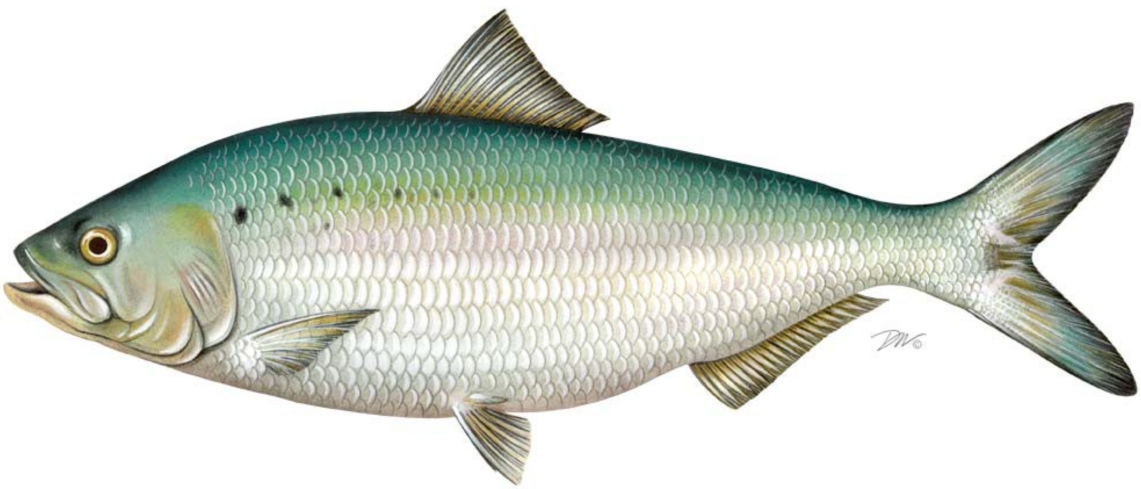
American Shad Habitat Plan for theJames, York and Rappahannock Rivers



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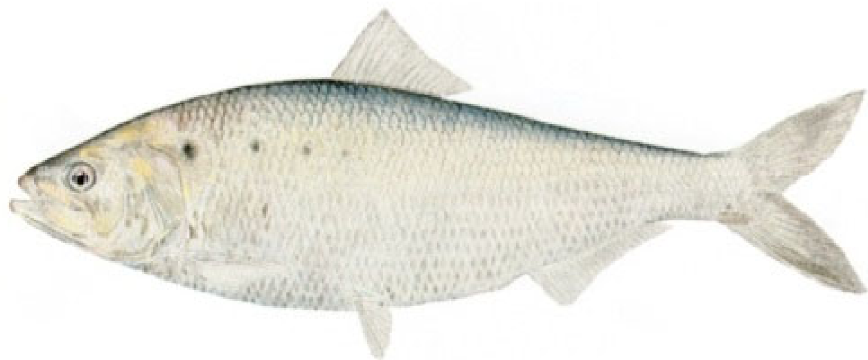
Approved October 19, 2021

Commonwealth of Virginia American Shad Habitat Plan

2021 Update



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Introduction

The Virginia American Shad Habitat Plan for the ASMFC is a joint effort between staff of the Virginia Institute of Marine Science, Virginia Department of Wildlife Resources, and the Virginia Marine Resources Commission. This 2021 report includes additional information or progress on existing threats recorded within the 2014 report, but also includes documentation of three additional threats considered to impact American Shad habitat: 1) In-river construction and blockage to migration; 2) Agricultural water intakes; and 3) Industrial water intakes and discharge. The scope of this report is limited to the three primary tributaries of the Chesapeake Bay within Virginia (James, York, and Rappahannock rivers. We thank Emily Hein (VIMS), Eric Brittle (VDWR), and Randy Owen and Tiffany Birge (VMRC) for information.

Agencies within the Commonwealth of Virginia with Regulatory Ability Related to American Shad or American Shad Habitat Management

Virginia Marine Resources Commission (VMRC). The VMRC is divided into three divisions: 1) Fisheries Management, which is charged with regulation of fisheries resources in tidal and marine environments, including collection of fisheries statistics, development of management plans, and promotion and development of recreational fishing activities; 2) Habitat Management, which manages and regulates the submerged bottom lands, tidal wetlands, sand dunes, and beaches; and 3) Law Enforcement, which enforces state and federal fisheries laws and regulations.

Virginia Department of Wildlife Resources (VDWR). The Department of Game and Inland Fisheries became the Department of Wildlife Resources on July 1, 2020. The VDWR manages and regulates inland fisheries, wildlife, and recreational boating for the Commonwealth of Virginia, and is responsible for enforcement of laws pertaining to wildlife and inland fisheries management.

Virginia Department of Environmental Quality (VDEQ). The VDEQ is charged with monitoring and regulating the quality of air and water resources in Virginia. VDEQ is organized into many programs, including Air, Water, Land Protection and Revitalization, Renewable Energy, Coastal Zone Management, Enforcement, Environmental Impact Review, Environmental Information, and Pollution Prevention.

In addition to state agencies, the Army Corps also regulates all of these areas from the federal perspective (with input and/or official consultation with other federal agencies such as NOAA-Fisheries and Fish and Wildlife Service).

Habitat Assessment

In Virginia, American Shad is found in the Chesapeake Bay and its major tributaries, including the Potomac, Rappahannock, York, and James rivers, as well as smaller tributaries and other coastal habitats (e.g., along the Delmarva peninsula) (Fig. 1). Additionally, American Shad are found in certain rivers in Virginia that drain to North Carolina (Desfosse et al., 1994). We include description of the habitat of these systems in Virginia, but there are no regular surveys of the status of these stocks in Virginia's portion of these systems beyond their presence in the systems. We focus discussion on the major western tributaries of the Chesapeake Bay as these are the primary stocks in Virginia waters. Although certain spawning/rearing reaches are known for American Shad for individual rivers (Bilkovic et al. 2002), the amount of habitat used by American Shad for these life history stages at a river-wide scale is unknown for Virginia tributaries of the Chesapeake Bay. Several tidal portions of the three major Virginia tributaries of the Chesapeake Bay have been designated as high priority areas for living resources, and migratory fishes in particular (Figs. 2, 3).

James River

The James River forms at the junction of the Cowpasture and Jackson rivers (rkm 580), and its drainage is the largest watershed in Virginia, totaling 26,164 km^2 (Jenkins and Burkhead, 1994). Average annual spring discharge on the James River is 294.2 m^3/s (Tuckey 2009). Prior to damming, which began in the colonial period, shad and river herring were reported to reach these headwaters and far into the major tributaries of the James River (Loesch and Atran, 1994). The two primary tributaries of the James River below the fall line at Richmond are the Appomattox River, which joins at the city of Hopewell (rkm 112), and the Chickahominy River, which joins at rkm 65. The extent of salt water is variable, but brackish conditions are observed as far up as the mouth of the Chickahominy River on a seasonal basis. Tidal water reaches the City of Richmond at approximately rkm 167 at the lower end of the fall zone. Boshers Dam is at the upper end of the fall zone at rkm 182.

York River System

The York River system includes the Mattaponi and Pamunkey rivers, which merge at West Point, VA, to form the York River (53 rkm). This is the smallest of the three western tributary systems, with a watershed of 6,892 km^2 (Jenkins and Burkhead, 1994); the Pamunkey drainage is larger and has greater average spring discharge than that of the Mattaponi (3,768 km^2 and 47.5 m^3/s vs. 2,274 km^2; 27.2 m^3/s, Bilkovic 2000). Tidal propagation extends to approximately 67 rkm in the Mattaponi and 97 rkm in the Pamunkey (i.e., approximately 120 km and 150 km, respectively, from the mouth of the York River; Lin and Kuo, 2001). The extent of the salt intrusion varies by season, but moderate salinity values (>2 ppt) are often observed in lower portions of these rivers.

Rappahannock River

The Rappahannock River, which is approximately 314 km in length (172 km is tidal; 118 km is salt water), has its headwaters in the Piedmont and is fed by the Rapidan River. The Rappahannock watershed encompasses a total of 7,032 km^2 (Jenkins and Burkhead, 1994), and the average annual discharge at the fall line is 45 m^3/s (O'Connell and Angermeier 1997). An estimated 125 tributaries of the Rappahannock River are potentially used by alosines (O'Connell and Angermeier 1997).

Other systems

American Shad are known from the Chowan River drainage, which in Virginia comprises the Meherrin River, and the Nottoway and Blackwater rivers (the latter two form the Chowan River in North Carolina). Collectively, the watershed of these rivers forming Virginia's portion of the Chowan River drainage is 10,518 km^2 (Jenkins and Burkhead, 1994). The Nottoway and Blackwater rivers support American Shad, which were collected in the mainstems of the rivers in 2020 (Brittle, 2020a, b). There are no dams that impede American Shad migrations on either river (E. Brittle, VDWR, pers. comm. Sept. 2021).

The Meherrin River, which originates in Virginia, joins the Chowan River in eastern Hertford County, North Carolina. The Meherrin is largely blocked for migration by fishes by a dam at Emporia, VA (E. Brittle, VWDR, pers. comm. Sept. 2021), although American Shad have been collected within the Meherrin at the base of the Emporia Dam. A fish lift is present at the dam, and based on surveys conducted up river, there is at least historical (1990s) use of the lift by migrating American Shad. There is currently little directed sampling above the dam and the hydropower operator is not required by FERC to monitor the lift, so the current usage of upstream portion of the river by American Shad is unknown. The downstream portion of this river has not been surveyed for anadromous fishes since 2006 (E. Brittle, VDWR, pers. comm. Sept. 2021).

