NUTRIENT MANAGEMENT STRATEGIES FOR THE CHESAPEAKE BAY WATERSHED, USA: SUSTAINING AGRICULTURE IN THE FACE OF CHANGES IN SCIENCE, POLICY, AND CLIMATE

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Introduction

The Chesapeake Bay, located on the Eastern seaboard of the USA (Fig. 1), has been referred to as a "national treasure" for its widely recognized value as a unique natural resource, its historical importance, and its critical value to state, regional, and national economies. The Bay is North America's largest and most biologically diverse estuary, home to 3700 species of plants and animals and habitat for >3000 migratory and resident bird species. Its economic value, from fishing, tourism, property, and shipping, was estimated as > \$1 trillion in 2004 (CBWBRFP, 2004). Unfortunately, the Bay's ecological health has been degraded for > 40 years by pollution from "point" (direct pollutant discharge by industries and municipalities) and "nonpoint" (diffuse runoff from farms, cities; stormwater runoff from cities/suburbs) sources. Primary pollutants of concern today are nutrients and sediments, as clearly stated by the Chesapeake Bay Program (CBP, 2010): "*The Chesapeake Bay and its tributaries are unhealthy primarily because of pollution from excess nitrogen (N), phosphorus (P) and sediment. The main sources of these pollutants are agriculture, urban and suburban runoff, wastewater, and airborne contaminants*."

Efforts to restore the health of the bay, discussed in more detail below, go back more than 40 years, beginning in the 1960s. Bay restoration is a complex task, requiring scientific understanding of multiple factors affecting a myriad of components intertwined into the overall "health" of the Bay. Directly linked to this has been the need to understand, model, predict, and manage the numerous sources that transport nutrients and sediments to the Bay from a very diverse, constantly changing watershed, with the largest land:water ratio (14:1) of any major coastal estuary in the world. Social, economic, and political factors have always influenced the policies and practices recommended or mandated to point and nonpoint source contributors of Bay pollution. More recently, questions have arisen about influences far beyond the Bay Watershed (atmospheric deposition, global climate change) on Bay health and restoration. Despite these challenges, a clear and determined commitment has been made by Bay states and federal government to accelerate efforts to restore this vital national estuary. Leading this regional effort is the Chesapeake Bay Program, a watershed partnership established in 1983 between the six states that drain into the Bay (Delaware (DE), Maryland (MD), New York (NY), Pennsylvania (PA), Virginia (VA), West Virginia (WV)), the District of Columbia, and the US Environmental Protection Agency (USEPA); citizen advisory groups such as the Chesapeake Bay Foundation also play active roles by pressing for faster and more comprehensive actions. Unfortunately, progress on Bay restoration has been slow, leading to issuance of an Executive Order by President Obama where he stated, "*Restoration of the health of the Chesapeake Bay will require a renewed commitment to controlling pollution from all sources as well as protecting and restoring habitat and living resources, conserving lands, and improving management of natural resources, all of which contribute to improved water quality and ecosystem health*" (Exec. Order 13508, 2009).

The objective of this paper is to look to the future of agricultural nutrient management in the Chesapeake Bay Watershed, based on present day socio-political realities, emerging advances in science, and what we know today about expected changes in climate.

Agriculture has been identified as a major nonpoint source of pollution to the Bay, but is also widely recognized and appreciated as an integral part of the Bay Watershed's history, culture, and economy - and as a land use that must be sustained if restoration is ever to occur. In this paper, we briefly describe the environmental and ecological problems facing the Bay and the history of restoration efforts. However our focus is on the future, in particular emerging new policies ("TMDLs" and "WIPs", nutrient trading), advances in agricultural research, and what is known (or speculated) today about how climate change is likely to affect both agricultural productivity and future directions in nutrient management as restoration efforts for the Chesapeake Bay enter the 21st Century.

