into the Bay, initiating stratification for the calendar year. During spring and summer, the Bay's surface waters warm more quickly than deep waters, and a pronounced temperature difference forms between surface and bottom waters, strengthening stratification. In autumn, fresher surface waters cool faster than deeper waters and freshwater runoff is at its minimum. The cooler surface water layer sinks and the two layers mix rapidly, aided by winds. During the winter, relatively constant water temperature and salinity occurs from the surface to the bottom (CBP, 2013).

Water Level Variations

Normal water level variations in the Chesapeake Bay are generally dominated by astronomical tides, although wind and freshwater discharge into the Bay have impacts as well. The tidal range is 2.8 feet at the mouth of the Bay at the Atlantic Ocean. Progressing northward up through the lower and middle Bay, the tidal range diminishes, but unevenly. The tidal range is higher at the same latitude along the Eastern Shore, as compared to the Western Shore. In the middle Bay, the tidal range reaches a minimum of 1.0 feet along Maryland's Western Shore, having a range of as much as 1.8 feet on the corresponding Eastern Shore. The tidal range increases somewhat in the upper Bay, and funneling effects increase tidal range in some tidal tributaries. The tidal range at the mouth of the Susquehanna River is 1.7 feet. Strong winds have the ability to force water in and out of the Bay, which can temporarily alter water levels. The most extreme changes in water levels occur due to storm surge caused by northeasters and hurricanes (Boicourt et al., 1999). Sea level in the Bay varies seasonally in accompaniment with prevailing wind patterns; it is typically higher in the summer than in the winter (Boicourt et al., 1999; Zervas, 2001).

K.4.2 Watershed and Surface Nontidal Waters

The Susquehanna River is the longest river located entirely within the U.S. portion of the Atlantic drainage, flowing 444 miles from Otsego Lake, NY, to the Chesapeake Bay. The drainage basin covers 27,510 square miles, including half of the land area of Pennsylvania and portions of New York and Maryland. The basin contains more than 49,000 miles of waterways. There are six major subbasins: the upper Susquehanna, Chemung, middle Susquehanna, West Branch, Juniata, and lower Susquehanna. The Susquehanna watershed encompasses over 43 percent of the Chesapeake Bay's total drainage area. The lower Susquehanna River subbasin contains numerous tributary watersheds, including Conestoga River, Conodoguinet Creek, Swatara Creek, West Conewago Creek, Penns Creek, Codorus Creek, Pequea Creek, Muddy Creek, Octoraro Creek, and Deer Creek (SRBC, 2013a).

The Susquehanna River basin includes free-flowing as well as dammed rivers. The Susquehanna mainstem is a large free-flowing river over most of its length downstream to Safe Harbor Dam in Pennsylvania. Over its free-flowing length, the river has several run-of-river dams (the final being the York Haven Dam about 14 miles downstream of Harrisburg, PA), but these have minimal water storage and do not create upstream reservoirs. Downstream of York Haven Dam, three major hydropower dams impound large segments of the Susquehanna River, creating lake environments: Safe Harbor Dam (Lake Clarke), Holtwood Dam (Lake Aldred), and Conowingo Dam (Conowingo Reservoir or Pond).

Non-tidal streamflow varies seasonally. Winter months have relatively high-flows due to low evapotranspiration and snowmelt delivering water to streams in moderately high pulse events. Streamflows peak during spring months as snowmelt increases. High pulse events are highest in magnitude and frequency during this season. More than 50 percent of the mean annual flow is delivered between March and May. Flows are lowest between July and October, when evapotranspiration rates are highest. The magnitude of median daily streamflow is significantly higher (approximately 10 times) in spring than in the summer and fall when flows are at their lowest because of evapotranspiration (TNC, 2010). During extreme flood events, strong river currents extend downstream into the upper Bay.

During the period 1985 to 2010, USGS determined that the annual average flow in the Susquehanna River near Conowingo, MD, ranged from a minimum of 23,560 cfs (cubic feet per second) to a maximum of 65,540 cfs. Median annual average flow over this time period was 35,575 cfs (Zhang et al., 2013). Droughts and storms produced substantially lesser and greater flows, respectively, over that time period, however.

USACE and SRBC recognize the Susquehanna River basin as one of the most flood-prone basins in the United States from a human impacts perspective. Flow conditions can vary substantially from month to month; floods and droughts sometimes occur in the same year. Floods can scour large volumes from the river bed and banks, and convey large quantities of nutrients and sediment downstream. Floods can occur in any month, but are most frequent in the spring months in response to rain on snowmelt events or rain on saturated soils. Floods in winter months occur typically in response to rain on snow events, possibly combined with ice jams (as in January 1996). Coastal storms or severe hurricanes typically cause summer floods (Shultz, 1999; SRBC, 2013a). Hurricane Agnes (June 1972) was the most severe flood in recent history. Flow was nearly 1 million cubic feet per second (cfs) at the Harrisburg gage, which is more than 60 times median daily streamflow (TNC, 2010; SRBC, 2013a). Together, Hurricane Irene and Tropical Storm Lee contributed more than 2 feet of rain on much of the watershed between August 27 and September 8, 2011, resulting in flows peaking at 778,000 cfs, 41 times the normal September flow of 18,800 cfs. This is the third highest flow measured at Conowingo Dam since recordkeeping began (MDNR, 2012). Although there are numerous flood control reservoirs in the basin, the cumulative hydrologic impact of these structures on the magnitude of flood events reaching the three lower dams is minimal.

The flows and water levels of the lower Susquehanna River are affected by four conventional hydroelectric stations (York Haven, Safe Harbor, Holtwood, and Conowingo) and one pumped storage project (Muddy Run). River flows in the lower basin are highly variable during any given year. Flows and water levels below each hydroelectric station fluctuate considerably based primarily on natural flow variations resulting from precipitation events, but also from electric power demand, water withdrawal, recreational use, hydropower project-related operational constraints, and point and nonpoint source discharges (URS and Gomez and Sullivan, 2012a).

Conowingo Reservoir, Lake Aldred, and Lake Clarke

Conowingo Reservoir straddles the boundary between Pennsylvania and Maryland, whereas Lakes Aldred and Clarke lie entirely in Pennsylvania. Table K-5 presents information on the physical characteristics of the three reservoirs.

Conowingo Reservoir is occasionally subject to strong winds during storm events that may result in wind-generated wave action along shorelines of the reservoir, islands, and tributaries. These winds in combination with incoming river flows and outgoing dam flows contribute to vertical circulation in the reservoir (Normandeau Associates and GSE, 2012).

Table K-5. Physical Characteristics of Manmade Water Bodies on Lower Susquehanna River

Dam	Water Body	Width Range (miles)		Channel Length (miles)
		Minimum	Maximum	
Conowingo	Conowingo Reservoir	0.3	1.3	14.7
Holtwood	Lake Aldred	0.2	1.0	8.1
Safe Harbor	Lake Clarke	0.6	1.7	9.3

Source: Hainly et al., 1995.

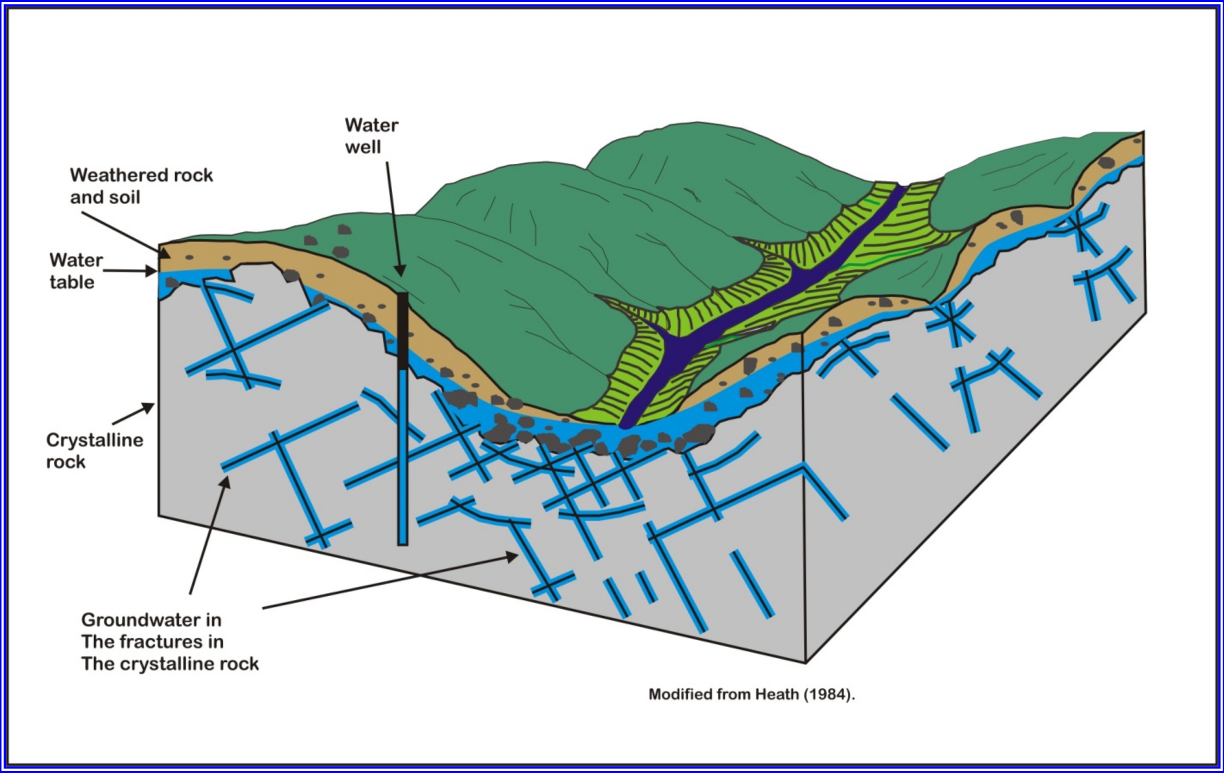
Environmental History

Changes in forest cover directly influenced historic hydrology. Following European settlement, as a consequence of reduced forest cover, streams and rivers had higher base flows during the summer and fall months. Base flows were higher because fewer trees resulted in a decrease in evapotranspiration during the growing season. Periods of low forest cover are also associated with flashier hydrographs (TNC, 2010). Water yield and sediment load from the landscape increased following European settlement with denudation from deforestation and farming (Seagle et al., 1999).

K.4.3 Groundwater

Groundwater in the Piedmont occurs at the base of saprolite (decomposed rock that has weathered in place) and in underlying bedrock. Generally, most groundwater in the crystalline rock of the Maryland Piedmont is contained in the saprolite; there is very little storage capacity in the rocks themselves, as depicted in Figure K-5. Groundwater in bedrock occurs in fluid-filled fractures in the rock, including joints and faults. These features may be subsequently expanded through weathering of the bedrock. Joints and fractures are recharged by water from the overlying saprolite (Nutter and Otton, 1969). Groundwater in Harford and Cecil Counties, MD, is typically somewhat acidic, soft to moderately hard, and may occasionally have high iron concentrations (Nutter, 1977; Otton et al., 1988). Low amounts of total dissolved solids are also common in the area's groundwater.

Figure K-5. Typical Piedmont Hydrogeologic Condition in the Chesapeake Bay Watershed



K.5 WATER QUALITY

Water quality considers chemical, physical, and biological characteristics of water. Of principal interest to this study are water quality characteristics affecting aquatic life. These include salinity, temperature, dissolved oxygen (DO), water clarity, and nutrient content. Natural physical characteristics of waterways, as well as effects of human activities, control water quality. Section 2.1 of the main report of this assessment provides information on the Clean Water Act as it relates to water quality.

K.5.1 Chesapeake Bay

Salinity

Salinity is an important factor controlling the distribution of Bay plants and animals. Salinity is the concentration of dissolved solids in water and is often discussed in terms of parts per thousand (ppt). In Maryland, Bay surface waters range from fresh in headwaters of large tidal tributaries to a maximum of about 18 parts per thousand (ppt) in the middle Bay along the Virginia border, as illustrated in Figure K-6. Salinity varies during the year, with highest salinities occurring in summer and fall and lowest salinity in winter and spring. Table K-6 provides water salinities and their classifications. Waters with 0.5 ppt to 30 ppt are described as brackish, while concentrations less than 0.5 ppt are considered fresh (CBP, 2013). Bay salinity affects other water quality parameters by controlling microbial activity and processes in the water column and sediment.

Seasonal stratification produces vertical salinity differences in warm weather months in the middle and lower Bay. Waters below the pycnocline may be several to more than 10 ppt greater in salinity than surface waters in warm water conditions. Vertical salinity differences are greatest when substantial freshwater inflow occurs during warm weather months (Maryland BayStat, 2013).

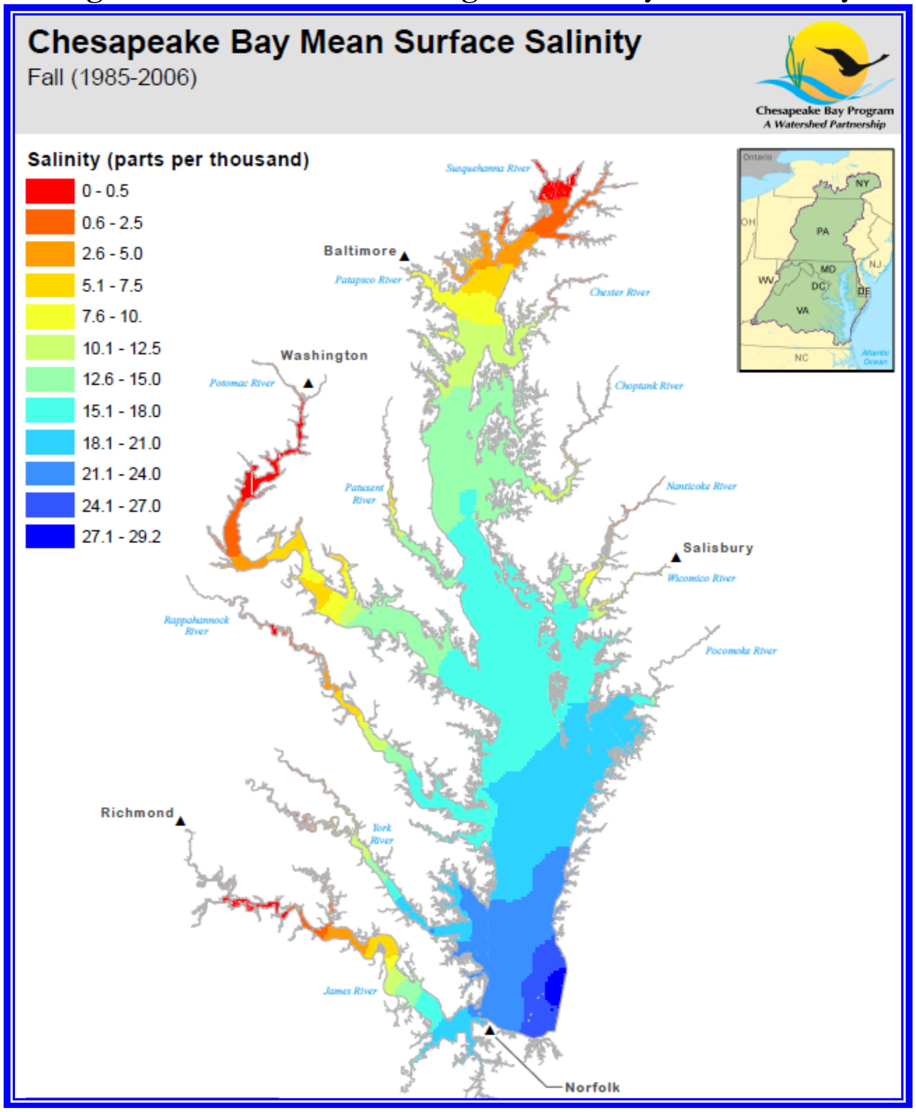
The Susquehanna River provides about half of the Bay's freshwater inflow. The relative importance of the Susquehanna River as a source of freshwater inflow becomes greater progressing northward in the Bay. The Susquehanna River provides 87 percent of freshwater inflow for the portion of the Bay north of the Potomac River (Boicourt et al., 1999).

Table K-6. Water Salinity Classification and General Occurrence in Bay Mainstem

Water Salinity (ppt)	Venice System Salinity Classification	Common Term	Bay Region Generally Occurring In
0 to 0.5	Fresh	Fresh	Upper
0.5 to 5	Oligohaline	Brackish	Upper
5 to 18	Mesohaline	Brackish	Middle
18 to 30	Polyhaline	Brackish	Lower

Classification Source: Cowardin et al., 1979.