Threats Assessment and Habitat Restoration Programs

Rulifson (1994) identified the following river specific factors potentially involved in the decline of migratory alosines in Virginia, including American Shad:

<u>Rappahannock River:</u> dams, overfishing, turbidity, low oxygen

<u>York River System:</u>
- York River: industrial water intakes, industrial discharge locations, overfishing, chemical pollution, thermal effluents, low oxygen, sewage outfalls
- Mattaponi River: industrial discharge locations, overfishing, thermal effluents
- Pamunkey River: industrial discharge locations, overfishing, thermal effluents

<u>James River System:</u>
- James River: channelization, dredge and fill, dams, industrial water intakes, industrial discharge locations, overfishing, chemical pollution, thermal effluents, turbidity, sewage outfalls
- Nansemond River: dams
- Chickahominy River: dams, industrial discharge locations, overfishing.
- Appomattox River: dams
- Pagan River: turbidity, sewage outfalls

Further Rulifson (1994) identified the potential habitat management practices, or rather their effects, involved in the decline of migratory alosines in Virginia, including American Shad:

Rappahannock River: inadequate fishways, reduced spawning habitat

York River System:
- York River: poor water quality
- Mattaponi River: poor water quality
- Pamunkey River: poor water quality

James River System:
- James River: inadequate fishways, reduced freshwater input to estuaries, reduced spawning habitat, poor water quality, water withdrawal
- Nansemond River: inadequate fishways, reduced freshwater input to estuaries, reduced spawning habitat, water withdrawal
- Chickahominy River: reduced freshwater input to estuaries, reduced spawning habitat, fishing on spawning area, water withdrawal
- Appomattox River: inadequate fishways, water releases from dams, reduced spawning habitat, water withdrawal
- Pagan River: turbidity, poor water quality

From the above threats assessment, several primary classes of threats and their associated repercussions are identified here in relation to American Shad habitat needs and restoration in Virginia. These are discussed below.

Threat: Barrier to Migration (Dams). As an anadromous fish, American Shad are negatively impacted by obstructions to migration from marine and estuarine habitats to the upstream freshwater spawning and rearing habitats. Here we provide a review of the primary obstructions found on the three Virginia tributaries of the Chesapeake Bay.

Rappahannock River: The main stem of the Rappahannock River was dammed until 2004-2005 when the submerged Crib Dam (built in 1854) and the Embrey Dam (built in 1910) at Fredericksburg (rkm 179) were removed. Removal of the dam reopened 170 km of potential habitat on the Rappahannock and Rapidan rivers for migratory fishes, such as American Shad and river herring (American Shad and Blueback Herring have been collected 45 km upstream of dam). Over 2,200 miles of Upstream Functional Network miles were reopened by the removal of Embrey Dam, which was the last remaining dam on the Rappahannock main stem. Upstream Functional Network miles are all miles accessible on the barrier stream plus all accessible tributary miles above the passage project (Martin, 2019). There are dams in place on tributaries of the Rappahannock (e.g., the Rapidan River) that may impede migration of American Shad (although it is unknown if American Shad used these reaches prior to dam installation). A fish passage was installed on the Orange Dam on the Rapidan River, a tributary of the Rappahannock (http://www.dwr.virginia.gov/fishing/fish-passage/) 16 km upstream of Rapidan Mill Dam, which remains as a migration barrier.

York River System: The Mattaponi, Pamunkey, and York rivers are all completely undammed. There are few dams in place on some tributaries of these rivers (e.g., the Ashland Mill Dam on the South Anna River, a tributary of the Pamunkey, which is known to block American Shad migration).

James River: Numerous dams on the James River and its tributaries have historically blocked migration of fishes. Between 1989 and 1993 three dams in the fall zone in Richmond were breached or notched, extending available habitat to the base of Boshers Dam. A fish passage was installed in Boshers Dam (built in 1823) in 1999, reopening 221 km of the upper James River and 322 km of its tributaries to American Shad and other anadromous fishes; the next dam of the mainstem is at Lynchburg, VA (Weaver et al., 2003). A total of 4,700 upstream functional network miles were reopened by the Boshers fishway (Martin, 2019). Approximately 204 km of the main stem of the Appomattox River is accessible to American Shad. Harvell Dam (rkm 17) in Petersburg, VA had a Denil fishway (1998) and then the dam was removed in 2014. Brasfield Dam (rkm 28) that forms Lake Chesdin near Matoaca, VA has a fish lift that completes passage through the Appomattox fall zone resulting in access to 2,957 upstream functional network miles. The first dam on the Chickahominy is Walkers Dam at rkm 35 that has a functioning double Denil fishway built in 2015 that reopens 48 mainstem river kilometers (508 upstream functional network miles). American Shad are known to use the Walkers fishway (2021 DWR trapping data) and have been found over 40 km upstream (Michael Odom, USFWS personal communication 2020). A number of additional dam removal and fishway construction projects have occurred in the past on several smaller creeks and streams in the James River drainage as well (http://www.dwr.virginia.gov/fishing/fish-passage/).

Recommended Actions: Installation of fish passage systems, breaching and removal of dams as appropriate (see Fig. 4 for recent activities in Virginia and the Chesapeake Bay watershed generally). Continued monitoring of fish passage systems currently in place for effectiveness for American Shad passage.

The remaining significant American Shad habitat that is yet to be reopened in Virginia includes the South Anna River, a tributary of the Pamunkey River, upstream of the Ashland Mill Dam (this would open 59.5 km of shad habitat on the mainstem plus any suitable tributary miles). American Shad were routinely collected during sampling for several years below Ashland Mill Dam at Rt. 1 and continue to be caught by anglers below the dam. Discussion of removal of this dam was proposed as mitigation for the King William Reservoir and there have been recent discussions of removal being done for mitigation credits, but the dam is still in place. Ashland Mill Dam is a Tier 1 (top 5% priority) barrier in the Chesapeake Bay Fish Passage Prioritization Tool (https://maps.freshwaternetwork.org/chesapeake/#) . In the James River, there remain seven dams spaced over 34 km beginning with Scott's Mill Dam in Lynchburg, VA (removal of these barriers or passageway installation would open a significant amount of habitat). Within the Rappahannock River system, removal or fish passage at the Rapidan Mill Dam (on the Rapidan River, a tributary of the Rappahannock; also a Tier 1 priority) would open 53.1 km of habitat because there is a Denil fishway on a water supply dam (Orange, VA) 16 km upstream of Rapidan Mill Dam. Passage options are currently being explored including removal for mitigation credits.

Agency or Agencies with Regulatory Authority: Licensing and relicensing of dams is regulated by FERC. Within Virginia, VDWR oversees the Fish Passage Program. VMRC, VDWR, and VDEQ all may be involved with the permitting process, regulations and monitoring of aspects of fish passage systems, dam removals, and other environmental factors associated with these activities depending on position of the dam. VDWR consults with fish passage engineers from the USFWS throughout fish passage projects.

Goal: "The importance of migratory fish species was recognized in the 1987 Chesapeake Bay Agreement and re-affirmed in Chesapeake 2000. A commitment was endorsed to 'provide for fish passage at dams and remove stream blockages whenever necessary to restore natural passage for migratory and resident fish.' The Fish Passage Work Group of the Bay Program's Living Resource Subcommittee developed strategies (1988) and implemented plans (1989) to fulfill this commitment. In 2004, the original Fish Passage Goal of 1,357 miles (established in 1987) was exceeded. Chesapeake 2000 led to the establishment of a new Fish Passage Goal, set in 2004, committing signatory jurisdictions to the completion of 100 fish passage/dam removal projects," to re-open an additional 1,000 miles of high-quality habitat to migratory and resident fishes. This increased the overall goal to 2,807 total miles for which Virginia is responsible for roughly one-third of the miles to be reopened. [from VDWR (https://dwr.virginia.gov/fishing/fish-passage/#background; accessed June 28, 2021)].

Progress: Through 2013 partners reopened a total of 2,690.75 miles based on the original method of counting miles (mainstem miles only on barrier stream). Starting with 2014, the method for counting miles reopened was modified to begin counting all accessible miles above a barrier on the barrier stream and its tributaries. This method calculates what is known as "upstream functional network miles" in order to provide a more realistic picture of habitat restoration and accessibility (Martin, 2019). Using this GIS based method over 12,000 miles have been reopened by dam removal and over 19,000 miles have been reopened by fish passage installation for a grand total of 31,313.4 upstream functional network miles. Because American Shad tend to spawn in larger streams not all of the upstream functional network miles are necessarily available to shad spawning. The current Long-term Target in the Chesapeake Bay Fish Passage Logic and Action Plan is as follows: Continually increase access to habitat to support sustainable migratory fish populations in the Chesapeake Bay watershed's freshwater rivers and streams. By 2025, restore historical fish migration routes by opening an additional 132 miles every two years to fish passage. Restoration success will be indicated by the consistent presence of Alewife, Blueback Herring, **American Shad**, Hickory Shad, American Eel and Brook Trout, to be monitored in accordance with available agency resources and collaboratively developed methods.

Cost: N/A

Timeline: N/A. Other than continuing to contribute to the overall Bay passage goal target dates there is no Virginia specific timeline set for dam removal and fish passage installation in Virginia. While not set for individual species (i.e., specific to American Shad), the next phase in prioritizing will use the prioritization tools and other existing information to create a Virginia plan that could include breaking down habitat total goals and accomplishments per anadromous species, including American Shad.