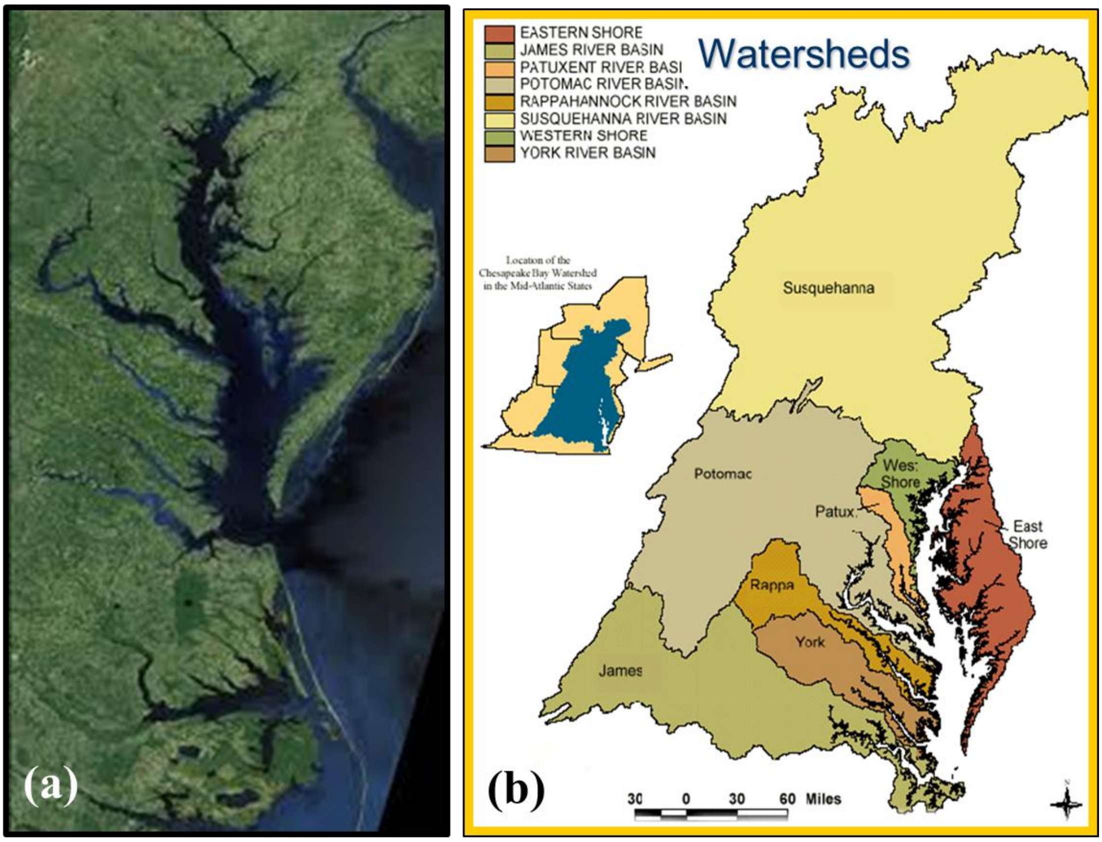


Figure 1. Perspectives on the Chesapeake Bay: (a) a vital estuary and "national treasure"; and (b) a coastal estuary impacted by point and nonpoint pollution from widely differing watersheds in six U.S. states (NY, PA, WV, MD, DE, VA).

The Chesapeake Bay: Environmental and Ecological Issues and Long-term Trends

Water quality problems in the Chesapeake Bay are directly and inexorably linked to anthropogenic activities in the watershed. Hence knowledge of the links between land use, both historically, now, and in the future, and factors affecting pollutant transport to the Bay (hydrology, climate) is vital to the development of effective restoration strategies. The Chesapeake Bay itself was formed ~12,000 years ago, as glaciers melted and flooded the Susquehanna River basin. It is long (320 km), narrow (6-65 km), and shallow (< 6 m) with a lengthy and complex shoreline (~18,000 km). The Bay Watershed is large (16,600 km^2), topography and climate highly variable from the hilly, mountainous and colder northeastern states to the flatter, warmer coastal plain regions of the mid-Atlantic US. One factor of considerable importance is that the Bay has the highest land:water ratio (14:1) of any major coastal estuary in the world, thus magnifying the effects of land use on water quality.

A central tenet of Bay restoration programs has been that Bay health can be improved if we systematically, and permanently, change the way we manage the lands in the watershed to reduce N, P, and sediment loadings. Consequently, extensive efforts have been made at the watershed and sub–watershed level to characterize relative loadings of key pollutants associated with all major land uses. Interestingly, despite being located on the densely populated eastern seaboard of the US, much of the Bay Watershed is either forested (58%) or used for agriculture (10% row crops, 18% hay/pasture). Urban lands, including major metropolitan areas such as Washington, D.C. and Baltimore, MD, occupy 8% of the land, with a total human population in the watershed of ~17 million. Latest estimates of pollutant loadings from major land uses show agriculture is the largest source of N (44%), P (57%) and sediments (59%) to the Bay. Given this, it is not surprising that much of the focus of "cleaning up the Bay" has been directed at reducing agricultural inputs, along with concerted efforts to modernize point sources such as municipal wastewater treatment plants to reduce direct discharge of pollutants to Bay tributaries. Also of considerable concern have been increases in stormwater runoff from impervious surfaces in cities and suburbs as development has replaced forests and agriculture in the past 20 years.