Figure K-6. Maximum Average Annual Bay Water Salinity

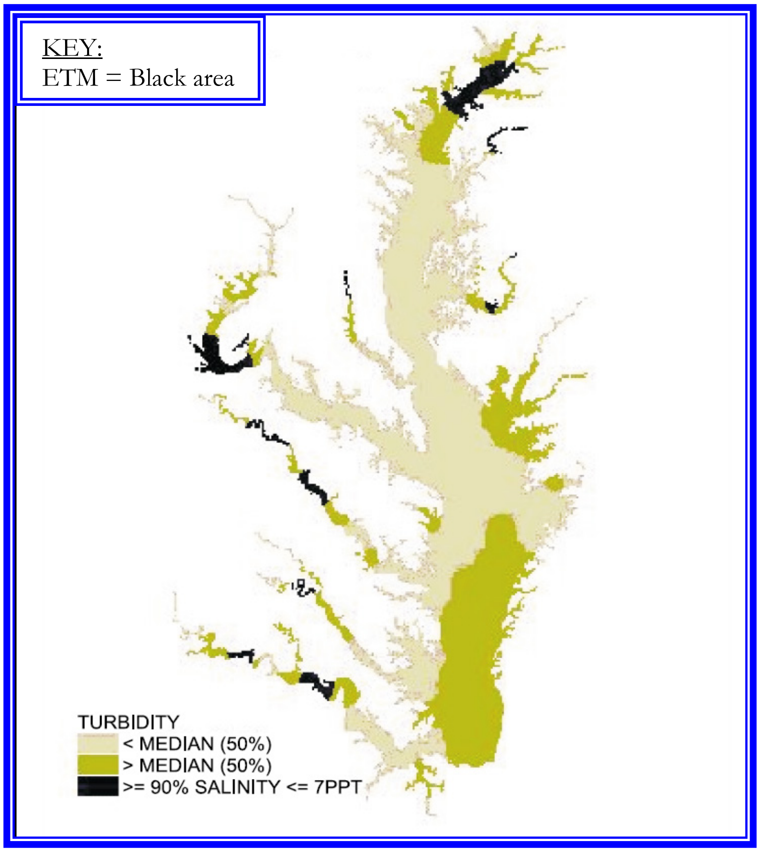


Source: Chesapeake Bay Program.

Estuarine Turbidity Maxima (ETM)

The ETM zone is an area of high concentrations of suspended sediment and reduced light penetration into the water column. Each of the Bay's major tidal tributary systems has an ETM zone near the upstream limit of saltwater intrusion, as shown in Figure K-7. The Susquehanna River ETM zone occurs in the upper Bay mainstem. The position of the ETMs changes seasonally and with large freshwater flow events from storms. The ETMs extend further downstream into the Bay during times of year when lower salinities occur and following major storm events, and further upstream when seasonally higher salinities occur. The ETM zone is produced by a complex interaction of physical and biological processes, including freshwater inflow, tidal and wave-driven currents, gravitational circulation, particle flocculation, sediment deposition and resuspension, and biogeochemical reactions.

Figure K-7. General Locations of ETMs



However, tidal resuspension and transport are primarily responsible for the maintenance of the ETM zone at approximately the limit of saltwater intrusion. Generally, fine-grained river-borne sediment in the ETM zones is exported further downstream into the main Bay only during extreme hydrologic events.

The mainstem Bay ETM zone occurs in the upper Bay; in this region, most of the fine-grained particulate matter from the Susquehanna River is trapped, deposited, and sometimes resuspended and redeposited. The mainstem ETM zone acts as a barrier under normal conditions for southward sediment transport of material introduced into the Bay from the Susquehanna River (USGS, 2003).

Eutrophication

Anthropogenic nitrogen and phosphorus nutrient pollution delivered to the Bay exceeds the Bay ecosystem's capability to process it without ill effect. The Bay's physical character and circulation patterns tend to retain water-borne materials, thus exacerbating the effect of anthropogenic pollution. The Bay's natural capability to buffer the incoming nutrient loads are governed by seasonal stratification and limited tidal mixing rate (Bever et al., 2013). Anthropogenic nutrient pollution to the Bay derives from agricultural runoff and discharges, wastewater treatment plant discharges, urban and suburban runoff, septic tank discharges, and atmospheric deposition of exhaust (CBP, 2013).

Water bodies possess a range of nutrient availability conditions. Water bodies possessing ample or excessive nutrients whether from natural or human sources are said to be eutrophic. The Bay became eutrophic because of inputs of large quantities of anthropogenic nutrients. Excess nutrients in the water column from human sources fuel the growth of excess phytoplankton. Zooplankton, oysters, menhaden, and other filter feeders eat a portion of the excess algae, but much of it does not end up being consumed by these organisms. The leftover algae die and sink to the Bay's bottom, where bacteria decompose it, releasing nutrients back into the water, fueling further algal growth. During this process in warm weather months, bacteria consume DO until there is little or none left in deeper bottom waters (CBP, 2013). Within the Bay, nitrogen is the principal limiting-nutrient regulating phytoplankton. The limiting nutrient is that nutrient available in lowest supply in proportion to biological demand. However, phosphorus is the limiting nutrient for phytoplankton growth in low salinity Bay waters in spring. Phosphorus is typically the limiting nutrient in freshwater ecosystems (Harding et al., 1999; CBP, 2013).

Oftentimes, pollution analyses consider total nitrogen and phosphorus contained in sediments and the water column. Nitrogen and phosphorus actually occur in a number of different forms in the environment that differ in their biological availability and effects on water quality. Total measurements lump together these different forms in a manner that makes interpreting their environmental effect difficult.

Total nitrogen (TN) includes nitrate, nitrite, ammonia, and organic nitrogen. As typically measured in labs and for the purposes of this section, ammonia also includes ammonium. Nitrate is the primary form of nitrogen in dissolved form in surface waters. Ammonia is a dissolved form of nitrogen that occurs in surface waters less commonly than nitrate. However, ammonia is the dominant dissolved nitrogen form in deeper waters during warm months. Nitrite is generally unstable in surface water and contributes little to TN for most times and places. Organic nitrogen (mostly from plant material, but also including organic contaminants) occurs in both particulate and dissolved forms, and can constitute a substantial portion of the TN in surface waters. However, it is typically of limited bioavailability, and often of minimal importance with regard to water quality. Conversely, nitrate and ammonia are biologically available and their concentration is very important for water quality (USGS, 1999; Friedrichs et al, 2014).

Total phosphorus (TP) includes phosphates, organic phosphorus (mostly from plant material), and other phosphorus forms. Phosphates and organic phosphorus are the main components of TP. Phosphates tend to attach to soil and sediment where their bioavailability varies as a function of environmental conditions. Dissolved phosphate is readily bioavailable to aquatic plant life, and consequently promotes eutrophication (USGS, 1999). Phosphorus binds to river sediments and is delivered to the Bay with sediment.

Nutrients contained in Bay bottom sediments are re-released into the water column seasonally, and these regenerated nutrients could provide a substantial portion of the nutrients required by phytoplankton, particularly in the middle Bay. Thus, nutrients mobilized from bottom sediments stimulate algal production and play an important role in Bay eutrophication. Phosphate and ammonium are typically released from sediments under anoxic conditions, with releases being relatively small in sediments in oxygenated waters. Nutrient fluxes from the sediment into the water column have been found to be greatest in the middle Bay, intermediate in the lower Bay, and least in the upper Bay (Cowan and Boynton, 1996).

Excess nutrients in the water column produce a soup of live and dead organic material; this soup impedes settling of sediments and the combined organic material and sediments degrade water clarity and create turbid conditions (CBP STAC, 2007). Suspended sediments in the water column normally derive from wave and tidal energy resuspending bottom sediments, as well as shoreline erosion. Generally, wave energies can move bottom sediments down to about a 6-foot depth, generating suspended sediments in the water column throughout Bay shallows (USACE, 2011). Following major storm events, watershed runoff can contribute suspended sediments that remain in the water column for periods of days (Gallegos et al., 2005; CBP STAC, 2007). Loss of oysters from the Bay has greatly reduced the Bay's natural filtering capability (Newell, 1988), and the loss of SAV has rendered greater shallow water area vulnerable to wave resuspension of bottom materials during the growing season.

Conveyance of Excess Nutrients Into Chesapeake Bay

Nutrient pollutants entering Chesapeake Bay originate from point and non-point sources. Point source pollutants originate from a specific, identifiable physical location such as from the end of a pipe or discharge channel. Point-source nutrients entering the Bay originate primarily from wastewater treatment plants, although some come from industries. Non-point source pollutants do not originate from an identifiable, specific physical location. Non-point source pollutants include nutrients that run off croplands, feedlots, lawns, parking lots, and streets. Nutrients that enter waterways via air pollution, groundwater, or septic systems are also classified as non-point sources (CBP, 2013).

Nutrient transport in rivers is usually considered in two fractions – that portion conveyed in dissolved form and that portion carried as particulates. Particulates include mineral sediments and plant debris. During downstream transport, bacteria and other stream organisms take up dissolved nutrients and convert them to organic form. When organisms containing these nutrients die, the nutrients return to the water in inorganic form, only to be taken up yet again by other organisms. This cycle is referred to as nutrient spiraling (Schlesinger, 1991).

Nutrient pollutants delivered to the Bay vary year to year as a function of amount and timing of precipitation. Wet years deliver greater nutrient pollution to the Bay than dry years. For example, the amounts of nitrogen and phosphorus transported during Tropical Storm (TS) Lee (a September 2011 high-flow event) were very large compared to long-term averages for the Susquehanna River over the past 34 years. However, this difference is less pronounced for nitrogen than it is for phosphorus, because on average, a large part of the nitrogen flux is delivered in dissolved form. Specifically, the amounts transported during the TS Lee event were estimated to be 42,000 tons of nitrogen and 10,600 tons of phosphorus. For comparison, the estimates of the averages for the entire period from 1978 to 2011 were 71,000 tons per year for nitrogen and 3,300 tons per year for phosphorus (Hirsch, 2012).

Nitrogen pollutants originate primarily from agriculture; urban runoff, wastewater releases, and atmospheric deposition are also substantial sources (CBP, 2013). Nitrogen pollution moves through the watershed in many forms and through many pathways from its sources (fertilizer, manure, atmospheric deposition, or point source discharges) to receiving waters. A portion of transport of nitrogen in the watershed occurs underground, as dissolved nitrate is moved through the soil by infiltration and into slow-moving aquifers. Transport also occurs through surface runoff in dissolved and particulate forms and associated episodic cycles of stream and river channel deposition, scour, and redeposition. Nitrogen pollutant delivery to the Bay differs from phosphorus pollutant delivery in that minimal phosphorus is transported to the Bay through the atmosphere and groundwater (CBP STAC, 2013).

Phosphorus pollutants originate primarily from agriculture; urban runoff and wastewater releases are also substantial sources (CBP, 2013). Nonpoint source phosphorus is strongly correlated to watershed and stream channel erosion rates because phosphorus is typically bound to sediments. Erosion rates in turn vary as a function of streamflow (precipitation) and land use. Soils to which phosphorus has been added for fertilizer yield more phosphorus when eroded than other soils (Najjar et al., 2010). Phosphorus transport to the Bay occurs primarily during storm events that produce runoff and cause phosphorus bound to sediment to be carried into streams where they can be desorbed through biogeochemical processes or deposited, only to be resuspended and redeposited by subsequent storm events (CBP STAC, 2013).

Phosphorus is conveyed in rivers as phosphate adsorbed to sediment particles. It is also conveyed bound to calcium, and as organic particles. The processes by which phosphorus is released from sediments is complicated and affected by biological as well as physical chemical processes. In oxygenated fresh water, phosphorus adsorbed to fine-grained sediments remains bound and has limited bioavailability. Under anoxic or hypoxic freshwater conditions, phosphorus becomes more bioavailable, but phosphorus rebinds to sediments if oxygen is again present. In the Bay's saltwater environment, biogeochemical conditions change causing phosphorus bioavailability to differ from in freshwater. As salinities increase above about 3 to 4 ppt, phosphorus bound to sediments is increasingly released and becomes mobile and bioavailable to living resources (Jordan et al., 2008; Hartzell and Jordan, 2012). The uppermost Bay remains generally below salinities of 3 ppt all year, which tends to favor phosphorus immobilization in sediments, but otherwise the Bay is salty enough to allow phosphorus release from sediments (CBP, 2013).

Monitoring of nutrients in the Susquehanna River has shown that the flow-adjusted annual concentrations of TN, TP, and suspended sediment delivered to the dams have been generally decreasing since the mid-1980s. With corrections to account for year-to-year variation in river flows, over the 20-year period from 1990 to 2010, TN and sediment loads delivered to the Bay from the Susquehanna River showed statistically significant declines of 26 percent and 17 percent, respectively. TP loads declined by 7% over this time period, but the trend was not statistically significant (Langland et al., 2012). Environmental management measures in the watershed contributed to this decrease. One study has indicated that loads of particulate nitrogen, particulate phosphorus, and suspended sediment from the reservoir system of the lower dams to the Chesapeake Bay are increasing, and attributes this, in part, to decreasing trapping capacity of Conowingo Reservoir (Zhang et al., 2013).

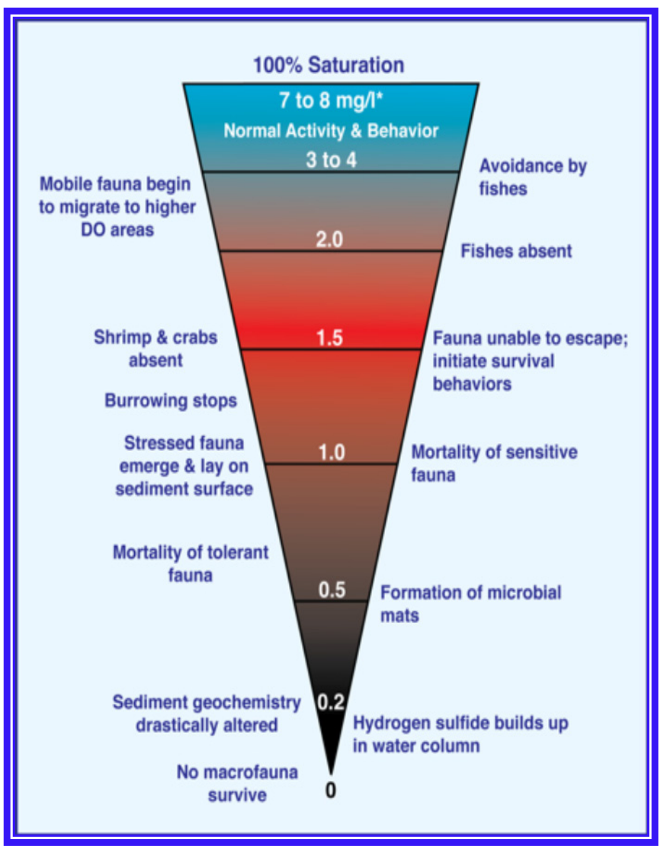
Dissolved Oxygen (DO)

Dissolved oxygen (DO) is critical to aquatic life in the Chesapeake Bay. Aquatic creatures, other than some microbes, need oxygen to survive. DO concentrations vary depending on location and time of year, based on temperature, salinity, nutrient levels, and biological uptake. Many factors interact to determine the DO content of Chesapeake Bay tidal waters. Nutrient loading, water column stratification, wind and tidal mixing, and water temperatures are important factors (CBP, 2013).

DO concentrations of 5 mg/L (milligrams per liter) or greater allow Bay aquatic life to thrive. At DO levels below 2 mg/L, the water is considered hypoxic, and when DO drops below 0.2 mg/L, it is considered anoxic. DO levels tolerable by aquatic life vary, with some organisms being more tolerant of low DO than others, as depicted in Figure K-8. Non-mobile and poorly mobile organisms, such as oysters, clams, benthic invertebrates such as some worms, are unable to relocate when low DO conditions occur. Mobile organisms, such as fish and crabs, can avoid low DO waters. However, chronically low levels of DO in the Chesapeake Bay reduce availability of inhabitable deep-channel and deep open-water habitat on a large scale. Availability of associated forage food for demersal (bottom-dwelling) fish species is also consequently reduced substantially, as illustrated in Figure K-9. Hypoxia (low oxygen) consequently reduces the numbers and catch of demersal fish species (Buchheister et al., 2013).

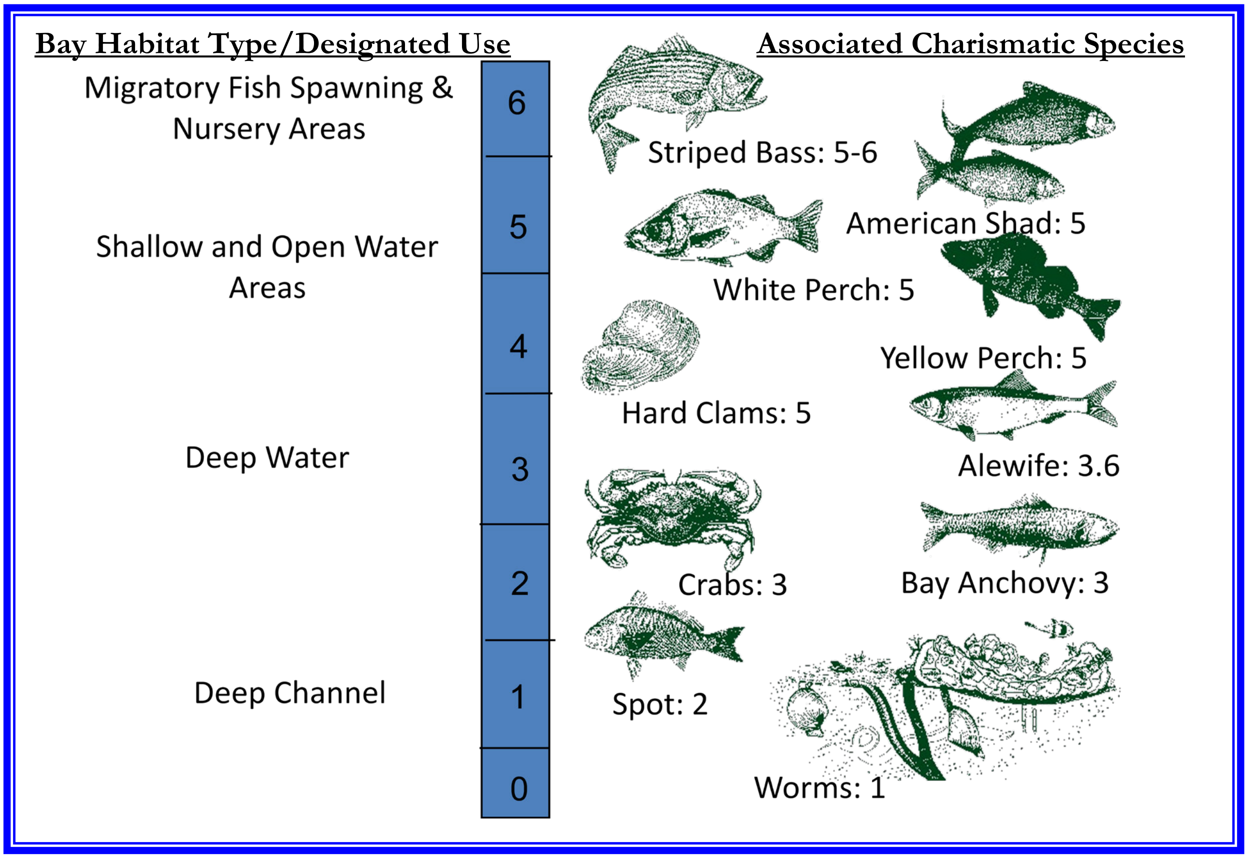
The upper Bay mainstem is not generally influenced by hypoxia; waters tend to remain oxygenated. Conversely, hypoxia typically impacts the middle and lower Bay mainstem. The pycnocline is typically the boundary between oxic (fully oxygenated) above and hypoxic or anoxic waters below in warm weather months. Oxygen consumed by respiration (principally by bacteria) below the pycnocline is only poorly replaced by oxygen from the atmosphere and photosynthesis above the pycnocline. More severe near-absence of oxygen conditions (anoxia) occur perennially in the deep channel (below 39 feet in depth) in the middle Bay and in certain bowl-shaped areas of the Bay's bottom (CBP, 2013; Versar, 2013).