Threat: Pressures from Land Use Associated with Population Growth

Many of the non-barrier threats identified by Rulifson (1994) can be collectively viewed as the results of changes in land use associated with population growth. The human population surrounding the three primary Virginia rivers is centered in Richmond (James River), with a significant population center in Fredericksburg (Rappahannock River); the remaining areas are rural (Fig. 5). According to the Chesapeake Bay Program, within Virginia land use pressure is highest along the James River at Richmond, with other significantly high vulnerability levels at the James River near the confluence of the Chickahominy River, and the peninsula separating the James River from the York River (Fig. 6). Land use surrounding rivers within the Chesapeake Bay watershed in Virginia likely is associated with contamination (significant levels throughout, principally PCBs, but also metals within the York River system; Fig. 7), sediment load (High in the Rappahannock, Low in the York River system, Chickahominy and Appomattox rivers, and Medium in the Upper James River; Fig. 8), and phosphorus yields (High in the Rappahannock, Medium in the Upper James River, and Low in the other rivers; Fig. 9); nitrogen yields are low in all three river systems (Fig. 10). Low summertime dissolved oxygen levels remains a threat in all portions of three rivers, except the upper Mattaponi and upper Pamunkey rivers (York River System), and the upper James River (Fig. 11).

Recommended Action: No specific actions can be identified related to mitigation against land use in Virginia as it relates to American Shad habitat use. Indeed, it is difficult to identify specific actions to be taken in land use management that will affect American Shad population status (Waldman and Gephard, 2011). However, further study of freshwater habitat use by American Shad in Virginia is needed. Specifically, quantification and analysis of specific reaches of riverine habitats used by American Shad during residency (adults during the spawning run, larvae, and juveniles) is needed to better manage and address habitat concerns of the species. As a first step toward addressing decline of American Shad in Virginia, in part due to habitat alteration, a hatchery stocking program ran from 1994 to 2017 in the James River and 2003 to 2014 in the Rappahannock River.

Agency or Agencies with Regulatory Authority: Land use regulations associated with water quality primarily are under the authority of VDEQ, although both VMRC and VDWR may be involved in the permitting process and other aspects of regulation for certain activities that will affect water quality.

Goal: No specific goals are identified for protecting American Shad from pressures associated with habitat alteration and other land use changes. Enforcement of a moratorium on fisheries of American Shad (VMRC; VDWR) is aimed at curbing further declines.

Progress: The moratorium for American Shad has been in place in Virginia since 1994. Stocking of hatchery fishes (VDWR) ceased on the Rappahannock after the 2014 season and on the James after the 2017 season.

Cost: N/A

Timeline: N/A

Threat: In-River Construction Blocking Migration

In-river construction projects such as bridge and tunnel construction and maintenance, dredging, and others, have the potential for disruption of American Shad migration (as well as that of other anadromous fishes) from both direct (e.g., acoustic interference) and indirect (e.g., habitat alteration) factors.

Recommended Action: Enforcement of time-of-year restrictions (TOYR). Current TOYR for American Shad are between February 15 and June 30 of any year (https://dwr.virginia.gov/wp-content/uploads/media/Time-of-Year-Restrictions.pdf). There may be case-by-case relaxation of this TOYR exceptions based on where the work is proposed. For example, upstream of Boshers Dam on the James River, VDWR recommend the TOYR to be March 15 to June 30 because American Shad do not reach this point in the river until mid-March. Case-by-case consideration of appropriate mitigation measures for individual projects (e.g., bubble curtains, coffer dams, etc.).

Agency or Agencies with Regulatory Authority: VMRC regulates any structures on, over, or under subaqueous bottom, the local wetlands board (or VMRC if a locality has not adopted the Wetlands Ordinance) regulates anything on, under, or over tidal wetlands (between mean low water and mean high water for non-vegetated areas and between mean low water and 1.5 x the tide range above mean high water for vegetated wetlands). VMRC distributes permit applications to other regulating agencies and other agencies (e.g., DWR, VIMS) that do not issue permits themselves to provide input to the permit process during the public interest review.

Goal: No specific goal is set for this threat, as the projects are sporadic and change year to year. However, with each application, measures of how the project will affect habitat are assessed and considered during the application process. Any request for TOY suspension for a specific project is vetted by inter-agency discussions.

Progress: Using the most recent five-year average (2016-2020), approximately 1,789 permit applications are estimated to be submitted per year for projects in Tidewater Virginia that have the potential to impact American Shad habitat. Within the same five-year time window, an estimated average of 346 permit applications per year for the non-tidal reaches of Virginia are received. An unknown number of these projects have the potential to adversely affect this species' habitat. Project scope ranges from small developments with minor impacts, if at all (e.g., dock construction and repair) to major infrastructure improvements (e.g., construction of a new tunnel across the mainstem of the James River).

Cost: N/A

Timeline: N/A

Threat: Surface Water Withdrawal and Discharge

Surface water is removed for power generation (nuclear and fossil fuel), manufacturing, and agriculture, and may be categorized as either consumptive (irrigation) or non-consumptive (e.g., power generation). Surface water withdrawals in Virginia include significant removal of water from reservoirs, ponds and other impoundments, springs, rivers, and streams, and in 2019 accounted for 89% of total (=surface + ground) water withdrawals within the Commonwealth (1.1 billion gallons per day); this was 1% lower than the five-year average due to decrease in manufacturing (VDEQ 2020). The surface waters used by American Shad are subject to significant withdrawals, with the largest volumes removed occurring in the waters surrounding Richmond, Hampton Roads, and Washington D.C. (as well as Giles County, which lies outside of the range of American Shad).

In Virginia, the withdrawal of volumes greater than the average of 10,000 gallons per day during a month, or 1 million gallons per month for non-tidal waters (60,000 gpm for tidal waters) for irrigation are required to be reported through the Water Withdrawal Reporting Regulation

(VDEQ 2020). The VDWR recently updated its recommendations for design and operation of stream intakes (https://dwr.virginia.gov/wp-content/uploads/media/Surface-Water-Intake-Design-Operation-Standards.pdf), with the following requirements: intake is fitted with a screen with openings no larger than 1 mm, the intake velocity does not exceed 0.25 feet per second, and the intake does not withdraw more than 10% of the instantaneous flow. However, because of the permitting thresholds, the withdrawal of surface water for most agricultural purposes is exempt from permitting requirements, but have the potential to directly impact American Shad through impingement and entrainment.

Recommended Action: Develop a better understanding of the amount of water intakes for agriculture, particularly in tidal streams and rivers that support American Shad spawning and nursery grounds. Further, the effects (e.g., temperature and chemical differences) of discharge in non-consumptive water withdrawals on American Shad (particularly on early life history stages) is unknown.

Agency or Agencies with Regulatory Authority: VDEQ regulates water withdrawals and discharges. The VDEQ reports annually (October) to the VA Governor and General Assembly on the status of Water Resources in the Commonwealth. In-stream work is permitted by VMRC. VDEQ regulates water withdrawals, although water intakes for agricultural use (i.e., irrigation) are exempt (see 9VAC25-210-310; https://www.deq.virginia.gov/permits-regulations/permits/water/water-withdrawal).

Surface water withdrawal permits are applied for through the VDEQ, with input from VMRC and the U.S. Army Corps of Engineers (USACE) with VDEQ determining the potential impact on aquatic life, water quality, recreation, and downstream impacts.

Goal: Although by law the withdrawal of surface water for agricultural purposes is unregulated, (i.e., exempt from permit requirements), these withdrawals, given their position within the watersheds, are undoubtedly a potential source of loss of early life history stages through impingement and entrainment. Data on the prevalence of agricultural intakes within specific river systems would allow for estimation of potential losses of larval American Shad. This is a recognized concern by the VDEQ (2020). VDEQ has "tentatively been approved for federal funding from the USGS Water Use Data Research Program to support a project to improve estimates of agricultural water use." This and other VDEQ studies, including habitat and water quality and ecological modeling, are steps to fill these information gaps.

Progress: Nothing yet to report.

Cost: N/A

Timeline: N/A

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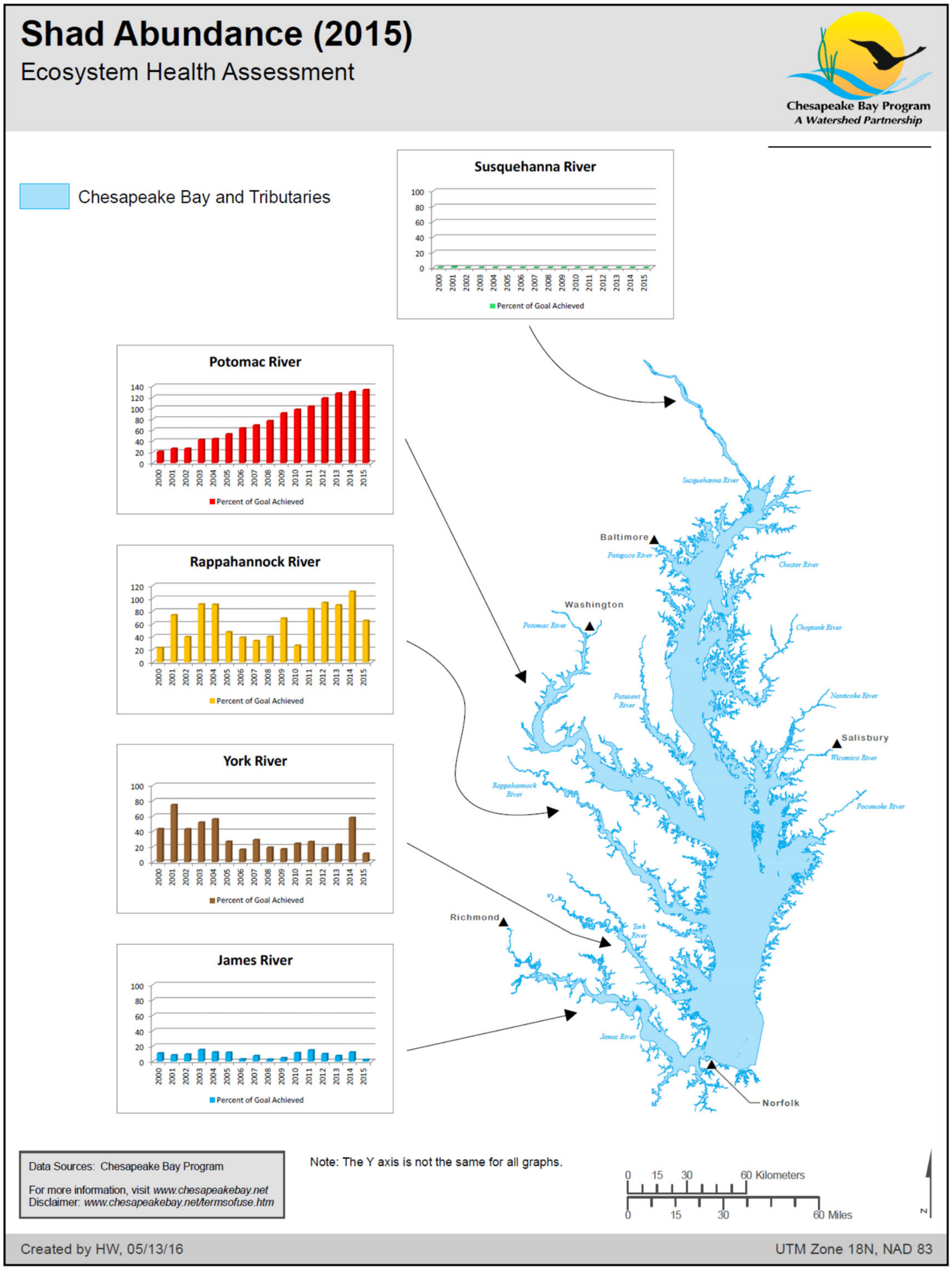