Nutrient and sediment inputs from all land uses have collectively degraded the "health" of the Bay, defined today based primarily on three water quality indicators (chlorophyll *a*, dissolved oxygen, and water clarity) and three biotic indicators (aquatic grasses, phytoplankton community, and benthic community). Extensive monitoring is conducted throughout the Bay Watershed to assess how restoration efforts are progressing, with "report cards" and detailed scientific studies published regularly to communicate the extent of success achieved (Figs. 2 and 3). As can be clearly seen, these analyses show that, while some progress is occurring, the health of the Bay remains at risk. In particular, the CBF State of the Bay score of 32 is still far short of the 70 value presumed to represent a "Saved Bay", prompting the CBF to recently state: *"We have made progress, but much of the Bay and many local waterways don't provide healthy habitat for fish, oysters, and other aquatic life. Pollution has cost thousands of jobs and continues to put human health at risk."*

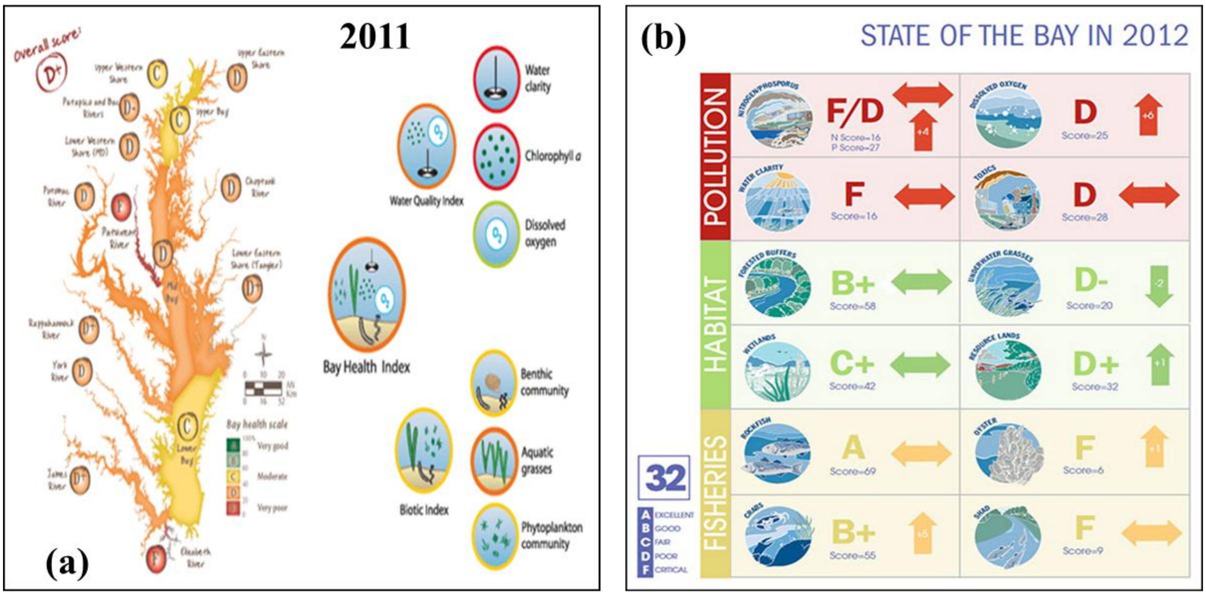
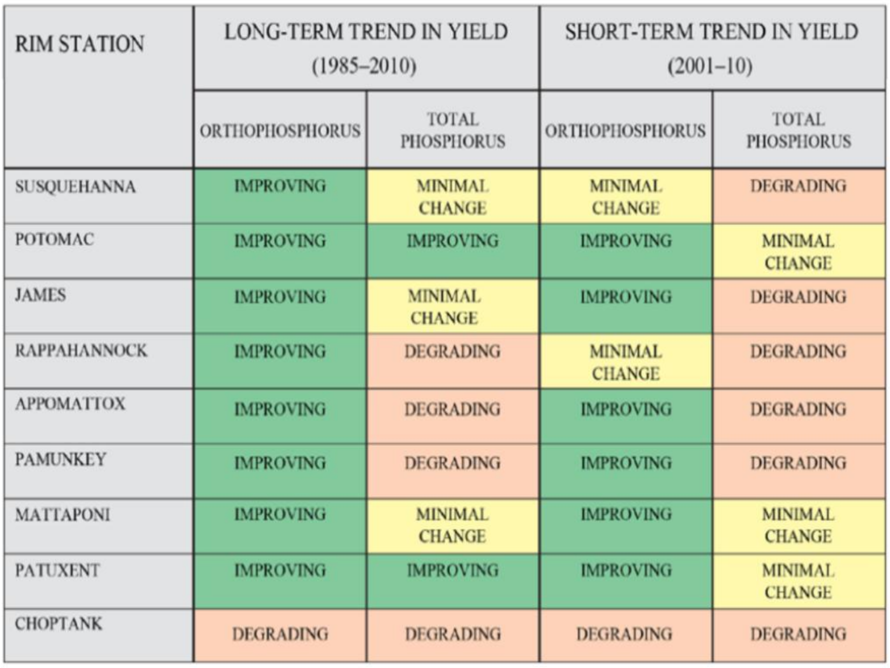


Figure 2. Chesapeake Bay "report cards", published annually by (a) University of Maryland Center for Environmental Science, for 2011 and (b) the Chesapeake Bay Foundation, for 2012 to document progress in Bay restoration efforts.