Figure K-8. Dissolved Oxygen Content of Bay Water and Effects on Living Things



Source: http://www.vims.edu/newsandevents/topstories/dead_zone_volume.php.

Figure K-9. Minimum Oxygen Survival Requirements (mg/L)



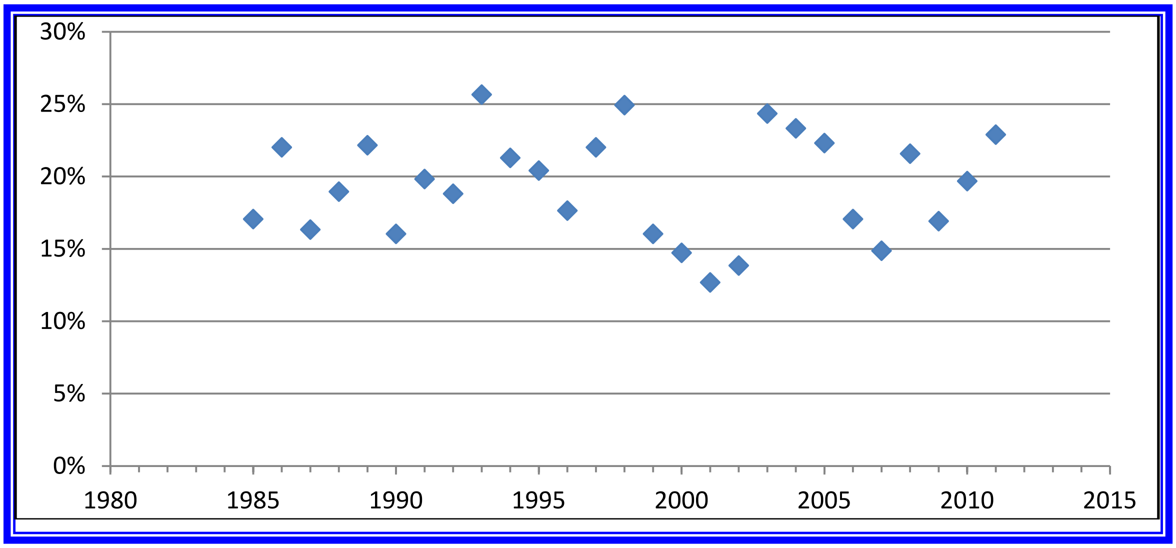
Source: Batiuk et al., 2009.

Hypoxia in the Bay generally begins in late spring to early summer (May to June), is most extreme in July, and ends by October. Over the period 1985 to 2009, hypoxic volumes showed a trend of increasing in early summer but decreasing in later summer (Murphy et al., 2011). Hypoxic conditions in the Bay vary from year to year. Bever et al. (2013) determined that from 1985 to 2011, the maximum percentage of Bay volume that was hypoxic ranged from 13 to 26 percent. Over this time period, 20 percent was the median annual maximum percentage of Bay hypoxic volume; Figure K-10 displays a time series of the annual hypoxic percentages.

Historic Water Quality

Investigations of bottom sediments have determined that some natural oxygen depletion in deeper waters of the Bay occurred in the 17th through 19th centuries driven by variations in river discharge, with low oxygen being associated with wet periods and high oxygen being associated with drought periods. Effects of European settlement were negligible at this time. Initial anthropogenic eutrophication of Chesapeake Bay began about 200 years ago. Signs of increased phytoplankton and decreased water clarity first appeared about 100 years ago. Anthropogenic nutrient loading rates increased markedly following World War II, concomitant with the pronounced increase in the use of artificial fertilizers. Severe, recurring deep-water hypoxia first became evident in the 1950s. The

Figure K-10. Annual Maximum Percent of Bay Water Volume Hypoxic



Hypoxia is <2.0 mg/L. Source: Bever et al., 2013.

resultant massive dead zone that occurs every year in warm weather months is unprecedented in the geologic and environmental history of the Chesapeake Bay ecosystem (Karlsen et al., 2000; Boesch, 2002; Kemp et al., 2005). Nitrogen inputs are currently entering the Bay at about 7 times greater than natural levels (Howarth et al., 2002). Phosphorus inputs from anthropogenic sources are entering the Bay at a rate about 16.5 times greater than natural levels (Seagle et al., 1999).

Conversely, the Bay was actually healthier at the times of highest known sediment inputs in the late 19th and early 20th centuries than at present. Although soil erosion increased nutrient inputs above natural rates, the nutrient input rates were substantially less than that provided from other anthropogenic sources following World War II, as described above.

K.5.2 Susquehanna River and Conowingo Reservoir

The Susquehanna River is a principal source of nutrients delivered to the Bay. Total phosphorus is one of the parameters that most often exceed standards. Excess phosphorus derives from fertilizer and animal and human waste. SRBC employs water quality standards for physiochemical and biological parameters to assess water quality of the Susquehanna River and its major tributary rivers through their Large Rivers Monitoring Program. Through the program's history, the Susquehanna River's documented water quality has been stable and fairly good with only very few limit violations, primarily temperature and total sodium. Instantaneous DO concentrations in river margin habitat of the Susquehanna River do fall below the 4.0 mg/L minimum water quality standard established by PADEP on occasion, while adjacent main channel concentrations did not fall below the minimum standard (PFBC, 2011).

Conowingo Reservoir water temperatures range from about 59°F to 91°F during the period of April through October. The reservoir remains relatively constant in temperature vertically for much of the year, but reservoir water can be up to several degrees cooler at the bottom than at the surface for brief periods. DO in Conowingo Reservoir becomes depleted in waters of the reservoir greater than 25-foot depth under conditions of low river inflow (less than 20,000 cfs) and warmwater temperatures (greater than 75°F). Reservoir DO levels occasionally drop below 2 mg/L (Normandeau Associates and GSE, 2012).

USGS collected and analyzed water samples of Conowingo Reservoir outflow during high-flow events during water year 2011 (which ran from October 1, 2010 to September 30, 2011) for this assessment. Appendix F presents a report on that effort.

K.6 SEDIMENTS AND GEOLOGY

K.6.1 Chesapeake Bay

Geologic Evolution

The Chesapeake Bay formed as the sea level rose over the last 10,000 years following the last Ice Age, and drowned what was formerly part of the Susquehanna River valley (Colman et al., 2002). The Bay continues to grow in area by several hundred acres per year as a consequence of shoreline erosion and land inundation driven by continuing sea-level rise (USACE, 2011).

Bay Bottom Materials and Processes

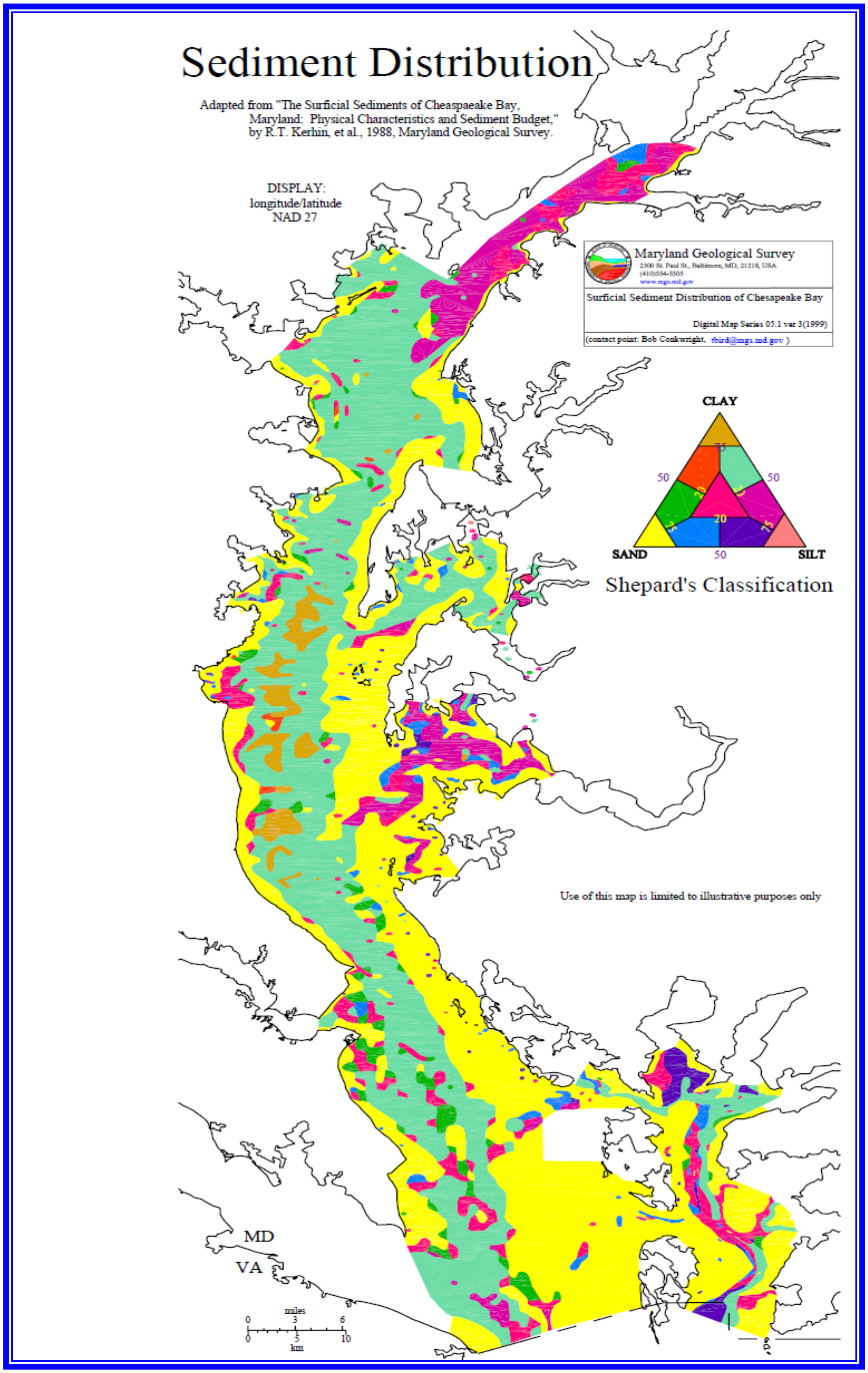
The Bay bottom consists predominantly of unconsolidated (i.e., not turned to rock) sediments. Shallow waters of the Bay out to about 15-foot depth have sands. Surficial bottom sediment in deeper waters of the Bay consists predominantly of silty clay as shown in Figure K-11. In the ETM of the upper Bay, the bottom is predominantly clayey silt (MDNR, 1988).

Surficial bottom sediments in the Susquehanna Flats consist of sand with a general fining trend away from the mouth of the Susquehanna River. Abundant coal occurs in Susquehanna Flats sediments, which were transported into the Bay from coal mining in the Susquehanna basin (Robertson, 1998). The Susquehanna Flats sediments are predominantly sand presumably because wave action at shallow depths removes finer sediments.

Investigations conducted for this study characterized bottom sediments of the uppermost Bay in 2012 where bottom sediment is not mapped in Figure K-11. Findings of these investigations are presented in Appendix E of this assessment report.

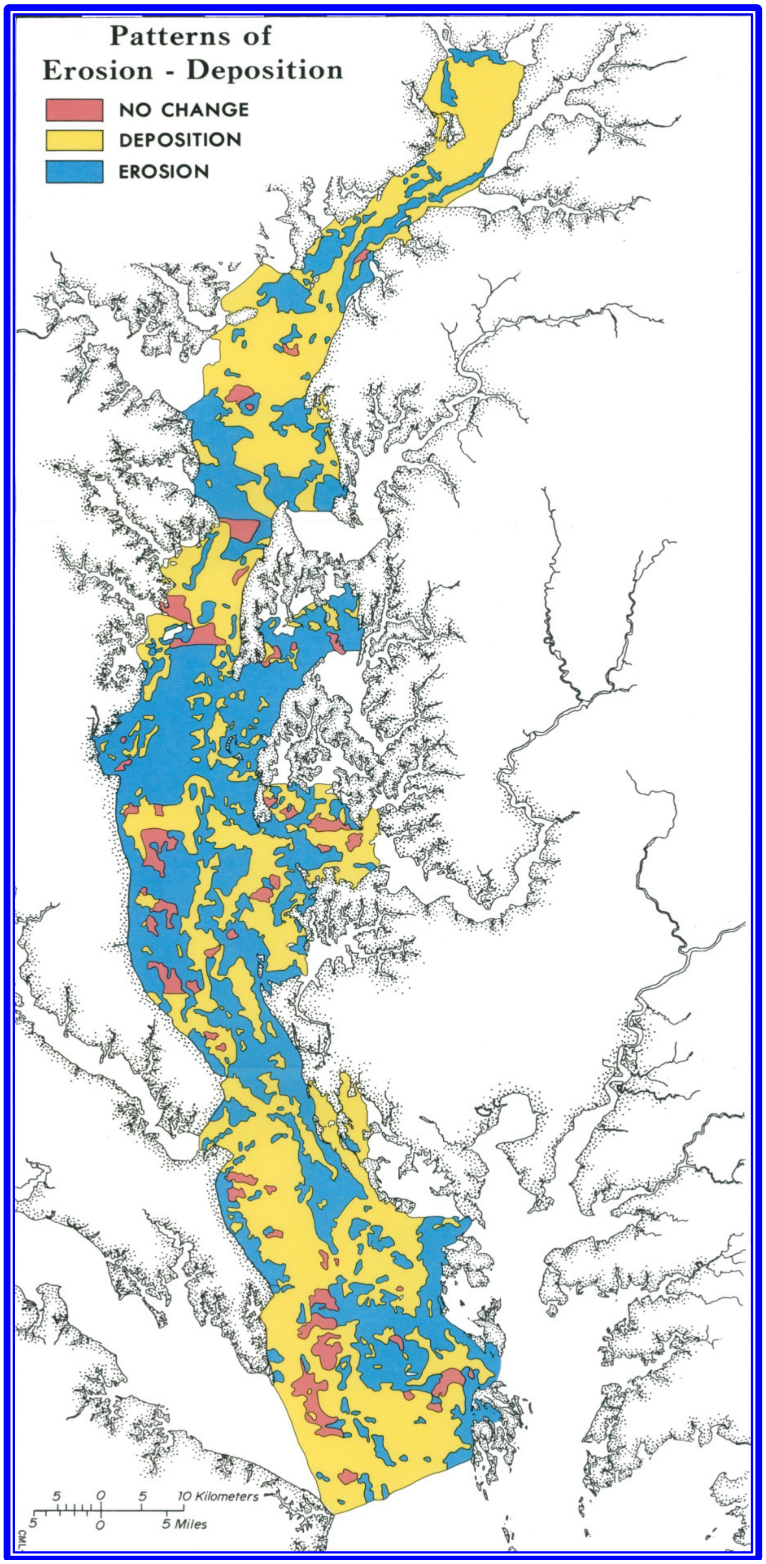
Recent sediments on the Bay bottom derive from upland (watershed) and shoreline erosion, in-Bay biological production, and atmospheric sources (dust), as well as the Atlantic Ocean in the lower Bay (Colman et al., 2002). However, in substantial areas of the Bay, erosion from waves and currents prevents deposition of new sediments on the Bay bottom. In these erosional areas, pre-Chesapeake Bay sediments from ancient riverine, estuarine, and marine environments are sometimes exposed (MDNR, 1988). Figure K-12 portrays regions of Bay bottom and whether erosional or depositional processes dominate. Processes producing these patterns occurred naturally over geologic time as the Bay evolved, driven by rising sea level. Conversely, human activity has induced substantial deposition in headwater tributaries and in the Susquehanna Flats over the last few centuries.

Figure K-11. Bottom Sediment Grain Size Distribution



Source: MDNR, 1988.