Figure 1. Shad distribution and abundance in the Chesapeake Bay. (Source: Chesapeake Bay Program)

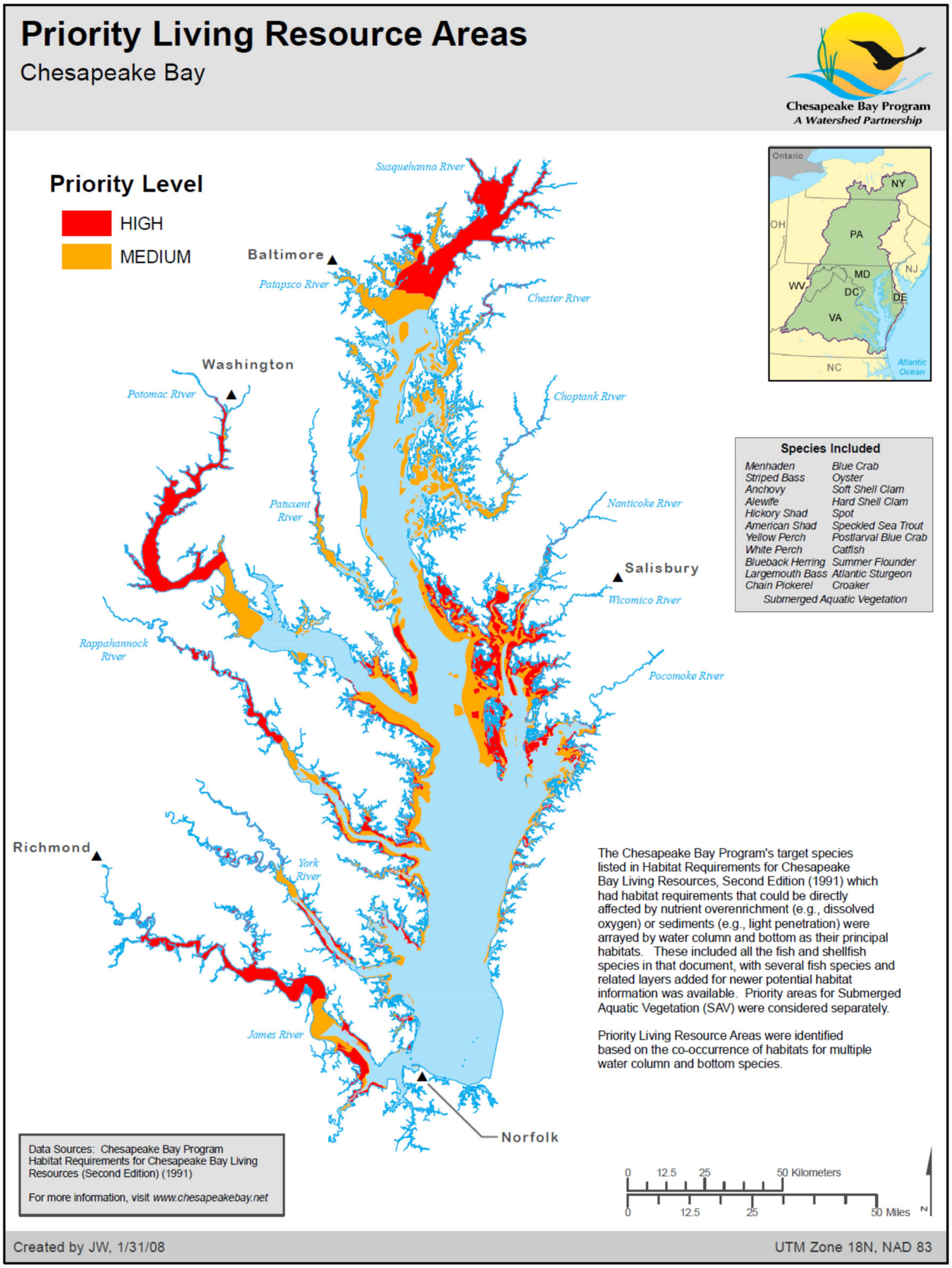

Figure 2. Priority living resource areas of the Chesapeake Bay watershed. (Source: Chesapeake Bay Program)

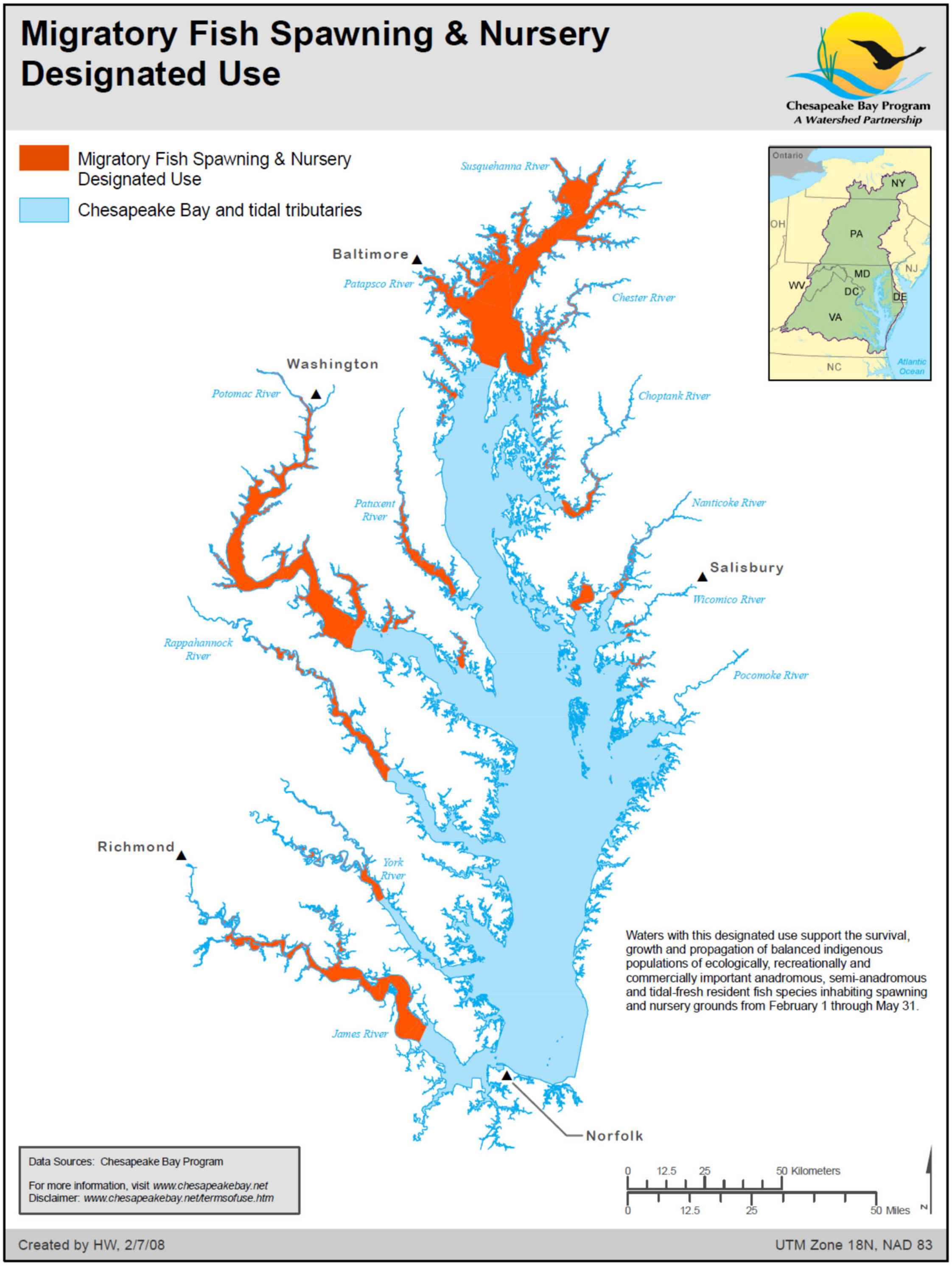

Figure 3. Migratory fish use of the Chesapeake Bay watershed (Source: Chesapeake Bay Program)