RIM STATION	LONG-TERM TREND IN YIELD (1985–2010)		SHORT-TERM TREND IN YIELD (2001–10)	
	ORTHOPHOSPHORUS	TOTAL PHOSPHORUS	ORTHOPHOSPHORUS	TOTAL PHOSPHORUS
SUSQUEHANNA	IMPROVING	MINIMAL CHANGE	MINIMAL CHANGE	DEGRADING
POTOMAC	IMPROVING	IMPROVING	IMPROVING	MINIMAL CHANGE
JAMES	IMPROVING	MINIMAL CHANGE	IMPROVING	DEGRADING
RAPPAHANNOCK	IMPROVING	DEGRADING	MINIMAL CHANGE	DEGRADING
APPOMATTOX	IMPROVING	DEGRADING	IMPROVING	DEGRADING
PAMUNKEY	IMPROVING	DEGRADING	IMPROVING	DEGRADING
MATTAPONI	IMPROVING	MINIMAL CHANGE	IMPROVING	MINIMAL CHANGE
PATUXENT	IMPROVING	IMPROVING	IMPROVING	MINIMAL CHANGE
CHOPTANK	DEGRADING	DEGRADING	DEGRADING	DEGRADING

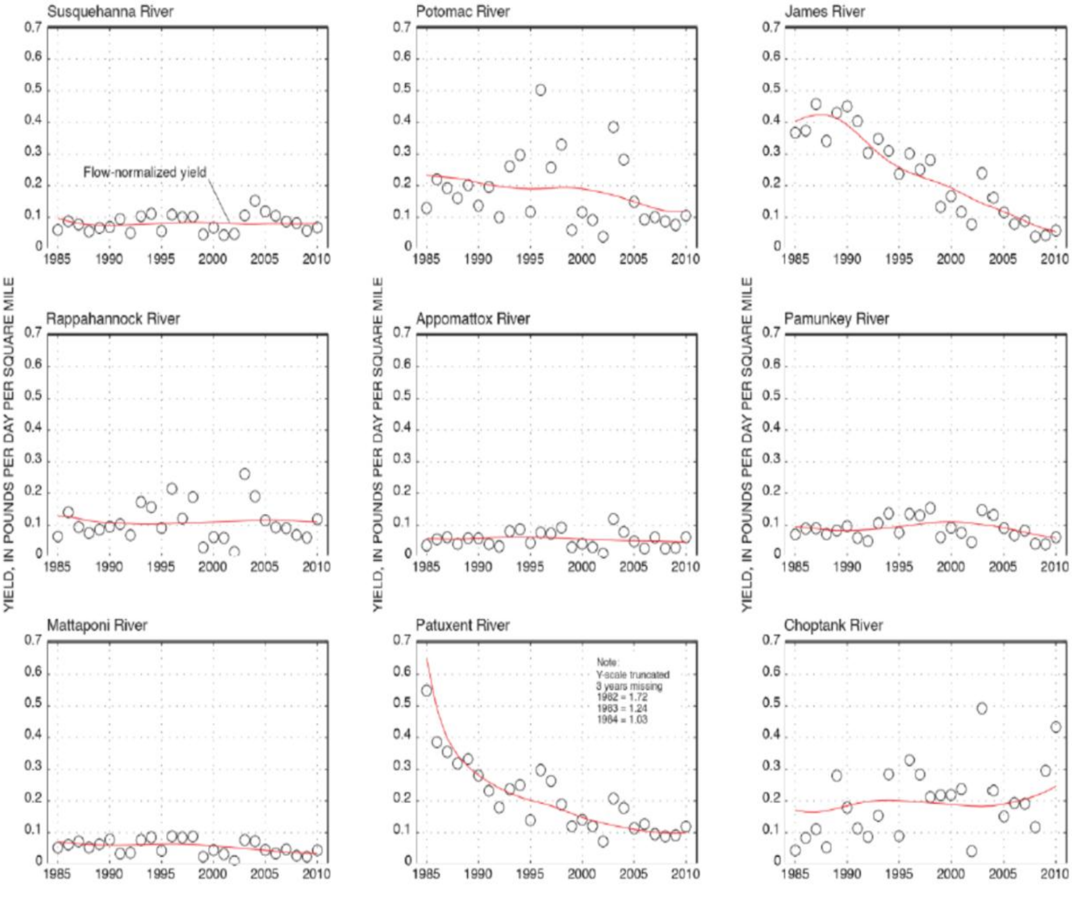


Figure 3. Long-term trends for total phosphorus and orthophosphate loads ("yields") to the Chesapeake Bay, indicating the relative progress towards Bay restoration at key monitoring stations positioned on major Bay tributaries (USGS, 2013).