Figure K-12. Depositional and Erosional Areas on Bay Bottom



Source: MGS, 1988.

Toxic contaminants enter the Bay from atmospheric deposition, dissolved and particulate runoff from the watershed, and direct discharge. Bay sediments accumulate many toxic contaminants, including metals (such as arsenic, cadmium, chromium, and mercury), butyl-tins, polycyclic aromatic hydrocarbons (PAHs), and chlorinated compounds (polychlorinated biphenyls [PCBs], chlorinated pesticides, furans, and dioxins). Contaminants accumulate in mud (fine-grained sediments) while sands tend to retain few contaminants. Generally, sediments in the mainstem of the Bay are relatively uncontaminated. Depositional areas containing fine-grained sediments in the Susquehanna Flats area and the upper portions of the deep trough have higher concentrations of contaminants than the middle and lower Bay.

Most tributaries have higher contaminant concentrations than the mainstem. Tidal portions of the Anacostia River, Baltimore Harbor, and the Elizabeth River are hotspot areas of contaminants (CBP, 2013).

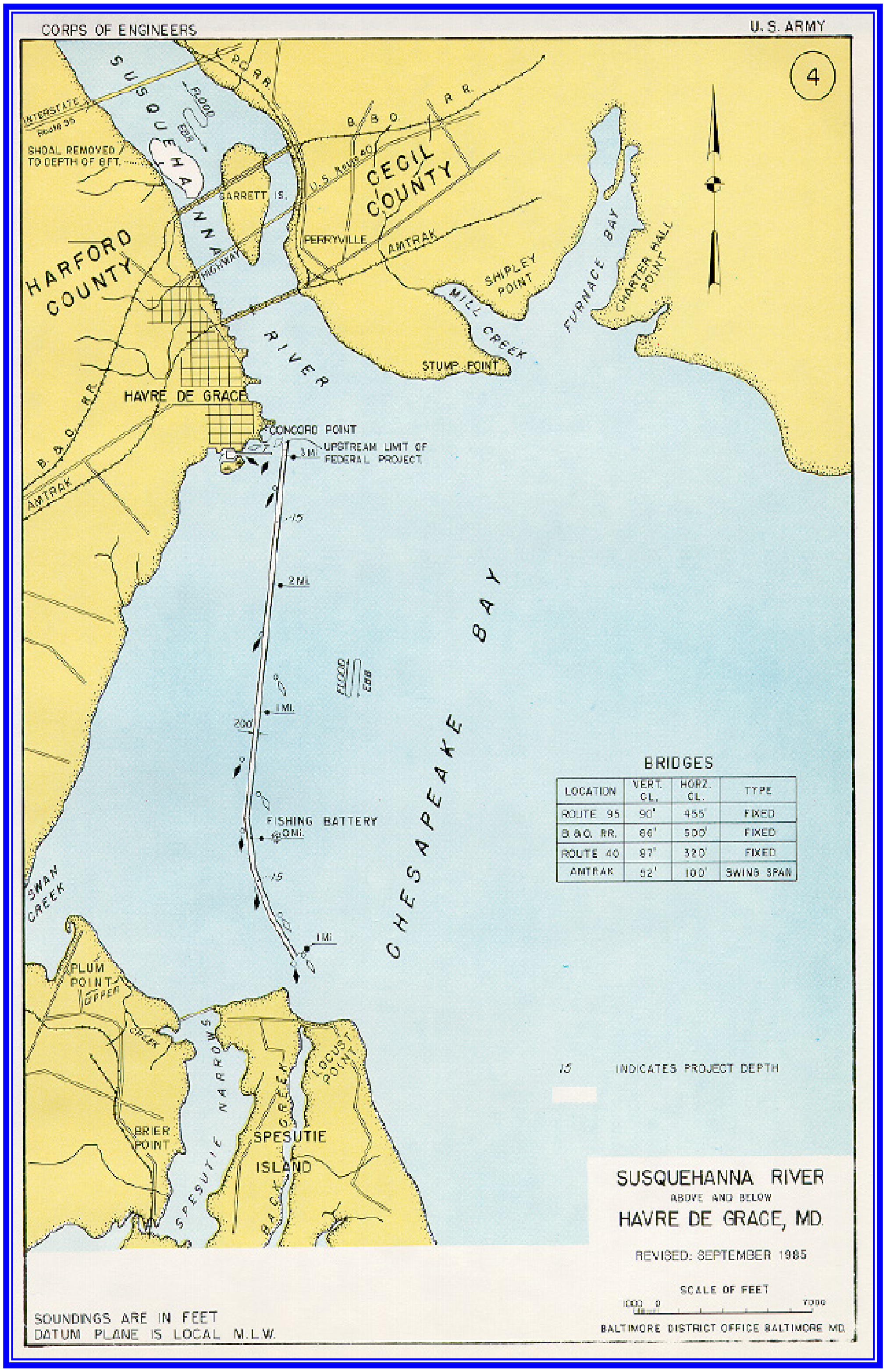
Eroded sediments from upland and riverine sources enter the Bay in quantities considerably greater than natural levels as a consequence of human activities and landscape alterations. Accumulating sediments shoal navigation channels. Nutrients adsorbed to fine-grained sediments derived from eroded topsoil contribute to eutrophication. Fine-grained sediments can remain suspended in Bay waters for extended periods of time because of eutrophic conditions. This reduces water clarity, limiting growth of SAV.

The Susquehanna River transports large volumes of sediment to the Chesapeake Bay. Two flood events, associated with Hurricanes Agnes (1972) and Eloise (1975), contributed approximately 44 million tons of sediment to the Bay. Recent estimates calculate that the Susquehanna River transports 3.1 million tons annually, depositing 1.9 million tons behind Conowingo Dam with the remaining 1.2 million tons deposited in the Chesapeake Bay (1996-2008 evaluation periods) (Langland, 2009). In the upper Bay, the Susquehanna River is the dominant source of sediment influx, supplying over 80 percent of the total sediment load in the area (SRBC Sediment Task Force, 2001).

However, historical data indicates that long-term erosional erosional areas can occur in this region along the northern shoreline bottom, and along the north/south channel bottom west of Susquehanna Flats (MDNR, 1988). The latter channel contains the USACE Susquehanna River/Havre de Grace navigational channel, purposefully located in this natural deeper water area; the location of the navigation channel is shown in Figure K-13. During the growing season from April through October, large SAV beds occur on shallows in the Susquehanna Flats in the center of the uppermost Bay. The SAV beds promote sedimentation within the shallows, and dampen wave energy that could otherwise erode bottom sediment (Gurbisz and Kemp, 2013; CBP, 2013).

Major flood events and wave energy are likely the major factors controlling the geomorphic character of the Susquehanna Flats (Larry Sanford, Professor, University of Maryland, Center for Environmental Science, personal communication, 2013). Although no research has yet been specifically conducted on the topic, it is likely that there was a great increase in sand delivery to the upper Bay following European settlement from anthropogenic erosion in the Susquehanna River basin. Sand delivery from the Susquehanna River into Chesapeake Bay would probably have peaked in the early 1900s. Then, following construction of the lower Susquehanna River dams, sand

Figure K-13. Location of USACE Susquehanna/Havre de Grace Navigation Project



Source: USACE, 1985.

delivery to the upper Bay would presumably have been disproportionately reduced compared to fines in the early 20th century.

Locally along the Bay shoreline and in nearshore waters, gravels, cobbles, and boulders as well as blocks of iron sandstone and other partially indurated (turned to rock) sediments from otherwise buried geologic materials occur where waves or currents have exposed them (USACE, 2011). The tidal Susquehanna River is unique in Maryland's portion of Chesapeake Bay in that it has a hard rock bottom where Piedmont rocks are exposed. Elsewhere in Maryland's portion of the Bay, Piedmont rock is deeply buried under sediment and not exposed on the bottom or shoreline.

K.6.2 Conowingo Dam and Vicinity

Upland Geologic Materials

Conowingo, Holtwood, and Safe Harbor Dams all lie within the Piedmont physiographic province and rest on hard metamorphic rock. Hard rock of the Piedmont is naturally exposed in locations where erosion exposes it, such as along rivers and steep slopes. Otherwise, rock in the Piedmont is typically buried by soil and decomposing rock known as saprolite. In the Maryland portion of the Piedmont, saprolite can range from just a few feet to more than 100 feet, while the average thickness is around 45 feet (Nutter and Otton, 1969). In Harford County, the average thickness of saprolite is thought to be 33 to 50 feet thick (Dingman and Ferguson, 1956; Nutter, 1977). Similarly, the average saprolite thickness in Cecil County is 41 feet (Otton et al., 1988).

Upland areas adjacent to the dams and along the Susquehanna River are underlain by a variety of hard metamorphic and sedimentary rock types northward of the dam and southward down to the boundary with the Coastal Plain physiographic province which lies several miles downstream of Conowingo Dam. In the Coastal Plain, layers of unconsolidated sediments overlie Piedmont hard rock. The Piedmont province slopes downward southeasterly at a rate of about 500 feet per mile below the Coastal Plain, although the contact between the two provinces has many irregularities. Piedmont hard rock is buried by increasingly thick Coastal Plain sediments proceeding southeastwardly from the boundary between the two provinces (MDNR, 1969 and 1990; Means, 2010). Investigations conducted for this study by MGS characterized the lowermost Susquehanna River bottom in the reach between Conowingo Dam and tidal waters. This information can be found in Appendix E of this Assessment.

Principal mineral resources of the area are rock and crushed stone from quarries in the Piedmont, and sand and gravel from Coastal Plain sediments. These geologic materials support the building and construction industries. Substantial rock for shoreline stabilization along Chesapeake Bay is quarried from quarries in the Port Deposit area. Historically, additional mineral commodities produced from the vicinity included building and decorative stone, roofing, slate, iron, chromite, talc, feldspar, and clay. Multiple inactive quarries occur within several miles of the Susquehanna River in Pennsylvania and Maryland (Shultz, 1999; MDNR, 1969 and 1990; Means, 2010).

Conowingo Reservoir, Lake Aldred, and Lake Clarke Substrate

Prior to construction of the dams on the lower Susquehanna River, minimal alluvial sediment storage occurred. Geomorphic features instead consisted of a bedrock channel flowing through gorges, the latter of which contained a series of terraces (Pazzaglia and Gardner, 1993).

The bodies of water formed behind the dams contain outcrops of Piedmont rock on areas of the bottom and shoreline subject to strong currents and or waves. The lakes have deposits of boulders and cobbles on the bottom in areas where strong river currents deposit them. Otherwise, Piedmont hard rock underlying the lakes is covered with sediment consisting of sand and mud (silt and clay). All the lakes have coal in their bottom sediments from upstream mining operations. Coal deposited in Lake Clarke and Lake Aldred was dredged from the lake bottom from the 1950s until about the time of Hurricane Agnes. Conowingo Reservoir and Lake Clarke show a general trend of increasing thickness of sediment proceeding downstream; Lake Aldred sediments are thickest near the middle of the lake (Hainly et al., 1995).

Bottom sediments in Conowingo Reservoir show a gradation from the upstream end of the reservoir to the area adjacent to the dam. At the upstream end, reservoir bottom sediments are mostly sand. Progressing downstream, the bottom sediments become increasingly fine, consisting of silts and clays (Hainly et al., 1995).

The sediment retained behind Conowingo Dam contains substantial quantities of nitrogen and phosphorus nutrients. The nutrients occur predominantly in muds; conversely sands have minimal nutrient content. TP in Conowingo Reservoir sediments was found to range from 0.3 to 1.4 grams per kilogram; TN was found to range from 1.5 to 6.9 grams per kilogram. However, about 96 percent of the TN consisted of organic nitrogen which is of limited immediate bioavailability. Organic nitrogen concentration decreased with depth into the sediment. Phosphorus immediately available to plants comprised only 0.6 to 3.5 percent of the TP (Langland and Hainly, 1997).

Soils typically contain approximately 0.8 grams TP per kilogram of soil, while river particulates typically contain approximately 1.15 grams TP per kilogram (Schlesinger, 1991). Because the phosphorus adsorbed to bottom sediments is minimally bioavailable and not being utilized by organisms nor reacting chemically, TP probably does not show a pattern of decrease with depth into the sediment. The nutrients stored behind the dam that are not in immediately bioavailable forms might, however, upon burial in the Bay bottom be expected to gradually become bioavailable from microbial processes in the sediment (Michael Langland, Hydrologist, U.S. Geological Survey, personal communication, 2014).

TN and TP in bottom sediment samples collected in Lake Clarke considered vulnerable to scour ranged from 3.3 to 5.3 g/kg and 0.8 to 1.2 g/kg, respectively. TN and TP in bottom sediment samples collected in Lake Aldred considered vulnerable to scour ranged from 1.2 to 5.7 g/kg and 0.3 to 0.5 g/kg, respectively. Lake Clarke had higher clay content than Lake Aldred at these locations, likely accounting for greater TP content. Clay content of bottom sediments in downstream Lake Clarke remained consistent in a comparison of studies conducted in 1990 versus 1996. Conversely, clay content in bottom sediments in downstream portions of Lake Aldred decreased from 1990 to 1996 (Langland and Hainly, 1997).

In summary, although vast quantities of nitrogen and phosphorus nutrients are stored in sediments behind the dam, they occur predominantly in forms which would not be of immediate bioavailability upon delivery to the Bay. These nutrients though may eventually become available to contribute to eutrophication if eroded and delivered to the Bay.

Human activities throughout the Susquehanna River basin have generated sediment contaminants that occur in varying levels in the system. Sediment studies in the Susquehanna River have identified several contaminants such as organocholorine insecticides, PCBs, radionuclides, and PAHs (PFBC, 2011).

Conowingo Reservoir sediments have about an 11-percent coal content derived from mining upstream. The concentrations of metals, radionuclide contamination, and overall organic contaminant concentrations are comparable to those found in the upper Bay mainstem. PCBs from the Susquehanna River appear to be readily transported into the upper Bay, while pesticides and PAHs appear to be trapped behind the dams. Compared to the Bay, reservoir sediments have lower levels of chemicals typically contained in seawater but absent from fresh water. The latter include sulfur which occurs as sulfate in seawater but is only minimally present typically in fresh water (SRBC, 2006a).

Substrate composition in the littoral zone (upper 10 feet) of Conowingo Reservoir transitions from gravel-cobble-boulder in the upper range of water level fluctuation to a gravel and sand mix at somewhat greater depths. In the lower range of the upper 10 feet of water, silt becomes dominant on the bottom. Steeply sloping rock outcrops occur along much of the western shoreline (URS and GSE, 2012a).

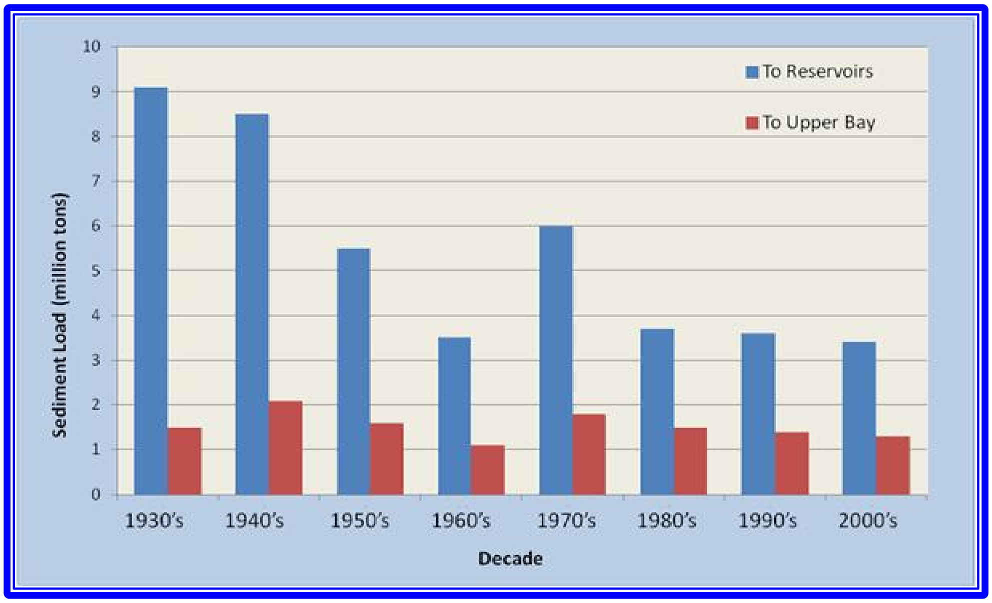
K.6.3 Environmental History – Watershed Erosion and River and Bay Sedimentation

Upland erosion in the Bay watershed increased substantially following European settlement from deforestation, farming, and mining. Consequently, sediment inputs to the rivers and Bay greatly increased, with rates peaking sometime between the late 1800s and early 1900s, with a decline generally occurring from the 1930s onward (Curtin et al., 2001; Langland, 2000; USGS, 2003). The long-term sediment inflow and outflow trends are depicted in Figure K-14.

Floodplains and an extensive array of dams and millponds throughout the Bay watershed trapped a substantial portion of these sediments, which continue to erode and flow into the Bay today (Walter and Merritts, 2008). Numerous headwater tidal tributaries on Maryland's Western Shore and along the Potomac River in Virginia demonstrated pronounced increased sedimentation rates following European settlement with shoaling so severe that navigation was prevented and tidal wetlands grew over accumulating sediments (Gottschalk, 1945).