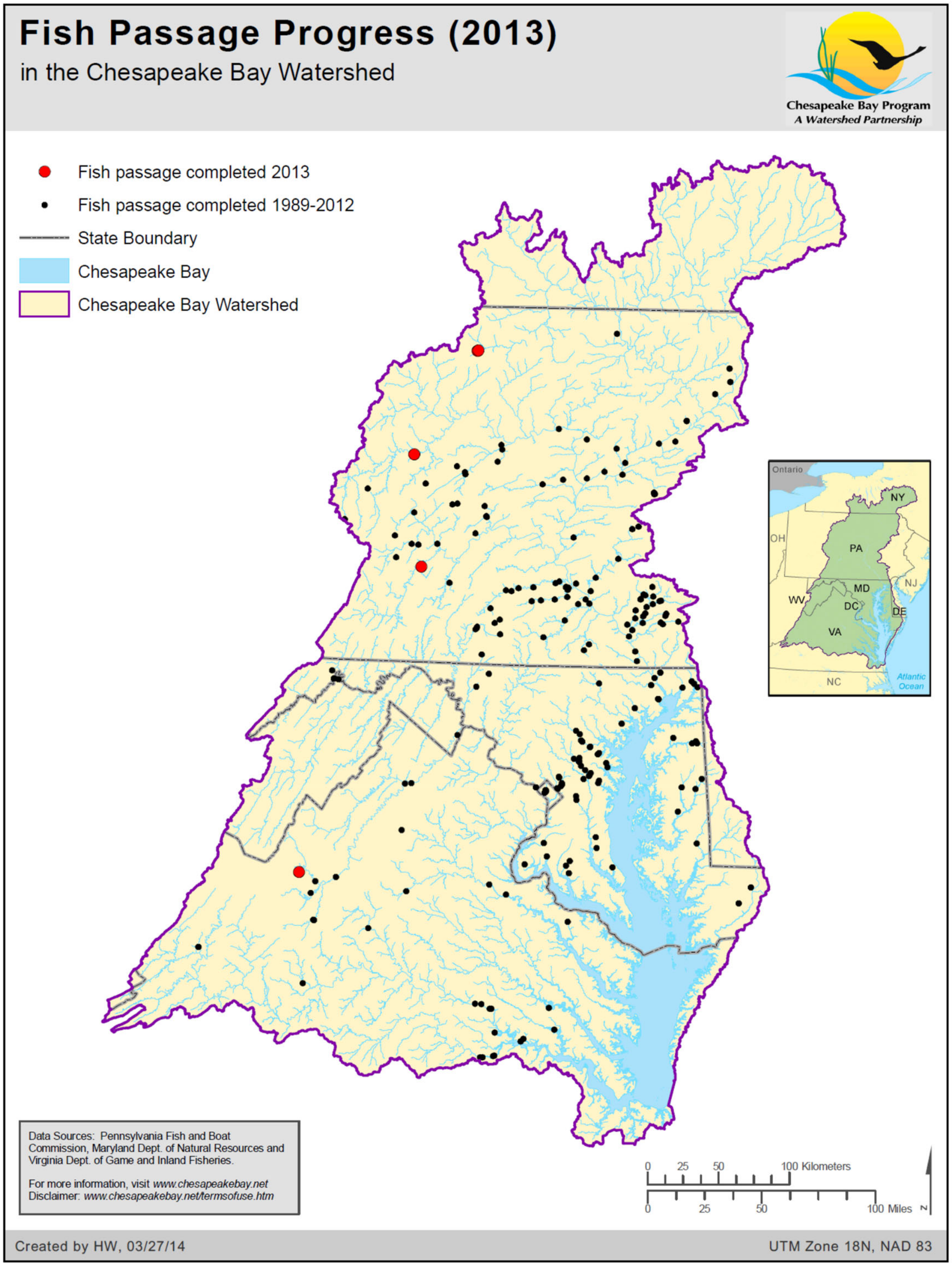

Figure 4. Fish passage projects in the Chesapeake Bay watershed. (Source: Chesapeake Bay Program)

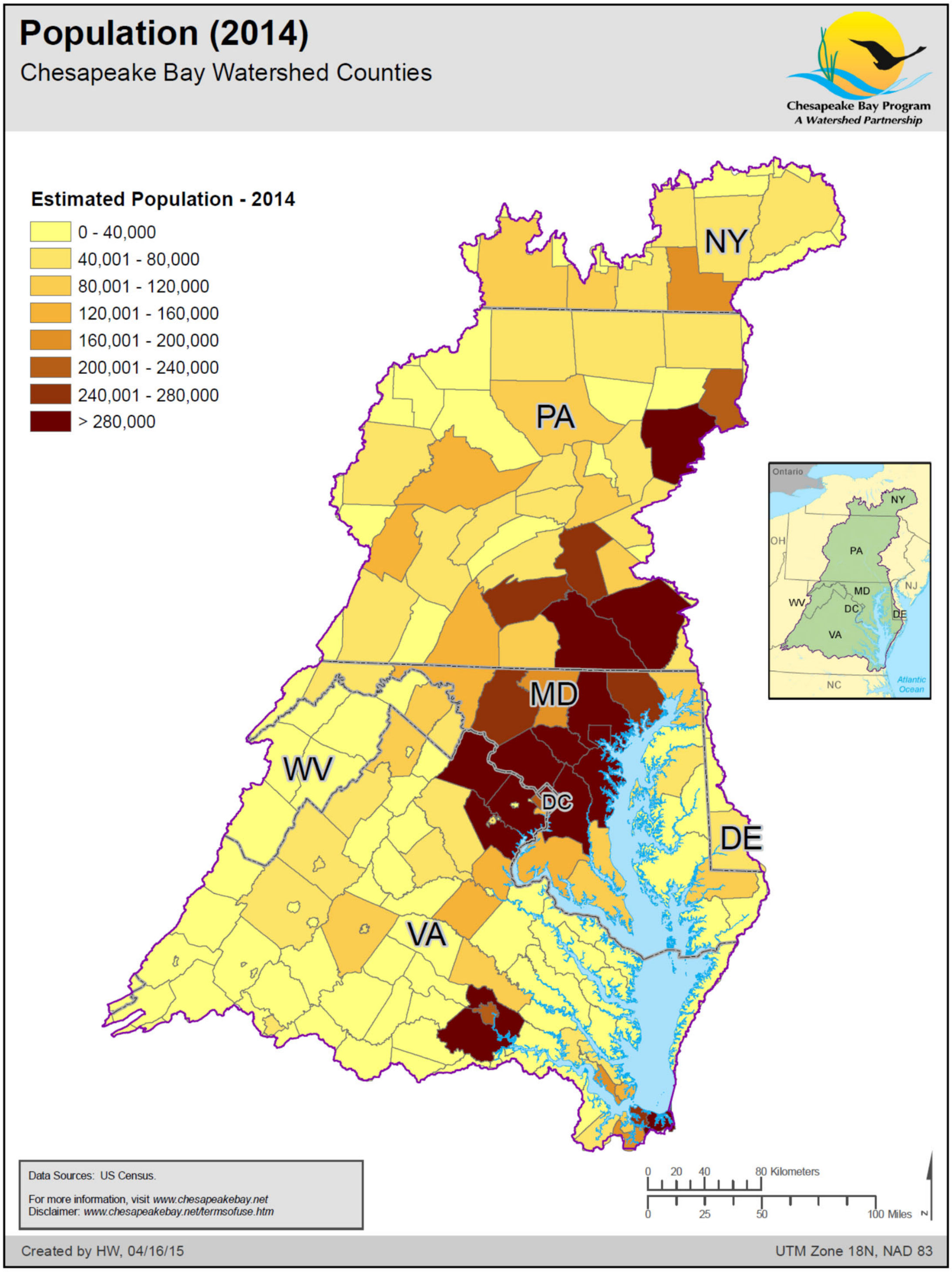

Figure 5. Population levels of the Chesapeake Bay region. (Source: Chesapeake Bay Program)