History of Chesapeake Bay Restoration Efforts

The water quality and ecological concerns described above have existed in the Bay Watershed for > 40 years. The first serious, organized and documented efforts to address water quality issues for the Bay emerged in the late 1960s, leading to the formation of the Chesapeake Bay Foundation, a not-for-profit organization founded in 1967 and dedicated to the restoration of the Bay and preservation of its health for future generations. In the 1970s and 1980s a series of wide-ranging, multi-disciplinary scientific studies were conducted on Bay health, gradually and systematically identifying the nature of ecological degradation, the causative factors, and the best indicators to assess the effectiveness of restoration efforts. A central component of this research was a seven-year EPA Chesapeake Bay Study, initiated in 1976, providing the scientific foundation for later agreements to address the Bay's complex pollution problems (USEPA, 1983). This comprehensive report gave a detailed description of the state of the Bay, types and sources of point and nonpoint pollution, alternative control options, the state of research on the Bay and future research needs, and outlined specific actions needed to begin to restore its health.

At about the same time as the EPA Bay Study (1983) the first Chesapeake Bay Agreement was signed by three Bay states (MD, PA, VA), the District of Columbia, and the USEPA. This agreement established the Chesapeake Bay Program Executive Council, formally recognized the historical decline in living resources of the Bay, led to a cooperative approach to fully address the extent, complexity, and sources of pollutants entering the Bay, and acknowledged shared responsibility for management decisions and resources related to Bay restoration. Later agreements in 1987 and 2000 broadened the partnership and focused restoration efforts on reducing loads of sediment, N, and P to the Bay by 40%. The "Chesapeake 2000" agreement defined five restoration categories (Living resources, Vital habitats, Water quality, Land use, Stewardship) and outlined ~100 specific actions to improve Bay health. In the 15 years since "Chesapeake 2000", major investments have been made in research and education, point source pollution control, stormwater management, and many new agricultural programs (voluntary & regulatory) focused on restoring the Bay.

Despite these agreements and major investments and actions by state and federal governments, the private sector, and non-profit groups, Bay health is still regarded as "dangerously out of balance" and pressure has grown for all sectors to do more. Consequently, in 2009, President Barack Obama signed an "Executive Order" spurring new initiatives by USEPA and Bay states, calling for a *"...renewed commitment to controlling pollution from all sources, protecting and restoring habitat and living resources, conserving lands, and improving management of natural resources, all of which contribute to improved water quality and ecosystem health"*(Exec. Order 13508, 2009). USEPA was mandated to:

(1) Define the next generation of tools and actions needed to restore water quality;
(2) Assess the impacts of a changing climate on the Chesapeake Bay;
(3) Strengthen scientific support for decision making to restore the health of the Chesapeake Bay and its watershed, including expanded environmental research and monitoring and observing systems; and
(4) Develop focused and coordinated habitat and research activities that protect and restore living resources and water quality.

In response to the Executive Order and Clean Water Act requirements, USEPA has recently set new and extensive pollution limits for the Bay ("TMDLs", described below) and required that all states in the Bay Watershed submit and put into practice "Watershed Implementation Plans" (WIPs) that further reduce pollutant loading to the Bay from all sources, with a target goal of 2025 for 100% implementation of the practices needed to fully restore the Chesapeake Bay's health.