Tremendous quantities of sediment were deposited into the upper Bay and onto the Susquehanna Flats from erosion in the Susquehanna River basin. The average water depth over an area of 32 square miles of the upper Bay was reduced by 2½ feet from the 1840s through 1930s (Gottschalk, 1945). Sediment accumulation measured from coring on the flats determined that about 7 feet of sediment was deposited on the flats from the 1890s to 1990s (Robertson, 1998). Thus, the character of the Susquehanna Flats today is largely the consequence of human activity in the Susquehanna

Figure K-14. Long-Term Trend in Inflowing and Outflowing Sediments



Notes: The difference in the bars represents the amount of sediment trapped in the reservoirs. These amounts represent annual averages during a particular decade.

Since 1929, approximately 430 million tons of sediment were transported into the lower Susquehanna reservoirs. Of this amount, approximately 290 million tons (70 percent) were trapped, and approximately 140 million tons were transported to the Chesapeake Bay.

Source: USGS, Appendix A.

River basin (Gottschalk, 1945). Sedimentation rates to deep-water portions of the Bay have increased by a factor of 4 to 5 over pre-European settlement rates (Colman and Bratton, 2003). Conversely, sediment accumulation on the shallower margins of the Bay overall is relatively slow and does not show consistent patterns related to European settlement, instead occurring at about pre-European settlement rates (Colman et al., 2002; USGS, 2003).

K.7 AQUATIC LIFE AND HABITATS

K.7.1 Plankton

Plankton are a wide variety of floating plants and animals, phytoplankton and zooplankton respectively, that live in the water and are, by in large, passively carried by currents. Phytoplankton include various green, red, and blue-green algae. Phytoplankton are the basis of most aquatic food chains. Zooplankton include microscopic animals, larvae of larger animals, and jellies (gelatinous zooplankton). Jellies include comb jellies (various ctenophora) and sea nettles (jellyfish, *Chrysaora quinquecirrha* and other species). Zooplanktons serve as food for many larger aquatic animals (MDNR, 2013). Nutrients supplied from coastal runoff and vertical mixing in the water column support a relatively high abundance of phytoplankton in the shallow waters of the Bay where sunlight can penetrate. Phytoplankton populations vary seasonally, with peak abundances occurring in late winter through spring and then again in summer. Limited fall blooms also occur. Water temperatures and seasonal variation in nutrient availability in the water column control phytoplankton population dynamics; phytoplankton themselves consume nutrients from the water as their populations increase (MDNR, 2013).

Nutrient loading increases to the Bay are believed to have greatly increased populations of jellies. Consequent excess consumption of finfish larval zooplankton by jellyfish is likely influencing Bay finfish populations (Purcell et al., 1999).

K.7.2 Submerged Aquatic Vegetation (SAV)

Submerged aquatic vegetation (SAV) is underwater plants that can occur to depths where water clarity is adequate for the plants to grow. SAV can grow in shallow water to minimum depths where air exposure is harmful to the plants. SAV occurs in both tidal and nontidal waters of the Chesapeake Bay watershed, in both salt and fresh water. The term SAV is generally used to refer to rooted plants. Underwater algal beds also occur in aquatic habitats that are similar in appearance from above the water surface to SAV beds, and provide similar ecological functions. SAV beds provide important habitat for numerous fish and wildlife species (CBP, 2013).

Chesapeake Bay SAV

SAV beds are among the Bay's most valued resources, but unfortunately are particularly vulnerable to turbidity during their growing season from April through October. SAV in the Bay occurs from about the lower range of the tide to depths of up to 6 feet; the distribution of SAV in the Bay is shown in Figure K-15. SAV is generally absent from deeper waters because of inadequate light penetration through turbid water conditions. SAV species occurring in the Bay are least diverse in the higher salinity regions, where only two rooted plant species are found. SAV beds increase in diversity as salinity decreases. Beds in freshwater and oligohaline portions of the Bay may contain more than 10 rooted plant species, as documented in Table K-7. SAV occurring in the Bay includes both native and exotic species; all are considered to have value as habitat for Bay aquatic life. Large SAV beds serve to dampen water turbidity within the bed itself, although water clarity controlling the health of most beds is primarily governed by Bay water quality (Orth et al., 2010; VIMS, 2013).

SAV in the Chesapeake Bay is perhaps the most extensively studied SAV resource in the world. Chesapeake Bay has possibly the best long-term data set allowing for chronicling status and trends, with comprehensive surveys dating from the late 1970s through present, with other records available from the 1930s onward (Orth et al., 2010). Studies of SAV remnants in sediment demonstrate that SAV coverage initially increased following European settlement, presumably as a consequence of somewhat increased nutrient availability, and perhaps increased availability of shallow water habitat from excess anthropogenic sedimentation (Brush and Hilgartner, 2000). SAV coverage declined drastically in the 1960s in accompaniment to water quality declines associated with nutrient loading and loss of oysters from disease and overharvesting.

Hurricane Agnes in 1972 compounded the impacts of eutrophication, and caused a dramatic Bay-wide SAV decline. SAV recovered somewhat over following decades, but exhibits pronounced interannual variation, as seen in Figure K-16. SAV beds tend to decline in years with high freshwater discharges immediately before and during the growing season. Conversely, successive drought years facilitate SAV bed recovery. These trends occur because wet years bring in greater

Figure K-15. Historic and Recent SAV Distribution in Bay

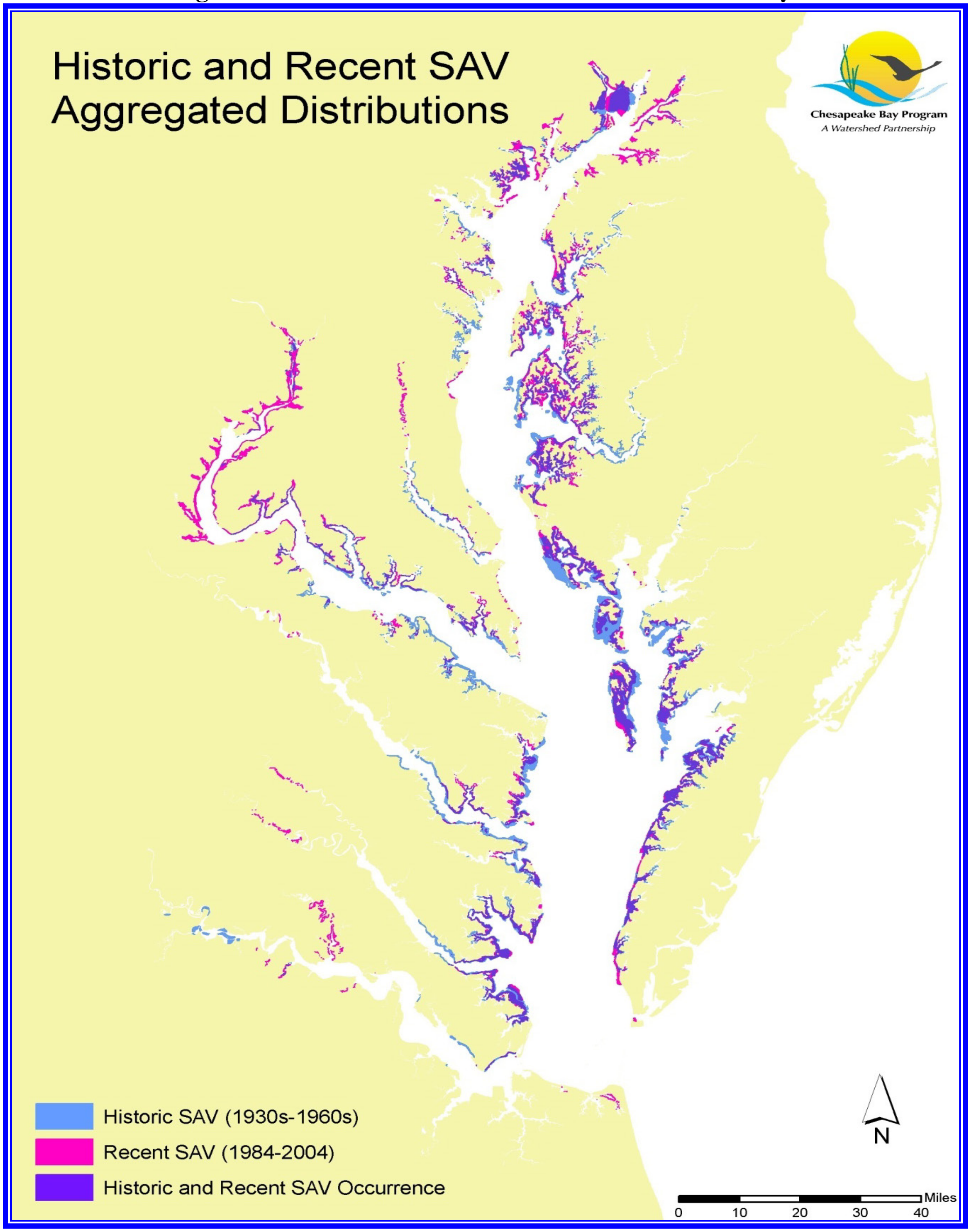
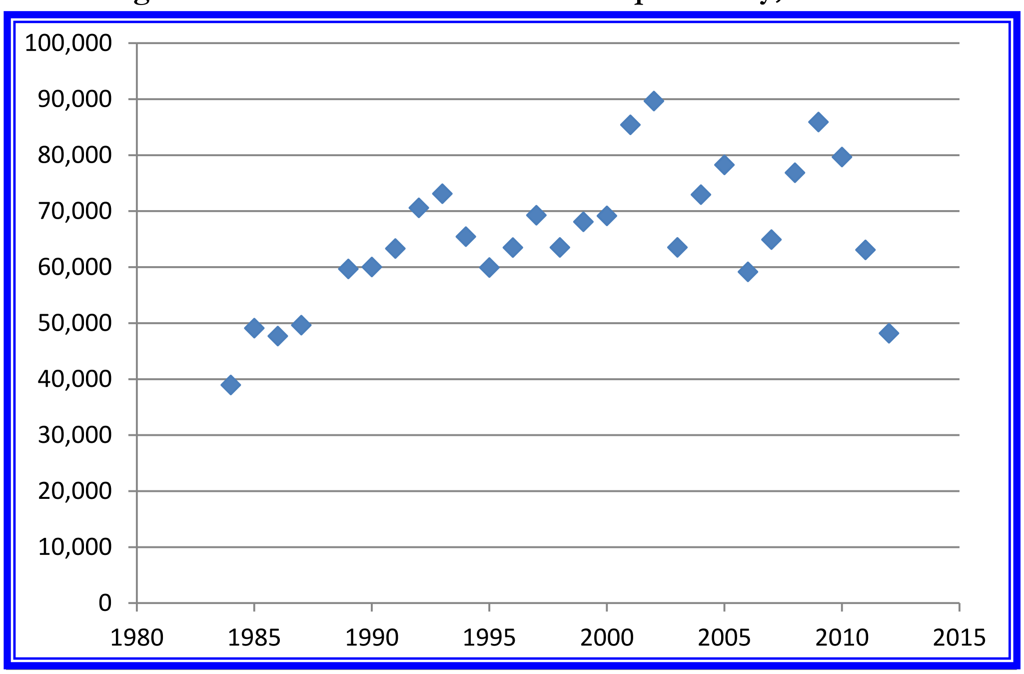


Table K-7. Chesapeake Bay SAV Species by Water Salinity

Common Name	Scientific Name	Salinity		
		Low	Medium	High
Coontail	*Ceratophyllum demersum*	x		
Common waterweed	*Elodea canadensis*	x		
Water stargrass	*Heteranthera dubia*	x		
Hydrilla	*Hydrilla verticillata*	x		
Water milfoil	*Myriophyllum spicatum*	x		
Southern naiad	*Najas guadalupensis*	x		
Spiny naiad	*Najas minor*	x		
Curly pondweed	*Potamogeton crispus*	x		
Redhead grass	*Potamogeton perfoliatus*	x	x	
Slender pondweed	*Potamogeton pusillus*	x		
Widgeon grass	*Ruppia maritima*		x	x
Sago pondweed	*Stuckenia pectinata*	x	x	
Wild celery	*Vallisneria americana*	x		
Horned pondweed	*Zannichellia palustris*	x	x	
Eelgrass	*Zostera marina*		x	x

Source: Orth et al., 2010.

Figure K-16. Total SAV Acres in Chesapeake Bay, 1984-2013



Notes: There is no data for the year 1988.
Source: VIMS, 2013.

nutrient loads, promoting eutrophic conditions and decreasing water clarity. Other factors also affect SAV, including grazing by mute swan (*Cygnus olor*) and bottom-disruption by bottom-feeding organisms such as the cownose ray (*Rhinoptera bonasus*) (Orth et al., 2010).

The CBP Partnership has set a 185,000-acre SAV restoration goal based on total area of known SAV occurrence over the period of Bay-wide data from the 1930s through 2004 (CBP, 2013). Grasses attained their greatest coverage over the last several decades in 2002 when 90,000 acres were observed (Maryland BayStat, 2013). While a substantial improvement over the historic lows of the 1970s through 1980s, SAV beds still only occupied 49 percent of their known historic coverage. It is considered likely that SAV historically occupied even greater than 185,000 acres in Chesapeake Bay prior to the 1930s based on the distribution of suitable habitat (Orth et al., 2010).

The Susquehanna Flats SAV bed is the single largest SAV bed in the Bay and the region is one of the best recovered regions in the Bay. SAV in the uppermost Bay was historically pronounced in the first half of the 20th century, and its use by waterfowl prompted establishment of a National Wildlife Refuge along the Susquehanna Flats' western shore. After undergoing a general gradual trend of decline in the 1960s and early 1970s, SAV on the Susquehanna Flats collapsed after Hurricane Agnes in June 1972. SAV then remained at a low level through the 1980s and 1990s. Early in the 21st century, it recovered to pre-Agnes levels and then underwent dramatic expansion in 2005-06 facilitated by several years of drought conditions, as demonstrated in Figures K-17 and K-18 (Orth et al., 2010; Gurbisz and Kemp, 2013). Extent of the beds on the flats have varied in response to large storm events, with a minor decline occurring following Hurricane Ivan in 2004 but with substantial decline following Tropical Storm Lee in 2011 (Gurbisz and Kemp, 2013).

Susquehanna River SAV

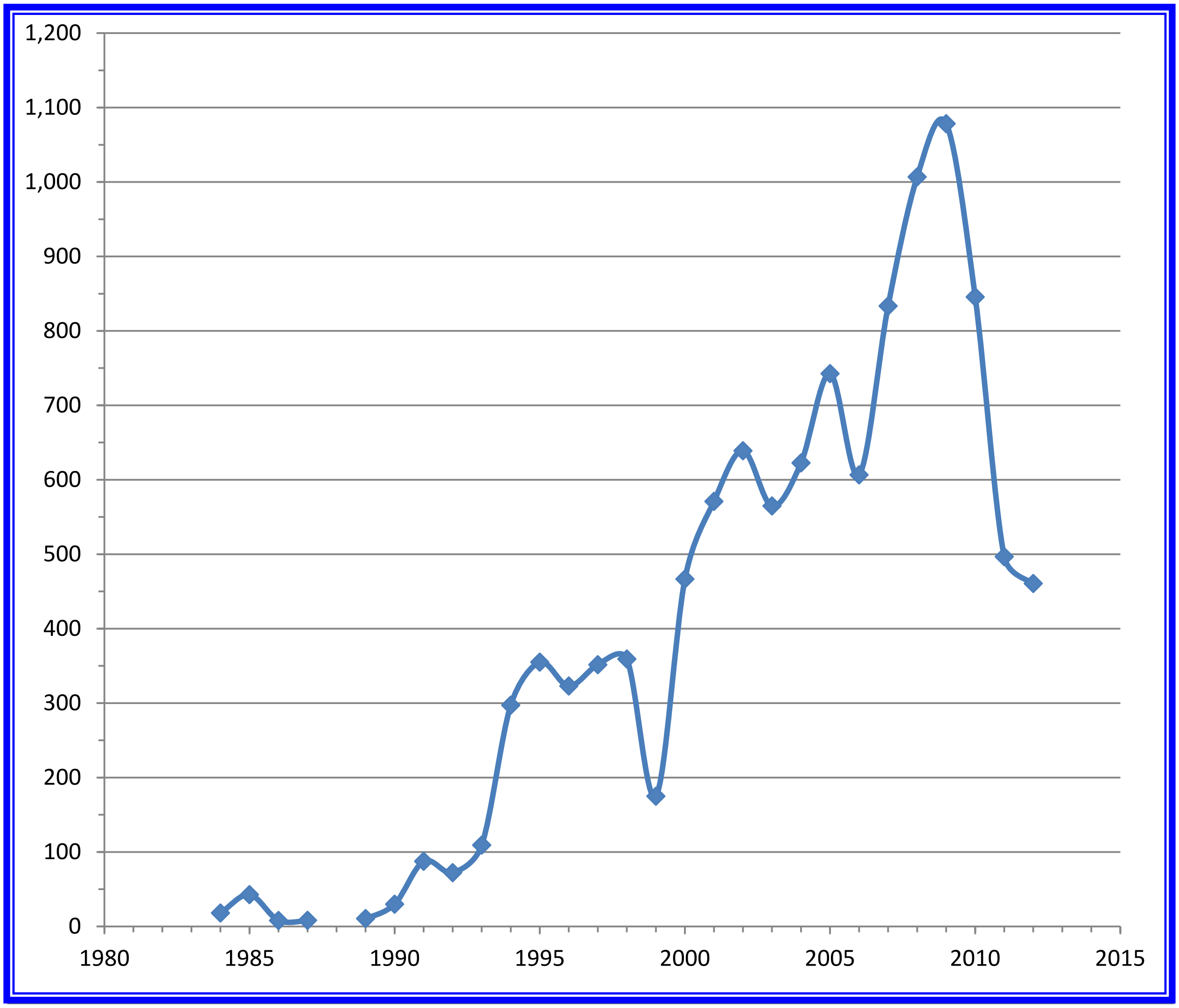
VIMS mapped no SAV beds immediately below the Conowingo Dam in the non-tidal and tidal Susquehanna River over the period 1997-2012. However, VIMS frequently mapped SAV in the non-tidal and tidal river downstream to the river mouth from the 1990s through 2010 (VIMS, 2013). SAV was found to occur in 2010 downstream of Conowingo Dam at creek mouths and islands between the dam and Port Deposit in shallow areas with coarser-grained sediment (sand and cobble), near sources of sediment supply and reduced flow velocities (tributary mouths and a protected island complex (URS and GSE, 2012c).