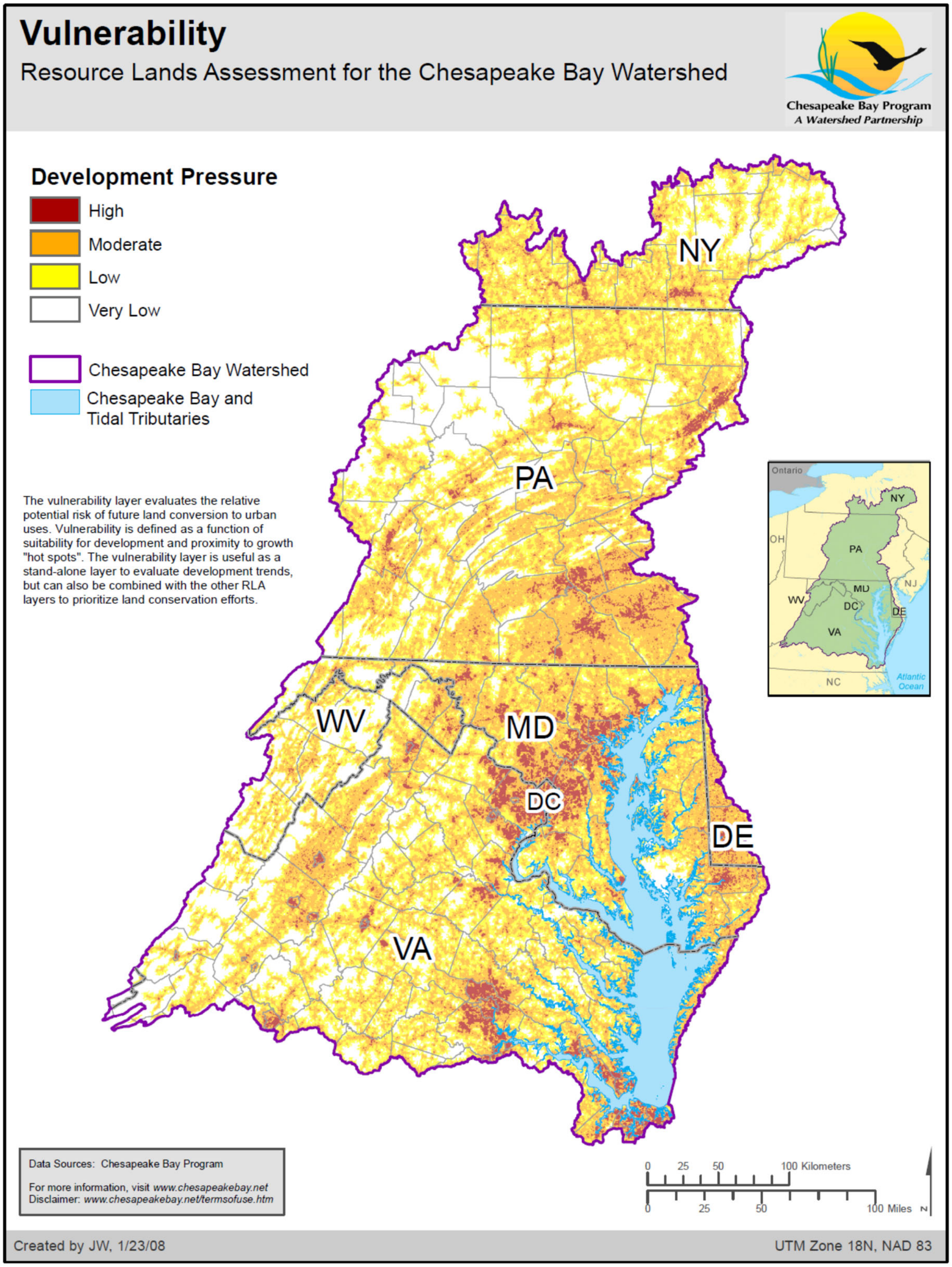

Figure 6. Potential for lands to become urban, representing significant land use changes and impacts. (Source: Chesapeake Bay Program)

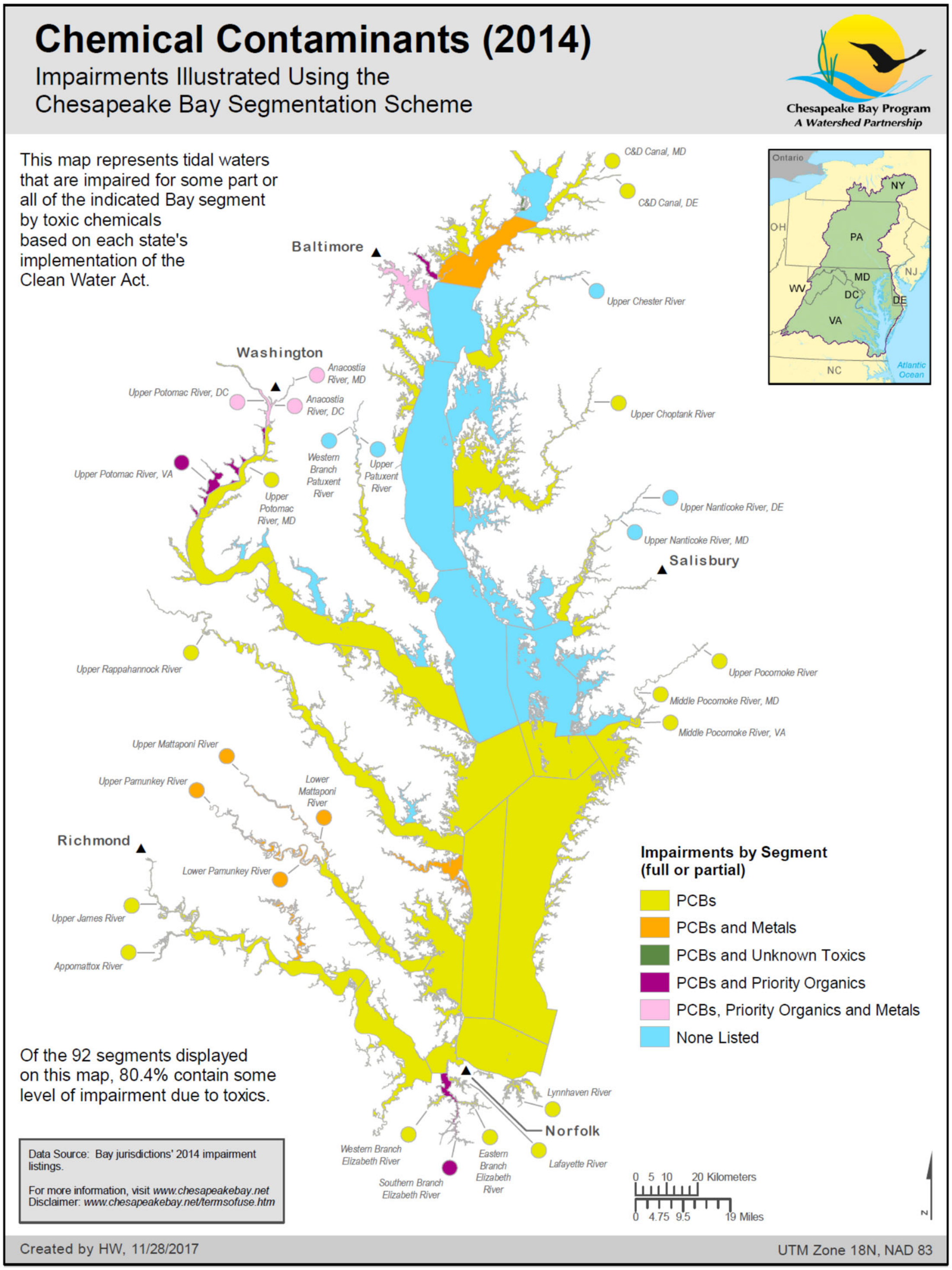

Figure 7. Chemical contaminants in the Chesapeake Bay watershed. (Source: Chesapeake Bay Program)

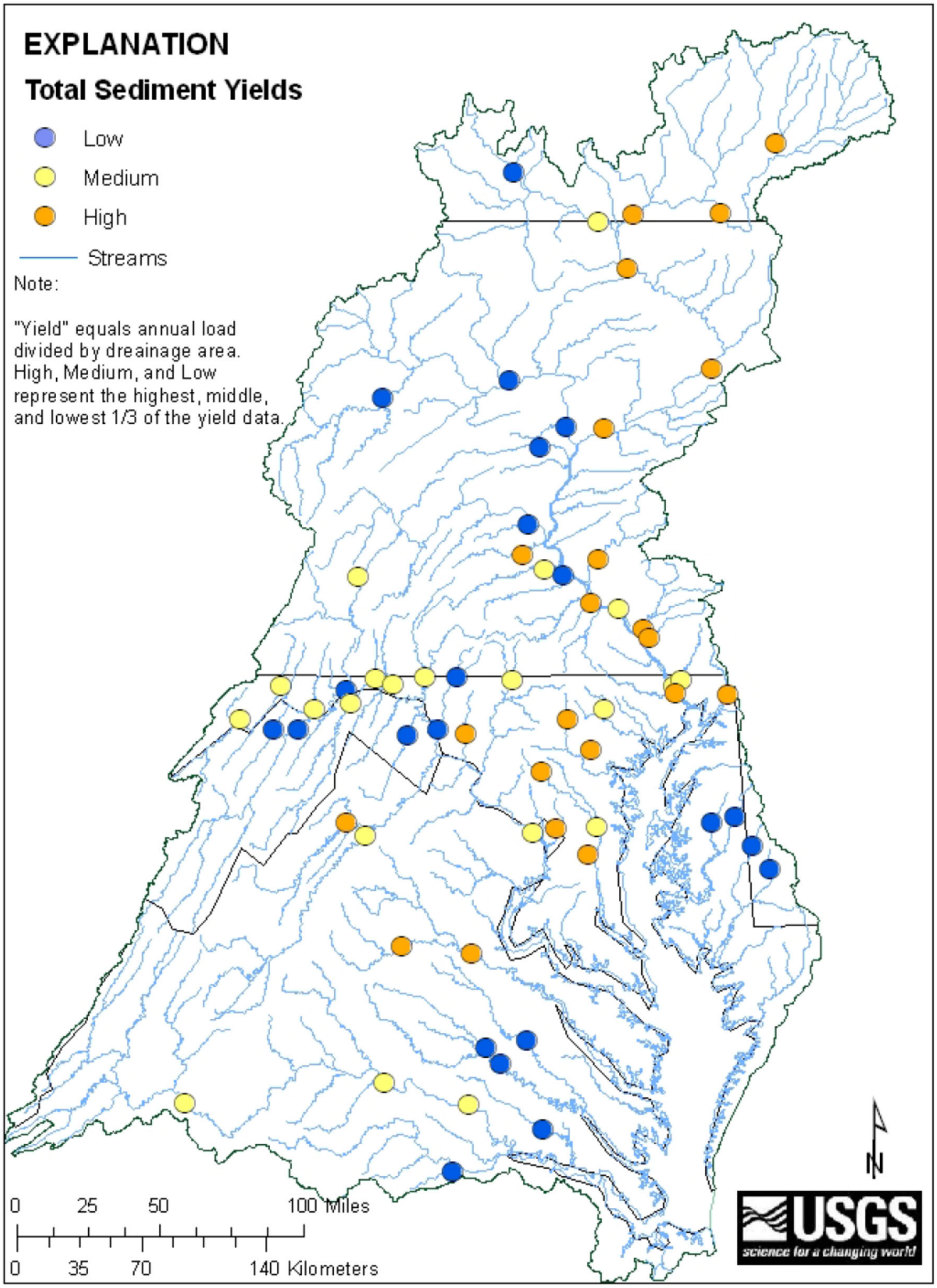

Figure 8. Sedimentation yields in the Chesapeake Bay watershed. (Source: Chesapeake Bay Program)