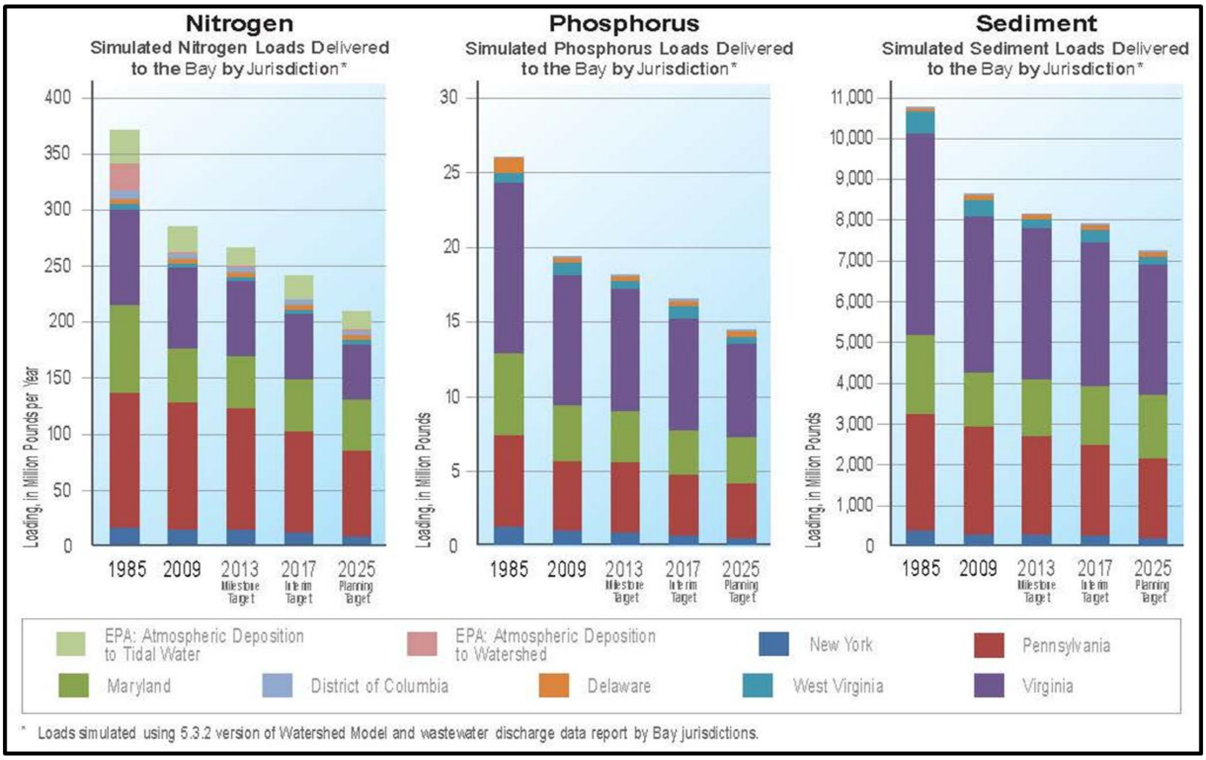
Chesapeake Bay: TMDLs and WIPs

Total Maximum Daily Loads (TMDLs): The US Clean Water Act (CWA) established the requirements for assessing, controlling, and mitigating pollutant discharge to the waters of the US, to ensure such waters are fishable and swimmable without risk of illness. States and other jurisdictions are delegated authority to implement the CWA and required to submit bi-annual reports and water quality monitoring data to USEPA to document water quality status and progress towards CWA goals. Of direct and considerable importance to the Bay is the CWA requirement that a Total Maximum Daily Load (TMDL) be developed for each pollutant in each impaired waterway (USEPA, 2002). TMDLs are limits that set maximum amounts of pollutants that can be discharged into a waterway without violating water quality standards and include a wasteload allocation for point sources, a load allocation for nonpoint sources, and a margin of safety. Monitoring data and water quality models are used to forecast if water quality standards can be achieved under various pollutant loading scenarios. Point source load reductions are mandated via National Pollutant Discharge Elimination System (NPDES) permits and nonpoint reductions require implementation of watershed-scale management strategies, developed by state and federal agencies, along with stakeholders, via a public review process, that detail how pollutant loads will be reduced to TMDL levels.

The initial decision to adopt and implement a multi-state TMDL for the entire Bay was taken by USEPA and Bay states as far back as 2000, when it was apparent that past restoration efforts were not succeeding. Actual preparations for the TMDL began in 2005, with the guiding principle being that efforts would be overseen and led by the USEPA in a collaborative process involving each jurisdiction. TMDL development involves modeling various pollutant load reduction scenarios to determine levels associated with a healthy Bay. In the Chesapeake, a series of models are used with output from one model providing input data to others. The *Airshed Model* estimates the amount of wet and dry N deposition to land and open waters from automobile, industrial, and utility emissions and takes into account growth and impacts from implementing the US Clean Air Act. The *Land Use Change Model* estimates annual changes in land use and land cover resulting from growth and expansion of sewer districts. The *Watershed Model* calculates hydrology and water quality conditions for river segments and considers meteorological data, point discharges and withdrawals, soils and sediments, land uses, and takes into account implementation actions already in place so jurisdictions receive credit for best management practices (BMPs) installed. Finally, the *Water Quality and Sediment Transport (Bay) Model* simulates water quality conditions in the Bay and tidal regions as a result of loadings from the watershed, atmospheric, and oceanic inputs. Models are calibrated using 21 years (1985-2005) of water quality and other data and each simulation is for a 10-year hydrologic period to provide long term average conditions and minimize the impacts of single large climatic events, such as hurricanes (USEPA, 2010).

Because the models are so large and comprehensive, they have been thoroughly reviewed by numerous expert groups including the Chesapeake Bay Program's Scientific, Technical Analysis and Reporting group, Scientific and Technical Advisory Group, Watershed Technical Workgroup, and each source sector workgroup. That being said, no model can perfectly replicate reality and concerned stakeholder groups often criticize modeling assumptions and input data. The Bay Program has agreed to continuously update the model with new data and procedures through a vigorous review process.