In free-flowing non-tidal segments of the river, SAV occurs within portions of the active channel that are permanently inundated during the growing season. SAV stems and leaves are susceptible to damage or death by atmospheric exposure during the growing season. One of the Susquehanna River basin's most abundant SAV species is riverweed (*Podostemum ceratophyllum*). Riverweed is a perennial found in moderate to high velocity riffles (TNC, 2010). Riverweed does not occur in the Chesapeake Bay proper.

Conowingo Reservoir SAV

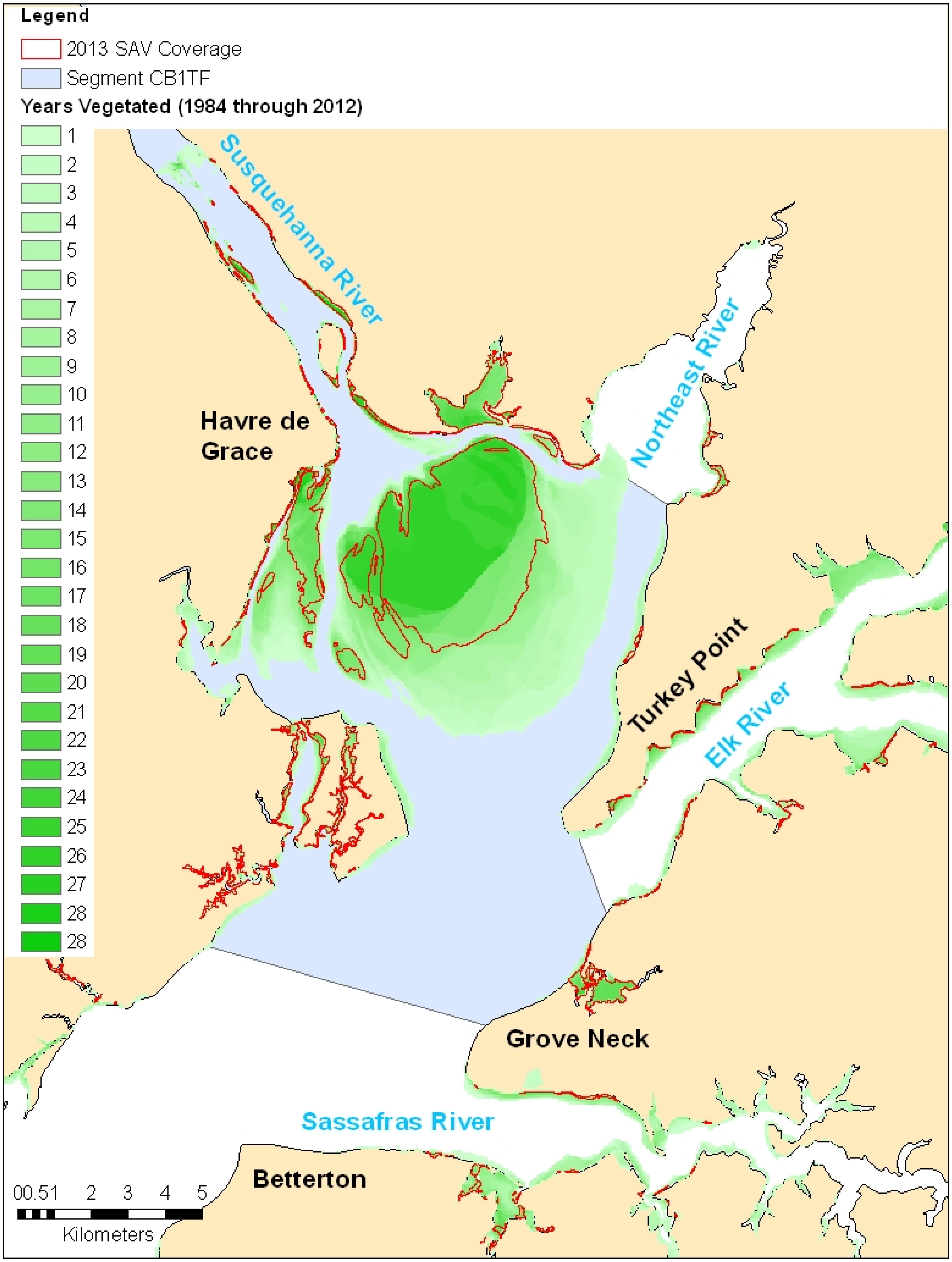
SAV occurs on unconsolidated alluvial deposits in the upper portion of the Conowingo Reservoir. SAV surveys in the reservoir conducted in 2010 found a total of seven species, but hydrilla (*Hydrilla verticillata*), a tolerant invasive species, dominated the coverage in the majority of locations where

Figure K-17. SAV Abundance for Northern Chesapeake Bay Segment 1



<u>Notes</u>: *SAV abundance is shown in acres.*
Segment 1 = CB1TF1, which contains the mouth of the Susquehanna River and Susquehanna Flats.

Figure K-18. SAV Bed Occurrence in Northern Chesapeake Bay Segment 1



SAV was growing. Hydrilla is also common in Chesapeake Bay. SAV in the reservoir covered 321 acres during this 2010 survey. Changes in water levels have the potential to decrease the extent of or dewater SAV beds (URS and GSE, 2012a).

Well-established SAV communities appear to be absent from the bedrock dominated portions of the Susquehanna River above Conowingo Reservoir. In general, steep rock-dominated shorelines do not provide habitat for SAV because of absence of bottom habitat within the photic zone (URS and GSE, 2012a).

K.7.3 Wetlands

Nearly 1.5 million acres of wetlands occur in the Chesapeake Bay watershed; 1.3 million acres are non-tidal and 200,000 acres are tidal (CBP, 2013). The tidal wetlands water regime is controlled by sea level and flood with tidal water at high tides. Non-tidal wetlands have water levels independent of sea level. Tidal and nontidal wetlands are divided into several general vegetation types. Emergent wetlands, generally called marshes, are vegetated by grasses, sedges, and other leafy, non-woody plants. Shrub wetlands are dominated by woody shrubs. Forested wetlands, often called swamps, are dominated by trees.

Chesapeake Bay Tidal Wetlands

Tidal wetlands provide habitat for numerous animals and plants, and debris from plants exported from tidal wetlands supports the Chesapeake Bay food web. Tidal wetlands are found along the shores of the Bay and in tidal portions of rivers. New tidal wetlands form as the rising sea floods the land, and on recent sediment deposits in tidal waters. Tidal brackish and salt wetlands generally range from a low elevation of about mean water to a maximum elevation of about spring-tide high water. Tidal freshwater wetlands can have floating leaved plants that grow permanently inundated, thus they can occur to below mean lower low water.

Tidal marshes found along the Chesapeake Bay are divided into three general categories corresponding to salinity of their waters: freshwater marshes of the upper Bay, brackish marshes of the middle Bay, and salt marshes of the lower Bay. Tidal wetlands of the uppermost Bay are typically described as being freshwater because they largely share the same vegetation as freshwater wetlands. However, tidal freshwater wetlands actually occur at sites of fresh to oligohaline salinities. Along the shoreline of the lower Susquehanna River and in the upper Chesapeake Bay, tidal wetland parcels occur locally in wave-protected tidal portions of creeks and rivers draining into the Bay. In the uppermost Bay, steep topography along the shoreline disfavors expansive tidal wetlands formation.

History of the Tidal Wetlands

Historic trends in Bay tidal wetlands have not been quantified accurately (Tiner and Burke, 1995). It is probable that a net loss since European settlement has occurred as habitat destruction via erosion and inundation driven by rising sea level has exceeded tidal wetland formation. New tidal wetlands form via migration onto the drowning mainland, and in delta and other settings on new sediment deposits. This loss trend was probably primarily natural, but exacerbated by human actions (Stevenson et al., 2000). Direct anthropogenic loss occurred as a consequence of filling and canal construction prior to the early 1970s, when modern environmental laws protecting wetlands were enacted. Approximately 0.5 percent of the Bay's tidal wetlands were lost over the period 1982 to 1989, with the majority of these losses occurring via conversion to open water (Tiner et al., 1994). There is a declining trend in tidal wetland abundance in the Chesapeake Bay now driven primarily by wetland conversion to open water occurring at a faster rate than new tidal wetland formation. Land change statistics show a 2,600-acre loss between 1996 and 2005 (CBP, 2013).

Tidal wetlands of the Bay are actually favored by conditions of sediment availability. Tidal wetlands in riverine settings receive greater mineral sediment input than do tidal wetlands isolated from regular tidal flows and are consequently less vulnerable to effects of rising sea level (U.S. Climate Change Science Program, 2009). Substantial areas of tidal wetlands formed on the Western Shore, historically in river valleys where excess sediment conveyed in from anthropogenic erosion was deposited intertidally (Gottschalk, 1945). Tidal wetlands did not form on the Susquehanna River delta from excess erosion in the Susquehanna River basin during the 19th and 20th centuries, however.

Susquehanna River Wetlands

Non-tidal wetlands are not flooded by the tides and contain fresh water. Non-tidal wetlands occur on floodplains bordering streams and rivers, on the shores of lakes and ponds, in depressions, and in broad, flat low-lying areas that drain poorly.

In the Susquehanna River basin, non-tidal wetlands occur within portions of the river channels and floodplains with a semi-permanent inundation frequency, typically on islands, edges of bars, and terraces. A variety of plant communities occur within the river channels as a function of ice scour, inundation, and soil development. Where severe flood and ice scour occurs, inundation duration is seasonal to temporary flooding, and geologic deposits occur but soil development is minimal, then herbaceous (non-woody) plants typically occur during the growing season. Plant growth of these wetlands dies back in non-growing season months, and these sites may appear unvegetated early in the growing season and in non-growing season months. During the growing season, emergent beds can tolerate inundation under high-flow conditions and exposure under low-flow conditions, but the frequency and duration of inundation and exposure can impact the condition of emergent vegetation. Where severity of ice scour is moderate on flats, bars, and low terraces of islands and banks, shrub communities often occur. Where ice scour is low and inundation duration just temporary, floodplain forests occur (TNC, 2010).

Downstream of Conowingo Dam, non-tidal shrub and forested wetlands are shown by the National Wetlands Inventory to occur along one or both shorelines of the Susquehanna River, as well as on islands in the river. Marsh occurs at the lowest, wettest sites as a consequence of the water base level being tidal and thus substantially less affected by seasonal low-flow conditions. Wetlands with woody vegetation occur generally at somewhat higher elevations.

Conowingo Reservoir Wetlands

Wetland vegetation occurs in crevasses on the protected downstream side of rocks in the bedrock-dominated portions of the reservoir. As typical river energy conditions diminish further downstream, wetlands become more prominent, growing in sediment deposits within cracks in the rock surfaces and bedrock islands. Wetlands are present primarily at sites of accumulating sediment, where it covers the hard-bottom substrate particularly along the margins of tributaries flowing into the reservoir. Emergent wetlands occur on point bars in shallow tributaries and at the confluences of tributaries with Conowingo Reservoir. Water level fluctuations in Conowingo Reservoir over the range at which they are typically managed have negligible effects on SAV there (URS and GSE, 2012a).

K.7.4 Benthic Invertebrates

Benthos is the community of organisms that live in or on the bottom sediment of water bodies. Benthos includes mobile and immobile organisms. Benthic invertebrates are animals without a backbone that live on top of or within bottom sediments in aquatic ecosystems.

They are often used as indicators of water quality and ecological health due to their abundance, known pollution tolerances, and limited mobility. A typical healthy benthic community includes species characteristic of unstressed communities. In a polluted environment, these species would be replaced by species more tolerant of pollution. Most degraded communities would also tend to have fewer species, fewer large organisms deep in the sediment, and a lower total mass of organisms (Versar, 2013).

Chesapeake Bay

The benthic community of the brackish Bay includes a wide variety of organisms including clams, oysters, small shrimp-like crustaceans, and worms. Benthic invertebrates provide food for many larger organisms, including bottom-feeding fish. Oxygen is the single best predictor of benthic density in Chesapeake Bay in the summer. At low oxygen levels, biomass is extremely low, resulting in substantial loss of benthic production and foraging habitat for fish and crabs. Benthic animals in deeper waters of the Bay are the principal group affected by poor water quality. Benthic monitoring shows that about one-fourth of the Bay benthos exhibit severely degraded conditions, about 20 percent show degraded conditions, 10 percent show marginal conditions, and about 45 percent are meeting program goals.

The upper Bay is healthier than the middle Bay. About 30 to 50 percent of the upper Bay has generally failed to meet restoration goals over the period 1995-2012. Approximately 50 to 80 percent of the middle Bay fails to meet benthic goals, largely because of hypoxic conditions. The lower Bay shows about 25- to 50-percent failure to meet restoration goals over the 1995-2012 period (Versar, 2013).

Regions of the Maryland mainstem deeper than 39 feet are subjected to summer anoxia and have consistently been found to be azoic (without higher life forms) in benthic sampling (Versar, 2013).

Oysters (Eastern oyster, *Crassostrea virginica*) are naturally absent from the upper portion of the upper Bay in the vicinity of Susquehanna Flats because salinity conditions there are too low for them to grow (generally oysters need salinities to be greater than 5 ppt). Oysters occur in the lower portion of the upper Bay, as well as the middle and lower regions of Chesapeake Bay. The most northerly oyster beds in the Bay occur in the vicinity of Pooles Island about 20 miles south of the

Susquehanna River mouth (MDNR, 2012). North of the Potomac River, oysters historically occurred in vast "beds" on the Bay bottom in water from 5 to 30 feet deep. Shells of these beds had some vertical relief off the Bay bottom sufficient to disfavor sedimentation on live oysters. From the Potomac River southward, oyster reefs occurred that had relief of up to several feet off the Bay bottom. These oyster reefs extended into intertidal waters and formed navigation hazards (Smith et al. 2003; Woods et al., 2004).

Intense overfishing and exotic disease/parasites caused a dramatic decline in oyster populations in the 20th century. Chesapeake Bay oyster resources underwent a 90- to 99-percent population and habitat loss. Oysters are filter feeders. Anthropogenic oyster loss exacerbated effects of Bay eutrophication on water quality by causing loss of filtration services that oysters historically provided. This loss further impaired water clarity to the detriment of SAV (Newell and Ott, 1999). Because of their ecological and commercial importance, a wide array of public and private efforts is underway to restore Bay oyster populations and habitat. Limited commercial harvesting of oysters occurs in Maryland and Virginia, but regulations limit the harvests and are designed to maintain oyster populations (CBP, 2013).

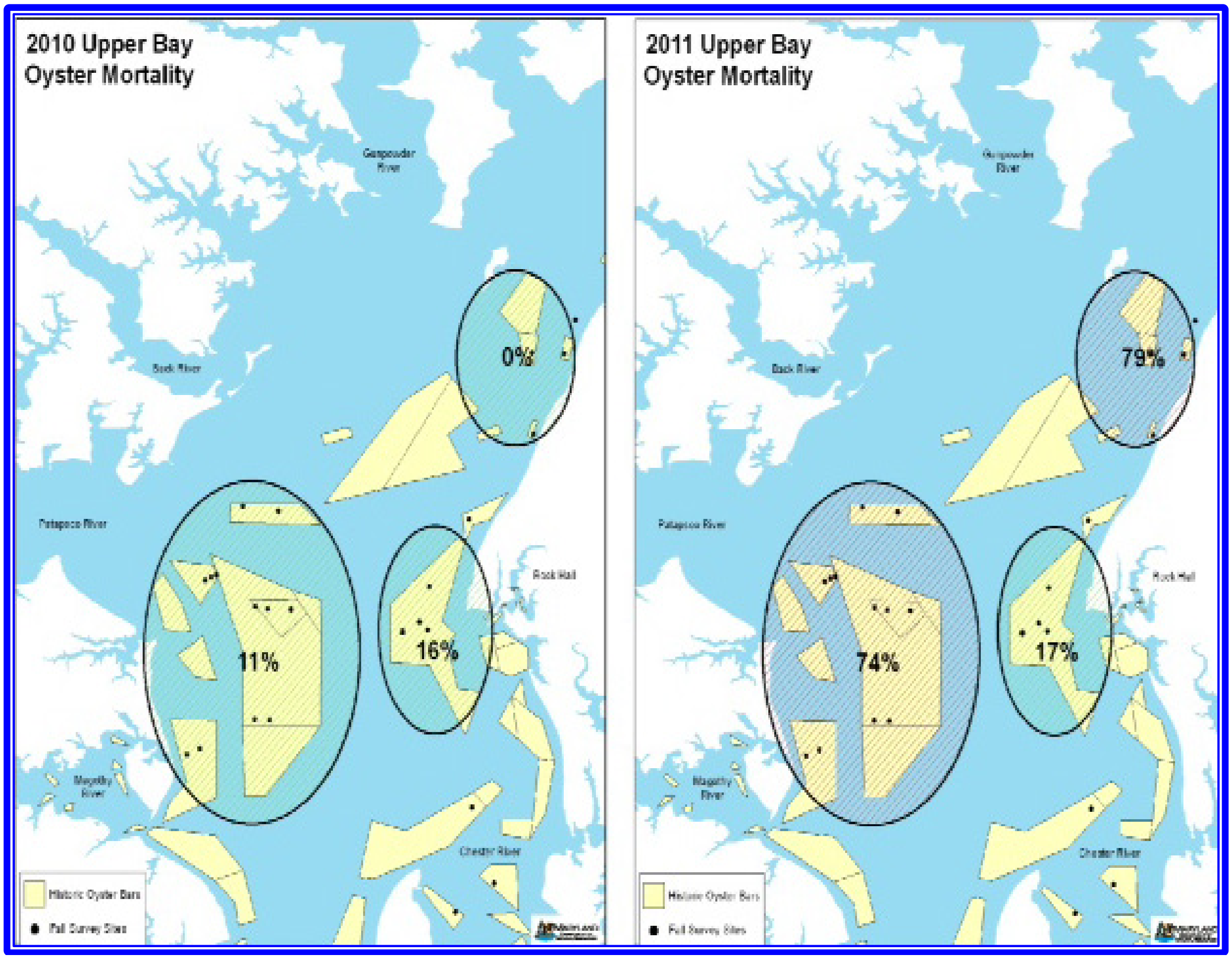
Oysters can survive substantial sedimentation, provided they are healthy and able to produce shells that maintain bed habitat and vertical structure (Smith et al., 2003). Sedimentation on former oyster beds today is generally occurring at rates characteristic of pre-European settlement conditions. Vast oyster beds generally did not occur in headwater tributary and deepwater locations where anthropogenic increases in Bay sedimentation rates have occurred. However, as a consequence of overharvesting, diseases, loss of physical habitat, and poor water quality, existing oyster populations are incapable of producing sufficient shell to enable beds to keep up with natural sedimentation. Sedimentation of former beds renders the substrate less suitable for oysters, ultimately eliminating bed habitat.