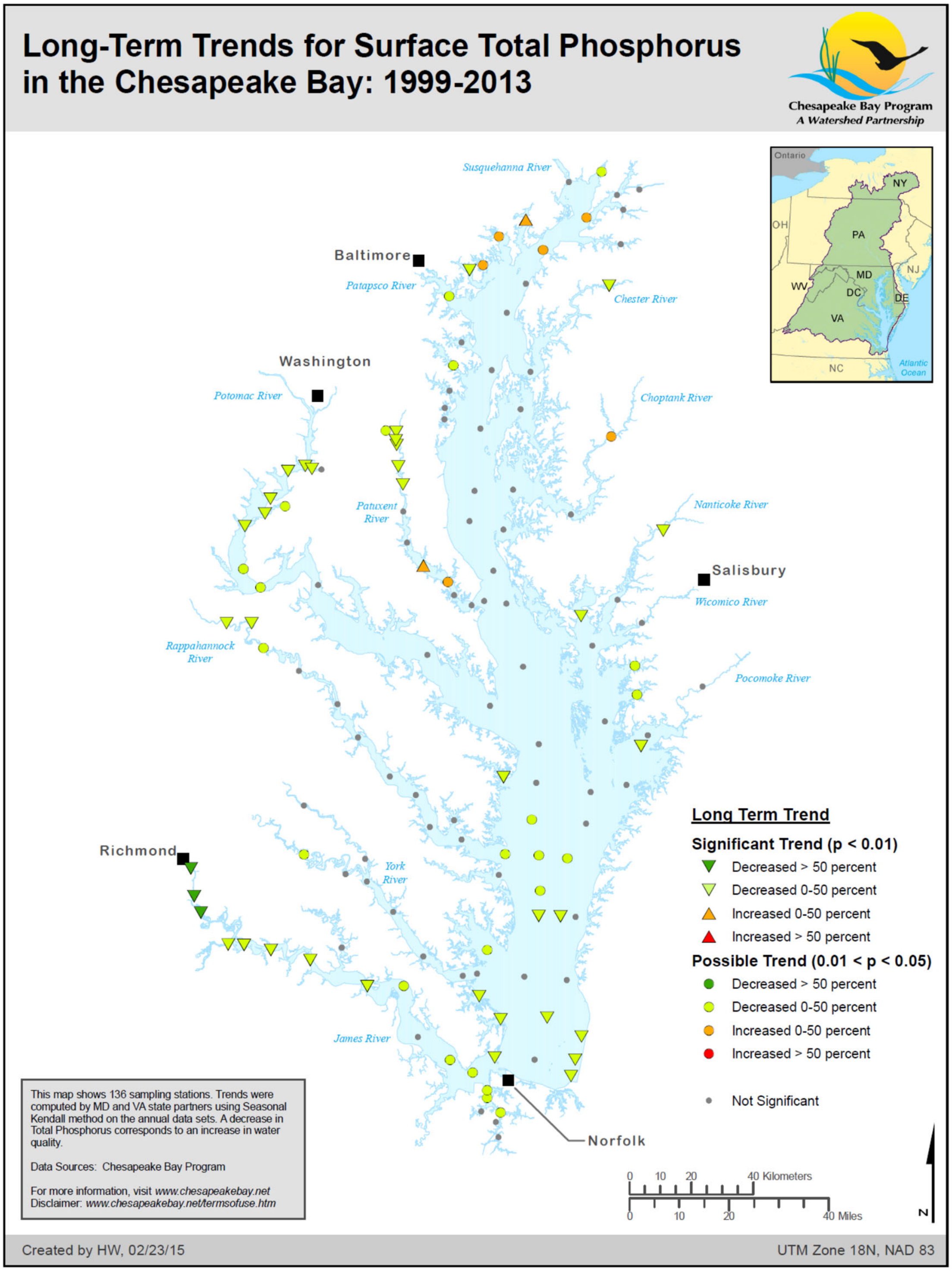

Figure 9. Total phosphorus yields in the Chesapeake Bay watershed. (Source: Chesapeake Bay Program)

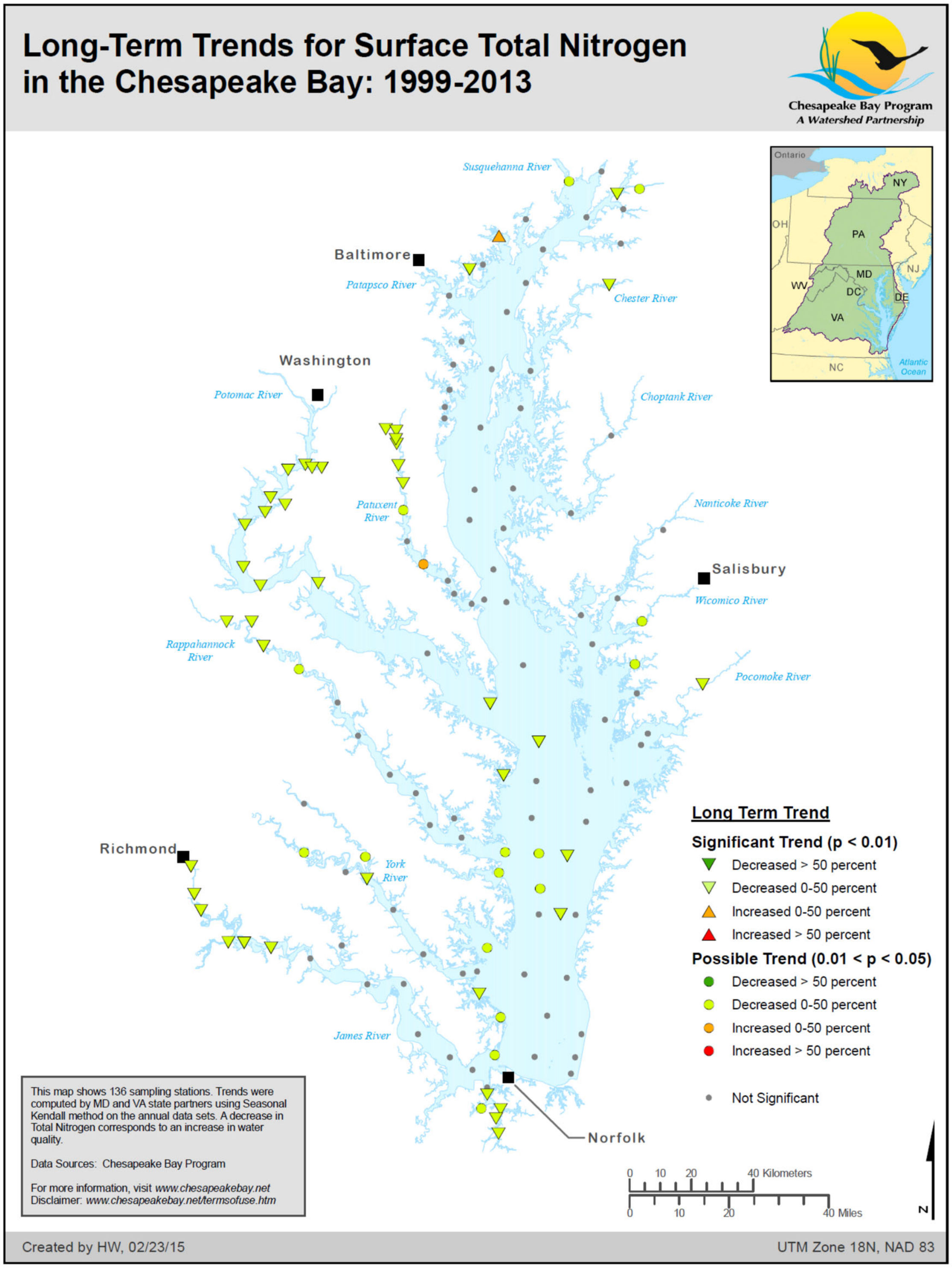

Figure 10. Total nitrogen yields in the Chesapeake Bay watershed (Source: Chesapeake Bay Program)