Extensive public participation was sought leading up to finalization of the TMDL. A website was devoted to TMDL and WIP topics and monthly webinars were held to educate and inform partner organizations and stakeholder groups on these activities. USEPA opened a public comment period for 45 days, during which time they held 18 public meetings across the watershed along with numerous smaller stakeholder focused meetings. They received and considered ~14,000 comments. The final TMDL established by USEPA in December 2010 for the Chesapeake Bay Watershed is the largest and most complex TMDL in the US. In fact, there are actually individual N, P, and sediment TMDLs set for each of the 92 modeled watershed segments, establishing overall annual limits of 202 million pounds of N, 12.5 million pounds of P and 6.45 billion pounds of sediment. Using 2009 as a baseline, achieving the TMDLs requires a 20% reduction in N, 24% reduction in P, and 20% reduction in sediment from all jurisdictions within the watershed. To accomplish this Bay-wide goal, EPA has allocated specific loads to individual jurisdictions and major basins within the jurisdictions. As a result of these smaller scale allocations, each load is protective of local living resources and all segments of the mainstem and tidal tributaries should achieve water quality standards for dissolved oxygen, chlorophyll *a*, water clarity, and underwater grasses (USEPA, 2010). All actions to achieve the TMDLs must be in place by 2025, with 60% of the actions implemented by 2017, as illustrated in Fig. 4 below.



* Loads simulated using 5.3.2 version of Watershed Model and wastewater discharge data report by Bay jurisdictions.

Figure 4. Modeled loads by jurisdiction for N, P, and sediment for 1985 (beginning of modeling record), 2009 (TMDL baseline), 2013 (next 2-Year Milestone target), 2017 (60% implementation target), and 2025 (100% implementation target).

Watershed Implementation Plans: To meet the requirements of the Chesapeake Bay TMDL, USEPA crafted a unique, multi-part accountability framework, requiring each jurisdiction to: (i) develop a three-phase WIP to detail how pollutant load reductions will be achieved and maintained in the future; (ii) set 2-Year “Milestone” goals defining paths toward 2017 (60%) and 2025 (100%) implementation targets; (iii) assess their progress via annual model simulations of the latest data on their progress on BMP implementation; and (iv) establish a contingency plan should the original strategy not succeed. Collectively, milestones, annual assessments, and contingencies allow jurisdictions to use an adaptive management approach to achieve TMDL targets. Finally, USEPA will impose consequences if jurisdictions do not follow through with their strategies and fail to achieve load reduction goals.

Phase I WIPs were drafted and sent to USEPA before final TMDL issuance to inform that process. Phase I WIPs were required to: (i) show how jurisdictions would allocate loads to all pollutant sectors (agriculture, stormwater, septic systems, wastewater treatment plants); (ii) analyze existing capacity to implement WIPs, i.e, regulatory authority, staffing, and financial means, with gaps identified; (iii) detail mechanisms for tracking and reporting progress on implementation of strategies; and (iv) describe strategies and actions to be used, including an implementation schedule. Strategies could be qualitative and describe a programmatic action, such as "a new regulation for urban stormwater runoff will be promulgated in 2013." Quantitative actions and goals, such as total acreage of riparian forest buffers to be planted by 2025, also had to be identified and were used in model scenarios to assess the potential effectiveness of each strategy. USEPA reviewed all *Phase I WIPS* and jurisdictions were given a short time to revise plans and address EPA criticisms and public comments. If a plan did not meet USEPA's expectations of reasonable assurance, backstop consequences were imposed and USEPA specified it would begin enhanced oversight of jurisdiction activities. *Phase II WIPS* were developed after the TMDL and submitted to USEPA in March of 2012, providing greater detail at more refined geographic and temporal scales. Since many actions to address nonpoint source pollution must be done locally, Phase II plans relied heavily on outreach to local governments, environmental organizations, and agricultural agencies/groups. This process better identified partner responsibilities for achieving WIP goals. As in Phase I, the Phase II WIPs had quantitative components and specific implementation targets for 2013 and especially for 2017 and 2025 (60% and 100% implementation in place). Finally, *Phase III WIPS*, due in 2017, outline each jurisdiction's planned approach for implementation by the 2025 deadline, when all actions to achieve TMDL loads must be in place. The 2017 mid-point assessment will be an opportunity for jurisdictions to use adaptive management and alter original goals in favor of new strategies that may incorporate new policy decisions, practices, or technologies.

Overview of State WIPs for Agriculture: Because of the magnitude of agriculture's contribution to the Bay, many WIPs focused heavily on using current and future agricultural BMPs to meet TMDL goals. State strategies ranged from reliance on voluntary or incentive-based implementation to increased regulatory measures and permitting of concentrated animal feeding operations (CAFOs). As expected, given the general similarities in Bay agriculture, there are a number of common elements in WIPs (nutrient management plans, reduced tillage, cover crops, buffers). States then tailored strategies based on major agricultural practices in their region, historic implementation levels, regulatory requirements, implementation costs, and available funding. For example, in areas of widespread poultry production (DE, MD), emphasis was on poultry litter storage structures, composting, and relocation programs. In regions with more dairy and beef (NY, PA), strategies emphasized stream fencing and pasture management. Most states planned to increase use of winter annual cover crops, planted to trap residual nitrate-N and decrease erosion, a practice well-accepted by farmers since cropland is not taken out of production. Practices that lead to cropland loss (buffers, wetlands) are unpopular, especially given recent increases in commodity prices. Despite this, every jurisdiction set ambitious goals for such BMPs, which are very effective at reducing nutrient and sediment loads and will likely be necessary to meet TMDL targets. The need to assess emerging practices was also common, as future strategies may focus on new BMPs, particularly if research shows them to work well and be more cost-effective. Examples are: in-stream P filtration systems; new, "low-till" manure incorporation methods; new N sensors to guide "on-the–go" fertilizer N applications; tree buffers for poultry houses to trap ammonia and fine particles; and manure-to-energy or manure-to-fertilizer technologies.