Oysters closest to the heads of tidal tributaries are susceptible to mortality from freshets. Widespread oyster losses in the Chesapeake Bay induced by excessive fresh water have occurred many times this century, with severe die-offs in 1909, 1944, 1958, 1972, and 1993 (MDNR, 2012).

MDNR investigated oyster mortality from Tropical Storms Lee and Irene by comparing findings of the annual fall oyster surveys of 2010 and 2011; these findings are shown in Figure K-19 (MDNR, 2013). The four northernmost bars suffered a cumulative mortality of 79 percent in 2011, compared with 0 percent in 2010. Higher than normal mortalities were observed down the Bay on the Western Shore, where combined observed mortality for six bars sampled in fall 2011 was 74 percent, a sevenfold increase over 2010 (11 percent). In contrast, there were no observed excess mortalities in the middle Bay from Sandy Point southward. Oysters in these areas seemed to be in prime condition.

Burial of the oysters due to sediment from Hurricane Irene (August 2011) and Tropical Storm Lee (September 2011) was suspected initially as the cause for high mortalities in fall 2011. However, investigations indicated that this is not the case. Live fouling organisms, including barnacles, mussels, and bryozoans, were found attached to the oysters and shells on these bars. Had the oysters been smothered by sediment, these organisms would not have been able to attach to the oyster shells and would not have survived. The likeliest cause of high mortality was determined to be excessive fresh water and its resultant lack of salinity, for an extended duration in the upper Bay.

Figure K-19. MDNR Fall Oyster Surveys, 2010 vs. 2011 Oyster Mortality



The fact that mortality was highest in the upper Western Shore, where salinity is lowest, reinforces this hypothesis. In summary while oysters are vulnerable to excess sedimentation because of the failure to produce sufficient shell, low salinity conditions restrict oyster beds from occurring within about 20 miles of the Susquehanna River. This substantial distance from the mouth of the Susquehanna River to extant oyster beds limits sediment that can be delivered to these beds from the river. Oysters in the lowermost section of the upper Chesapeake Bay appear to be more vulnerable to the effects of freshets (influx of fresh water typically from rain events) than sediment. Additionally, oysters occurring at greater depths in the lowermost upper Bay are probably vulnerable to effects of hypoxia and anoxia.

The benthic community of the uppermost freshwater Bay includes aquatic insects, snails, and clams comparable to freshwater non-tidal habitats. These organisms diminish downstream in the Bay as salinity increases (White, 1989).

Susquehanna River Benthic Invertebrates

Benthic macroinvertebrates of free-flowing river habitats include aquatic insects, crayfish, clams, snails, and worms. Macroinvertebrate communities of the mainstem lower Susquehanna River have been stable with indices reflecting mostly non-polluted and slightly polluted conditions, with a small number of moderately impaired conditions and no severely polluted conditions (PFBC, 2011).

Conowingo Reservoir Benthic Invertebrates

Conowingo Reservoir provides habitat for benthic macroinvertebrates typical of rivers as well as lakes (URS and GSE, 2012a).

K.7.5 Finfish

Chesapeake Bay

The uppermost Chesapeake Bay is a spawning and nursery ground for seven species of anadromous fish, including striped bass (*Morone saxatilis*), white perch (*Morone Americana*), yellow perch (*Perca flavescens*), American shad (*Alosa spadissima*), alewife (*Alosa pseudoharengus*), blueback herring (*Alosa aestivalis*), and hickory shad (*Alosa mediocris*) (Funderburk et al., 1991). Abundant shallow water (less than 3 feet deep), low salinities in spring, abundance of coarse bottom (sand, gravel, and cobble), abundant SAV, and retention of planktonic eggs and larvae above the ETM make this an important Bay fish habitat (NMFS coordination, Appendix I).

The upper Bay is also nursery habitat for numerous other finfish that spawn in Bay waters and nearshore coastal ocean waters off the Bay mouth. These include Atlantic menhaden (*Brevoortia tyrannus*), bluefish (*Pomatomus saltatrix*), spot (*Leiostomus xanthurus*), Atlantic croaker (*Micropogon undulates*), winter flounder (*Pseudoharengus americanus*), and Bay anchovy (*Anchoa mitchilli*) (Funderburk et al., 1991). High zooplankton content and detritus associated with the ETM make this nursery critical to maintenance of stock abundance for these mid-Atlantic species (NMFS coordination, Appendix I).

The upper Bay also provides habitat for many typical freshwater fish species. These species range well into brackish waters of the Bay, with their downstream extent dependent on their tolerance to salinity. Freshwater fish occurring in the upper Bay include a variety of darters, suckers, minnows, pickerel, sunfish, catfish, and other species (White, 1989)."

Fish species occurring along the length of the Bay differ as a function of salinity and other factors. The middle and lower regions of the Bay have greater biomass of fish species that spawn on the Continental Shelf, as well as sharks and rays, compared to the upper Bay. The upper Bay contains greater biomass of anadromous species that spawn in low salinity waters (Buccheister et al., 2013). Generally, the lower and middle Bay regions have more diverse and changing fish assemblage than the upper Bay through the year, primarily because of migration of many species. However, the upper Bay typically has more fish species occurring at any one place through the year because there is less turnover of species through the year (Buccheister et al., 2013).

Low DO levels limit distribution and abundance of fish, because fish avoid waters where DO drops below 4 mg/L. Demersal (bottom-oriented) fish of the Bay have had a substantial seasonal reduction in habitat availability with onset of vast anthropogenic hypoxia or anoxia. Forage for demersal fish in the middle Bay is reduced due to hypoxia and eutrophication stress, likely detrimentally affecting Atlantic croaker, white perch, and spot (Buccheister et al., 2013). Bay anchovy is one of the Bay's most important forage fish (food for larger fish). This year-round, open-water Bay resident, inhabits shallows during warm weather months, but moves to deep-water habitats in Bay in winter. The abundance of this species appears to have declined over the last several decades (CBP, 2013). Were it not for low DO conditions, Bay anchovy would likely utilize deep-water habitat of the Bay as a feeding ground and as a refuge from predators during warmwater months (Ludsin et al., 2009).

Susquehanna River and the Reservoirs

The three dams form manmade fish blockages which are probably the most important in the Chesapeake Bay watershed, having essentially eliminated access to the Susquehanna River basin for migratory fish ascending or descending the river to the Bay. Migratory fish species affected include various species of shad and river herring, as well as American eel (*Anguilla rostrata*). Construction of the dams contributed to regional declines of the populations of the migratory fish that formerly made use of upstream river habitat in much greater numbers than today. All three dams have fish passage projects in place to reduce the impacts of the dams to fish migration patterns. Improving passage of migratory fish through the dams is a topic of ongoing concern in relicensing of the Conowingo Dam hydropower (CBP, 2013).

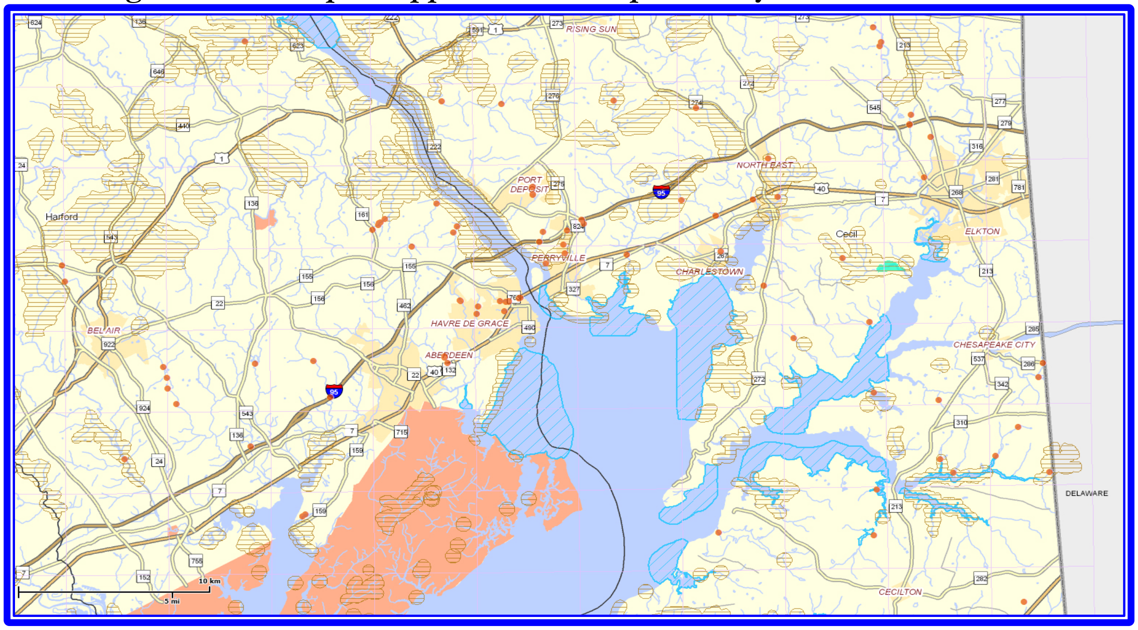
The reservoirs provide habitat for numerous freshwater fishes. In Conowingo Reservoir, principal resident fish species include gizzard shad (*Dorosoma punctatus*), largemouth bass (*Micropterus salmoides*), smallmouth bass (*Micropterus dolomieu*), walleye (*Sander vitreus*), channel catfish (*Ictalurus punctatus*), and a variety of minnows (Cyprinidae family). Optimal spawning habitat for the majority of species occurs over shallow vegetated and unvegetated gravel substrates. Gizzard shad and channel catfish will also spawn over shallow sandy habitat and shallow vegetated silt substrates. Shallow unvegetated gravel substrates and shallow vegetated sand substrates are preferred environments for the adult life stage of the majority of principal fish species. Adult gizzard shad, largemouth bass, channel catfish, and minnows also prefer shallow silt substrates containing vegetation. These habitat types are well represented in the littoral zone of Conowingo Reservoir, providing generally good quality habitat for recreationally and ecologically important fish species in the Susquehanna River (URS and GSE, 2012a).

K.7.6 Birds

The shoreline along the uppermost Bay near the Susquehanna River has been delineated as a historic waterfowl staging and concentration area by MDNR, as shown in Figure K-20 (MDNR, 2013).

The lower Susquehanna River is extremely important to migratory waterfowl and increasingly more important to waterfowl production in the Atlantic flyway. The area is an important wintering and migration area for greater snow geese (*Chen caerulescens*), tundra swans (*Cygnus columbianus*), and American black ducks (*Anas rubripes*), and also supports significant numbers of breeding waterfowl, primarily mallards (*Anas platyrhynchos)* and wood ducks (*Aix sponsa)*. Wintering birds are found

Figure K-20. Map of Uppermost Chesapeake Bay Waterfowl Habitats



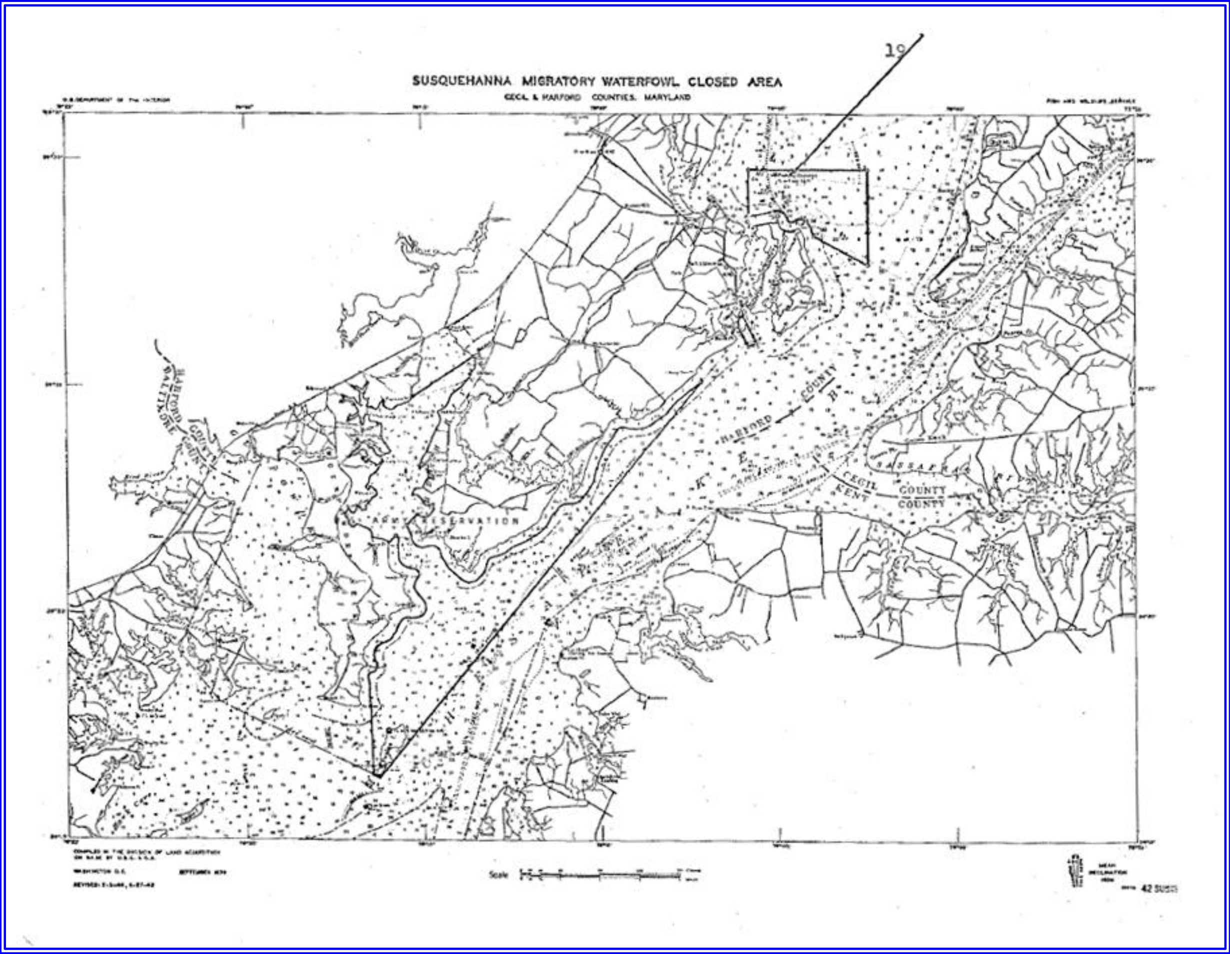
Notes: *Blue-diagonal hatched polygons are important waterfowl habitats.*
Red area is the Aberdeen Proving Ground, a U.S. Army materials testing site.
Source: *Prepared from http://dnr.maryland.gov/ccp/coastalatlas/index.asp.*

predominantly in the river mouth, whereas spring staging birds are distributed across the landscape (Ducks Unlimited, no date).

The upper Bay at the mouth of the river was formerly an important habitat for migratory waterfowl, with hundreds of thousands of individuals making use of the large SAV beds present in the early to mid-20th century. Because of its importance for waterfowl, 13,363 acres of water in the upper Chesapeake Bay and Battery Island were designated as a National Wildlife Refuge (NWR) in presidential proclamations and an executive order over the years from 1939-42; the extent of the NWR is shown in Figure K-21. Battery Island is located at the mouth of the Susquehanna River in Harford County, MD, about 3 miles south of Havre de Grace. The refuge extended from Battery Island to the Bush River along the western shore and primarily consisted of large areas of open water and SAV that were seasonally closed during waterfowl season. Waterfowl use of the area declined dramatically in the 1960s in concert with declines in SAV. Because of the dramatic decrease in waterfowl numbers and submerged vegetation in the area, the presidential proclamations designating the waters of the area as a NWR were lifted on September 1, 1978, and the waters were returned to the State of Maryland. Battery Island is the only extant, designated remnant of the former Susquehanna NWR. Today, only a few thousand geese typically utilize the waters around Battery Island during the winter months (http://www.fws.gov/northeast/susquehanna; USFWS, 2013).