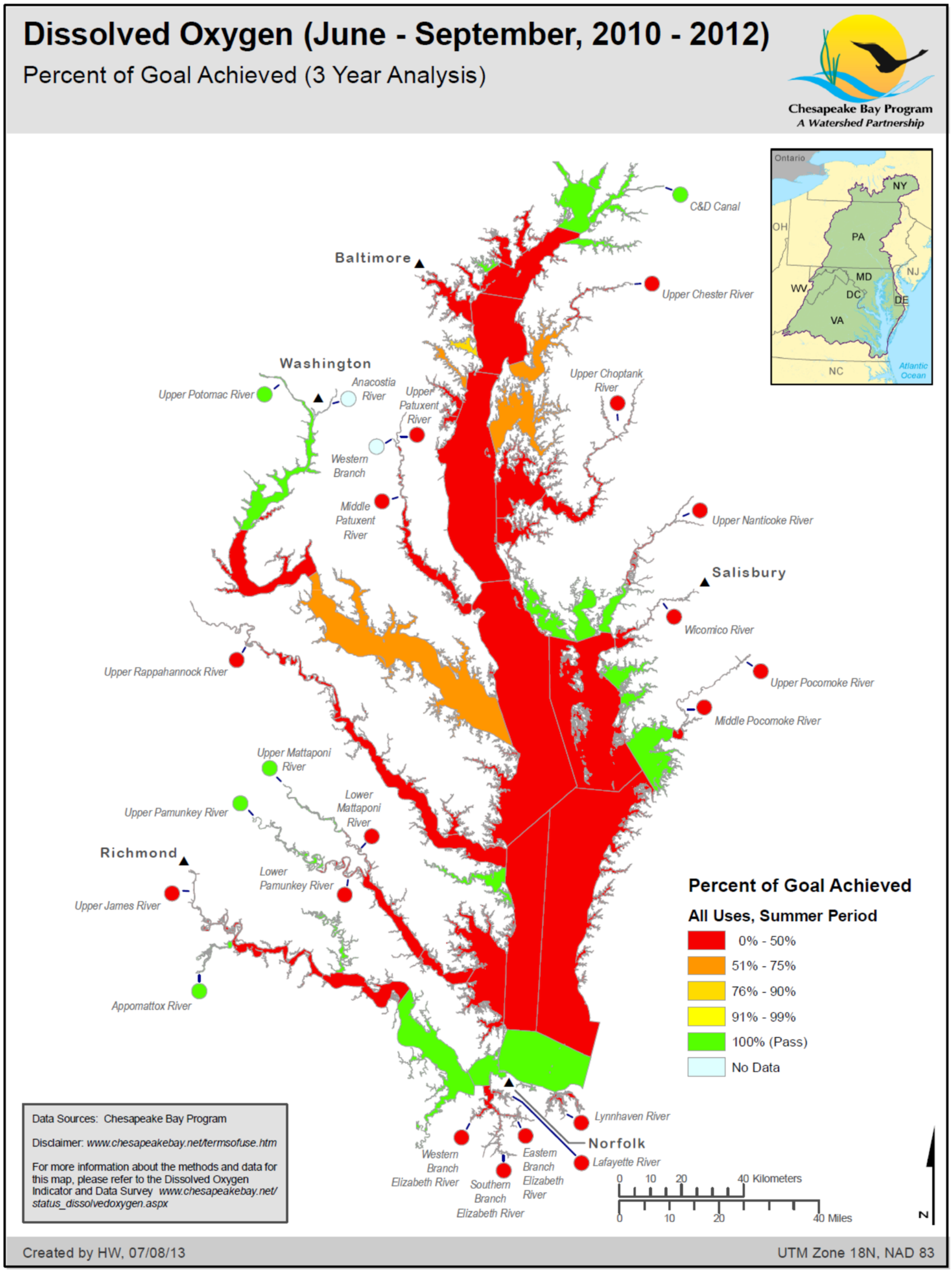

Figure 11. Dissolved oxygen in the Chesapeake Bay watershed. (Source: Chesapeake Bay Program)

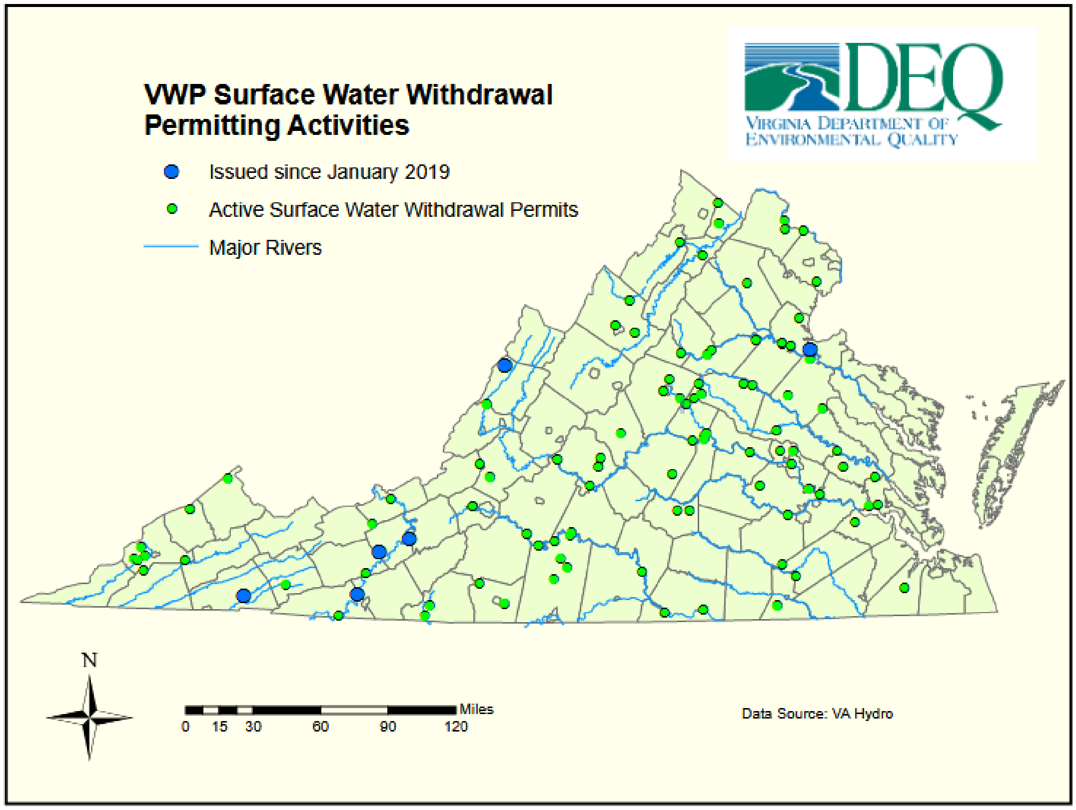

Figure 12. Surface water withdrawal permitting activities. Source: VDEQ (2020: fig. 4).

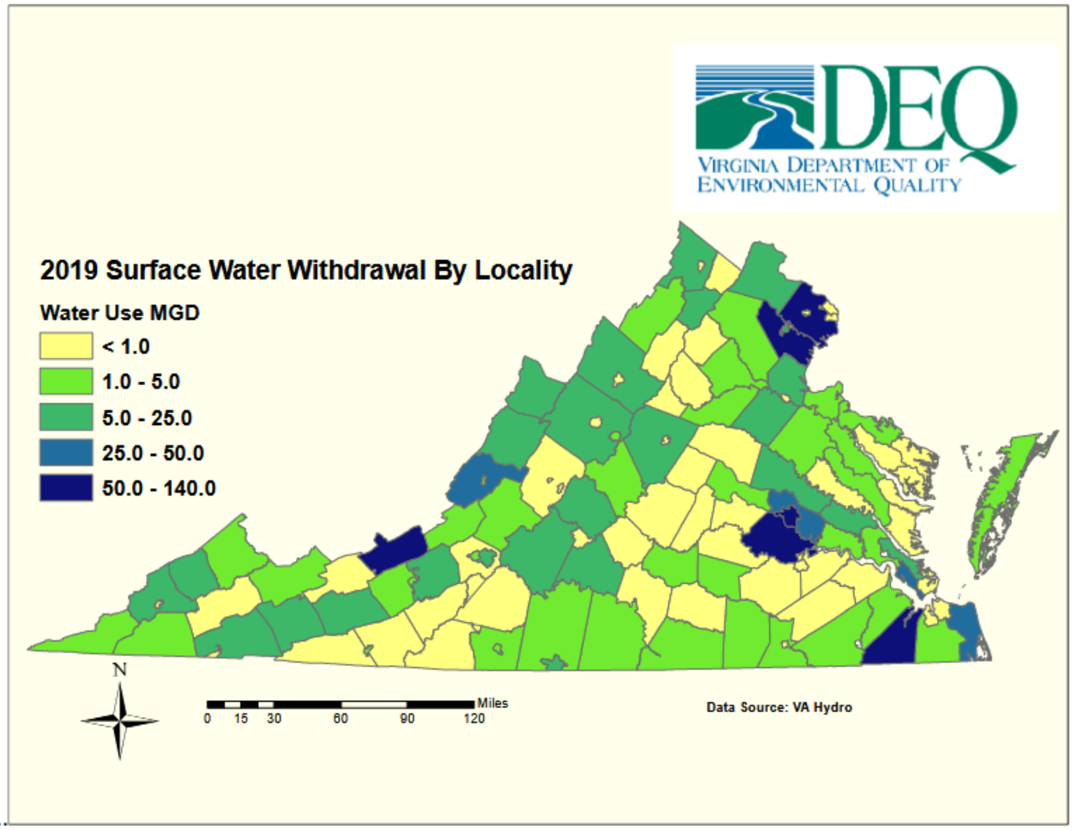

Figure 13. Surface water withdrawals. Source: VDEQ (2020: fig. 8).

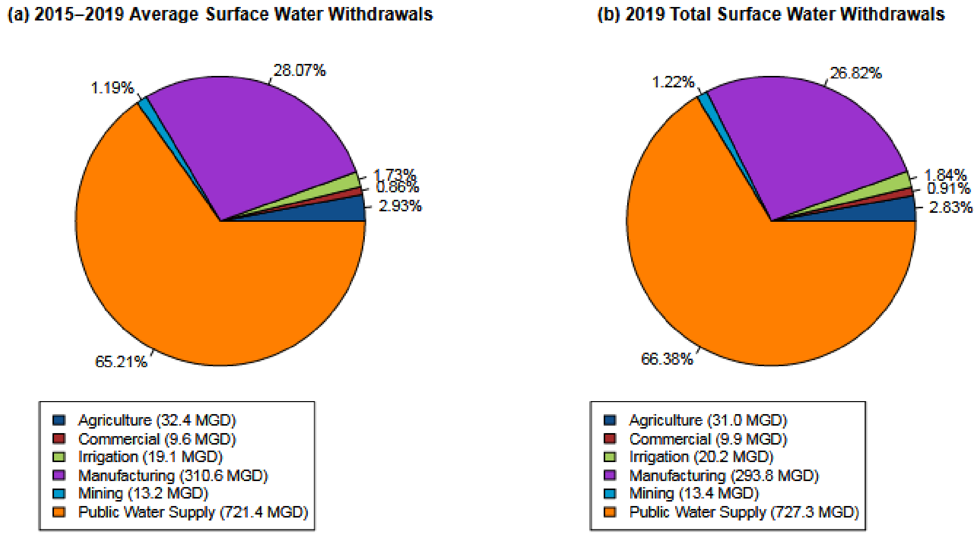

Figure 14. Surface water withdrawals by type. Source: VDEQ (2020: fig. 11).