Bird species utilizing Conowingo Reservoir include great blue heron *(Ardea herodias)*, green heron (*Butorides virescens)*, tern species, gull species, double crested cormorant (*Phalacrocorax auritus)*, spotted sandpiper (*Actitis macularia),* belted kingfisher (*Ceryle alcyon*), bald eagle (*Haliaeetus leucocephalus)*, and

Figure K-21. Map of Historic Susquehanna NWR Showing Boundaries



osprey (*Pandion haliaetus)*. Osprey and bald eagle nest along the Conowingo shoreline (URS and GSE, 2012a).

K.8 AIR QUALITY

Air quality is affected by natural and manmade emissions. The former include dust, forest fires, and lightning. Natural emissions occurring at natural rates and within natural ranges are not typically thought of as pollutants in that these produce air quality characteristic of the region. Air pollution derives from manmade emissions from large stationary sources such as power plants and manufacturing facilities, small stationary sources such as dry cleaners and gas stations, mobile sources such as vehicles and equipment, and agricultural sources, including livestock, poultry, and pesticides. The Chesapeake Bay airshed, or area of land from which airborne pollutants can travel to reach the Bay, covers approximately 570,000 square miles (nine times as large as the watershed) and extends from North Carolina in the south, west to Indiana, and north to Canada. On its eastern boundary, the airshed includes western and central New York, western New Jersey, and the Eastern Shore. This region includes the Baltimore-Washington metropolitan region which has among the nation's worst ground-level ozone problems.

Air pollution from the airshed falls back to the earth's surface, affecting people and terrestrial and aquatic environments. Forests absorb some air pollution. A portion of the air pollution falling back to earth and waters is transported into waterways and ultimately into Chesapeake Bay. Principal air pollutants of concern to freshwater and saltwater aquatic ecosystems of the Susquehanna River basin and Chesapeake Bay include nitrogen and contaminants (metals such as mercury, and chemicals such as PCBs and PAHs). Contaminants accumulate in some aquatic organisms in nontidal and tidal waters at levels locally harmful or toxic to the organisms, as well as to people that consume affected shellfish and finfish. Contaminants accumulate locally in fine-grained sediments, posing risk to aquatic life exposed to these sediments. Nitrogen washes into the Bay and contributes to eutrophication. Approximately one-fourth to one-fifth of the nitrogen reaching the Bay derives from air pollution (CBP, 2013).

K.9 WATERSHED VALUES

Uses of the lower Susquehanna River subbasin landscape by people align closely with land cover and land use. Agricultural lands are used to produce food for people and forage for livestock. Forested lands produce timber and produce clean water for streams. Urban lands provide places for people to live and work. Extraction of rocks and minerals also occurs to provide materials for construction and other uses. Some solid waste from human activities is disposed of in landfills. Waters of the Susquehanna River provide drinking water for numerous people in Pennsylvania and Maryland, and provide water for a variety of industrial and agricultural uses. Of particular importance to this study, water in the lower subbasin is used to generate hydropower, providing electricity for a wide area of southeastern Pennsylvania. Waters of the Susquehanna River are also used recreationally for boating and fishing.

K.9.1 Human Population

The Chesapeake Bay watershed has a population of more than 17 million people (CBP, 2013). The Susquehanna River basin itself has a population of 4.1 million people (SRBC, 2013a). The lower Susquehanna River subbasin has a population of 1.9 million, nearly half of the total Susquehanna River basin's population (SRBC, 2013a).

K.9.2 Community Setting

This section provides an overview of political entities of interest of the lower Susquehanna River corridor and was prepared by reviewing and summarizing a variety of readily available geographic maps.

Conowingo Dam sits astride the Susquehanna River in Maryland with its western landing in Harford County and its eastern landing in Cecil County. No incorporated municipalities in either county are located near the dam. Incorporated municipalities lie downstream of the dam along the Susquehanna River: Havre de Grace in Harford County, and Port Deposit and Perryville in Cecil County. The remaining lands along the river are unincorporated and under the governance of the respective counties. Maryland counties are not subdivided into townships, although they can contain incorporated municipalities with their own local governments distinct from that of the county in which they occur.

Unlike Maryland, Pennsylvania counties are subdivided into townships. Safe Harbor and Holtwood Dams have their western landings in York County and their eastern landings in Lancaster County. Each dam lies close to the respective community close to its eastern landing after which it is named. However, neither Safe Harbor nor Holtwood, both in Lancaster County, are incorporated municipalities. Holtwood is a village within Martic Township. Safe Harbor is a community located within Conestoga Township. That said, Safe Harbor Dam's eastern landing is actually within Manor Township which lies immediately northwest of Conestoga Township. The western landings of Safe Harbor Dam and Holtwood Dam lie in Chanceford Township and Lower Chanceford Township, respectively, both in York County. These communities are all effectively suburbs of Lancaster, PA and York, PA.

K.9.3 <u>Water Supply</u>

People in rural areas obtain drinking water from groundwater wells. Historically, people used water from the saprolite in the Piedmont. Today, groundwater for drinking is drawn from bedrock fractures and joints because of lower risk of contamination from surface sources. People in more densely populated areas obtain potable water from a variety of surface water sources.

Both Lake Clarke and Conowingo Reservoir are currently a surface water source for several entities, as detailed in Table K-8. SRBC has no records of significant intakes from Lake Aldred, presumably because of its more remote locale. Downstream of Conowingo Dam, several municipalities obtain water from the Susquehanna River. In Cecil County, Port Deposit and Perryville utilize water from the river. Both municipalities identify excess sediment as concerns for continued water use (Cecil County, 2008). In Harford County, the city of Havre de Grace has a water withdrawal permit for 10 million gallons per day from the Susquehanna River. The city's intake is exposed to tidal influence when the discharge from Conowingo Dam is low; consequently, its water quality can be impacted by salinity (SRBC, 2006c).

K.9.4 <u>Transportation Infrastructure</u>

Railroad tracks of Norfolk-Southern parallel the Susquehanna River on its eastern bank. The tracks connect to Perryville, MD, in the south, and to Harrisburg and other points in Pennsylvania in the north. These tracks pass on the east side of Conowingo, Holtwood, and Safe Harbor Dams. No railroad bridges cross near any of the three dams. The southwest/northeast-oriented railroad tracks of the CSX Corporation cross the lowermost Susquehanna River at Havre de Grace and Perryville, MD. Amtrak also has a bridge crossing between Havre de Grace and Perryville on southwest/northeast-oriented tracks.

U.S. Route 1 crosses the Susquehanna River over the Conowingo Dam. No roads cross over the Susquehanna River on either Holtwood or Safe Harbor Dams. Route 1 typically conveys about 12,270 vehicles across the bridge per day (MDOT, 2013). Pennsylvania Route 372 crosses the Susquehanna River about 1 mile downstream of Holtwood Dam. No highway bridges cross the Susquehanna River in the vicinity of Safe Harbor Dam.

Table K-8. Entities Using the Lower Susquehanna Reservoirs as a Water Source

Reservoir	Entity	Usage
Conowingo Reservoir	Peach Bottom Atomic Power Station, York County, PA City of Baltimore, MD Harford County, MD	Cooling Municipal water supply Public water supply (provided by Baltimore's system)
	Chester Water Authority, PA	Water supply utility, serving areas of southeast Pennsylvania and northern Delaware
	York Energy Center, PA	Water source
Lake Clarke	Columbia Water Company, PA	Municipal water supply
	Lancaster City Water System, PA	Municipal water supply
	Red Lion Borough Municipal Authority, PA	Municipal water supply
	Wrightsville Borough Municipal Authority, PA	Municipal water supply
	York Water Company, PA	Municipal water supply

Source: For Conowingo information, URS and GSE, 2012a*; for Lake Clarke information, SRBC records.*

K.9.5 Navigation

USACE maintains a navigation channel called the Susquehanna River at Havre de Grace Project (previously shown in Figure K-13) that extends from Havre de Grace at the mouth of the Susquehanna River along the west side of the Susquehanna Flats to waters of 15-foot depth in the upper Bay 4 miles southward (USACE, 2012). The project provides for: (1) a channel 200 feet wide and 15 feet deep from that depth in Chesapeake Bay to Havre de Grace, (2) removal of the shoal opposite Garrett Island to a depth of 8 feet, and (3) maintenance of the existing small boat harbor (380 feet wide, 400 feet long) with an approach channel 75 feet wide to a depth of 7 feet. The most recent dredging occurred in 2012 with the removal of 200,000 cubic yards of sand. The dredged material was placed to expand Battery Island and subsequently planted to provide habitat for waterfowl.

Navigable reaches occur in the Susquehanna River. However, the river is typically shallow, and boulders and rock outcrops are common, limiting commercial navigation in the river (PFBC, 2012).

Historically, there were canals on both the west and east banks of the lower Susquehanna River. The Susquehanna Canal on the east bank ran from the Chesapeake Bay to the Pennsylvania line in Maryland. The canal was completed in 1802 and closed in 1840. A canal on the west bank of the Susquehanna River called the Susquehanna and Tidewater Canal ran from Havre de Grace, MD, to Wrightsville, PA. The canal was completed in 1840 and ceased operations in 1894, although it was in decline through much of the late 19^{th} century (Wikipedia, 2013).

K.9.6 Recreational Water Activities/Uses

Recreational boating and fishing opportunities abound in Chesapeake Bay. Numerous private marinas and boat ramps provide access points for boats. There are also a limited number of public marinas and boat ramps. While the Bay shoreline is publicly owned, infrequent public access points from land effectively limit public shoreline use where privately owned lands lie adjacent to the Bay. Efforts are underway to increase public access to the Bay (CBP, 2013).

The uppermost Chesapeake Bay and its tributary rivers are a notable sport-fishing area. Fish species caught shift through the months of the year reflecting movements of migratory fish into and out of the upper Bay, as well as availability of resident fish. Fish caught typically start with yellow perch in February. Then white perch, striped bass, and shad are caught in March and April. Largemouth bass (*Micropterus salmoides*) become a target species beginning in May. In the summer and fall, striped bass, perch, and various species of catfish are caught (MDNR, 2003).

The upper Chesapeake Bay in the vicinity of Susquehanna Flats is notable in that low salinities restrict jellyfish, and waters there are swimmable throughout warm weather months. A number of public beaches that provide swimming opportunities are located along the shoreline. In contrast, the middle and lower Bays generally support large numbers of sea nettles in warm weather months and are unswimmable at those times.

Shallow depths and numerous rock obstructions limit boating opportunities in the Susquehanna River. However, small boat users who have knowledge of river conditions do make ready use of the river. In contrast, the series of lakes created by the lower Susquehanna River dams provide practical boating opportunities for sailing, water skiing, and fishing. The lakes have a variety of marinas, boat ramps, picnic grounds, playgrounds, and other recreational facilities. In addition, the lakes and adjacent lands provide opportunities for hunting waterfowl and large and small game, as well as hiking (PFBC, 2012). Heated effluent discharged from the Peach Bottom Atomic Power Station into Conowingo Reservoir attracts game fish during the winter and creates an extended open-water fishing season (SRBC, 2006a).

K.10 HYDROELECTRIC DAM STRUCTURES AND OPERATIONS

The three major hydroelectric facilities on the lower Susquehanna River, from upstream to downstream, are Safe Harbor Hydroelectric Station (at Safe Harbor Dam), Holtwood Hydroelectric Station (at Holtwood Dam), and Conowingo Hydroelectric Generating Station (at Conowingo Dam). The locations of these facilities are shown in Figure 1-2 of the main report. A comparison of their engineering attributes is included in Table K-9. Safe Harbor, Holtwood, and Conowingo are all peaking hydroelectric facilities that utilize limited active water storage reservoirs to generate electricity during peak generation periods. Because they supply power only occasionally, during critical peak demand times, the power supplied commands a much higher price per kilowatt hour than base load power.

Table K-9. Engineering Attributes of the Lower Susquehanna Hydroelectric Dams

Facility	River Miles from Chesapeake Bay	Dam Height (feet)	Dam Length (feet)	Reservoir Area (acres)	Usable Storage (acre-feet)	Normal Pool Elevation (feet, NGVD29)	Generating Capacity (megawatts)	Hydraulic Capacity (cfs)
Safe Harbor Dam and Lake Clarke	32	75	4,869	7,424	53,750	224.2 – 227.2	417.5	110,000
Holtwood Dam and Lake Aldred	24	55	2,392	2,400	14,700	163.5 – 169.75	196[1]	61,460[2]
Conowingo Dam and Reservoir	10	94	4,648	8,625	75,400[3]	104.7 – 109.2	573	86,000

Notes: [1] *Post-expansion total generation capacity.*
[2] *Post-expansion total hydraulic capacity.*
[3] *Usable storage in FERC-allowable pool (101.2 feet to 109.2 feet). Storage from 104.7 feet to 109.2 feet is approximately 40,000 acre-feet.*

Source: Gomez and Sullivan Engineers, 2012.

K.10.1 Safe Harbor Hydroelectric Station

Safe Harbor is owned by Safe Harbor Water Power Corporation. Construction started in November 1929, and the project became operational in December 1931. Safe Harbor Dam is a concrete gravity dam. Its outlet infrastructure consists of 3 double leaf regulating gates and 28 flood gates. The normal pool elevation range is from 224.2 to 227.2 feet (NGVD29, National Geodetic Vertical Datum of 1929). Safe Harbor does not currently have a minimum flow requirement. The original project license expired in 1980. When the project was relicensed, its owner proposed to add an additional five generating units to increase the authorized installed capacity from 230 megawatts (MW) to the current capacity of 417.5 MW. Because of this substantial redevelopment, the Federal Energy Regulatory Commission (FERC) issued a 50-year license for the project. Safe Harbor's current license expires in 2030.

K.10.2 Holtwood Hydroelectric Station

The Holtwood facility is owned by PPL Holtwood, LLC (PPL). Construction began in 1905, and the project began operation in 1910. The dam is an overflow-type structure raised by wooden flashboards and an inflatable rubber dam. No flood gates are installed at the dam. Prior to a 2010-14 expansion, Holtwood had an installed capacity of 107 MW and an estimated hydraulic capacity of 31,500 cfs. In the past decade, FERC issued PPL a license amendment to expand the capacity at Holtwood. Construction began in 2010 and is projected to be complete in 2014. Table K-9 shows the total generation capacity and hydraulic capacity following completion of this expansion. As part of the project expansion license agreement, PPL agreed to supply Conowingo with a continuous inflow of 800 cfs from the Holtwood Dam, and a daily volumetric flow equivalent to 98.7 percent of

Conowingo's minimum continuous flow requirement aggregated over a 24-hour period, or net inflow. Holtwood's current license expires in 2030.

K.10.3 Conowingo Hydroelectric Generating Station

The Conowingo Dam facility is owned by Exelon Generation, LLC. Construction started in 1926, and the project became operational in 1928. Conowingo Dam is a concrete gravity dam. The dam forms Conowingo Reservoir, with a surface area of 8,625 acres.

FERC license requirements allow Conowingo Reservoir elevation to fluctuate from 101.2 to 110.2 feet NGVD29. However, water levels are primarily confined to elevations between 107 and 109 feet NGVD29, and rarely fall below 106 feet NGVD29 (URS and GSE, 2012a).

Flow over the ogee spillway sections (S-shaped control weirs) is controlled by 50 stony-type crest gates and two regulating gates. Each crest gate is 22.5 feet high by 38 feet wide and has a discharge capacity of 16,000 cfs at a reservoir elevation of 109.2 feet NGVD29. The two regulating gates are 10 feet high by 38 feet wide and have a discharge capacity of 4,000 cfs per gate at a reservoir elevation of 109.2 feet NGVD29. Each gate is lifted vertically by crane and can be set either fully open or fully closed with no intermediate setting. The total discharge capacity of the gates is approximately 808,000 cfs. Conowingo currently has seven Francis turbines (with a flow capacity of approximately 6,700 cfs each) and four Kaplan turbines (approximately 9,700 cfs each). Figure K-22 shows an aerial view of the downstream side of the dam and its regulating gates

The Conowingo Reservoir extends approximately 14 miles from Conowingo Dam upstream to the lower end of the Holtwood Dam tailrace. The reservoir has a design storage capacity of 310,000 acre-feet, of which 75,400 acre-feet are usable storage. The reservoir provides water for diverse uses including hydropower generation, water supply, industrial cooling water, recreational activities, and various ecological resources. Relative to hydropower generation, Conowingo Reservoir serves as the lower reservoir for the 800-MW Muddy Run Pumped Storage Project (Muddy Run), located 12 miles upstream of the Conowingo Dam. It also serves as the source of cooling water for the 2,186-MW Peach Bottom Atomic Power Station, located approximately 7 miles upstream of Conowingo Dam (URS and GSE, 2012a).

Managing Conowingo Reservoir requires an integrated and complex operational approach. The Conowingo license is set to expire on August 14, 2014. FERC, the licensees, and stakeholders have been involved in the integrated licensing process for Conowingo Dam over the past several years. A final license application was submitted to FERC on August 13, 2012, requesting a new license. Section 2.3 in the main report of this assessment provides more details on licensing requirements and status.

Figure K-22. Conowingo Dam Aerial

Photo credit: USACE, 1980.