Increased regulation and permitting were also addressed in WIPs. At USEPA's request, all states provided overviews of CAFO programs, defined as animal feeding operations where animals are stabled or confined, fed, or maintained for 45 days or more within a 12-month period. Such facilities are regulated by the CWA's NPDES program and states must adopt policies consistent with or more stringent than federal regulations and issue permits to CAFOs. USEPA is very interested in how Bay states manage CAFOs and specified in each WIP review they would object to permits not clearly shown to be protective of water quality. Several states (DE, MD, PA) already have laws or regulations requiring most agricultural operations to develop and follow a nutrient management plan (NMP); other jurisdictions plan to address mandatory NMPs in the future. Where NMPs are now common, jurisdictions stated plans to transition to more information/technology based (i.e., precision agriculture) practices by 2025. Maryland in particular, has taken a more aggressive approach and recently revised nutrient management regulations to address: (i) nutrient application setbacks; (ii) application timing for all chemical and organic nutrients; and (iii) temporary field storage of organic materials (MDA, 2012).

Incentive programs also play important roles in WIPs. The US Farm Bill authorizes the USDA Natural Resources Conservation Service (NRCS) and Farm Service Agency (FSA) to provide cost share funds that help agricultural operators install conservation practices. These incentive programs are often the primary mechanisms for increasing implementation of water quality BMPs. State WIPs rely on continued federal funding of these programs to achieve voluntary agricultural implementation goals, as state funding levels alone are often insufficient to achieve needed results. States are also exploring other options to diversify incentive programs and not rely on cost-share alone. "Nutrient trading" and offset programs (discussed below) allow agriculture to be compensated for installing practices that mitigate loads from other sectors, such as wastewater treatment plants. Finally, another new incentive concept that has started to emerge in the Chesapeake Bay Watershed is the idea of "certainty" programs. Under this framework, agricultural producers who enroll in a voluntary program are offered immunity from additional state environmental laws and regulations (e.g., nutrient management regulations) for a specified period of time. The programs however cannot be used to exempt farmers from federal requirements, such as CAFO rules. This immunity of state rules provides farmers certainty they are operating in a known regulatory environment and reduces the financial risks they accept to modify their operations and become compliant with new requirements. In exchange for this immunity and prior to acceptance into the program, farmers must demonstrate that they meet a minimum threshold of conservation. Thus, a farmer may opt to use a new nutrient management technique or install a BMP to become temporarily exempt from a pending new regulation. Virginia has passed legislation authorizing a "Resource Management Plan" program and is developing regulations for plan requirements. Delaware and Maryland are investigating certainty programs and seeking stakeholder input to determine if they are realistic and can help achieve TMDL goals.

While each jurisdiction in the Bay Watershed has committed to achieving TMDL goals, both to improve Bay water quality and also water quality in local waterways, several challenges must be overcome to secure that success. First, WIPs must be embraced at the local level and implemented by partners and stakeholders. Further, implementation must be paired with tracking and reporting of data needed for water quality simulation models, as the Bay Water Quality model is the final determinant of compliance with TMDLs. This task has challenges as existing databases must be modified to include model-required fields and new databases must be formed for previously unreported or emerging practices. Most jurisdictions are concerned that under- and un-reported BMPs are in place and that an exhaustive and costly audit would be required for a complete inventory. However, the greatest challenge is securing funding to help pay for and oversee implementation of BMPs needed to reduce nutrient and sediment loads. Most states are committed to working with USDA cost-share programs and local governments to leverage funds to the maximum extent. Finally, because N moves to the Bay primarily via groundwater discharges that occur over decades, a lag time exists between implementing BMPs and seeing water quality improve. Similarly, "legacy" P in many of the Bay's "high P" soils will take years, even decades to deplete to agronomically optimum levels, even if no manure or fertilizer P is applied. Regulators and stakeholders must be patient and understand that while practices to achieve the benefits may be in place by 2025, the full impact of these changes may not be apparent for years or even decades.

Chesapeake Bay: Nutrient Management Practices and Policies

Improving the efficiency of agricultural nutrient management has always been a key focus of Bay restoration efforts. While widely recognized as an important land use in the watershed and vital to national and global efforts to ensure a safe and secure food supply, the magnitude of the nutrient and sediment loads originating from agricultural lands has emphasized the need for widespread adoption of highly efficient nutrient management practices to restore Bay water quality. Today, states in the Bay Watershed promote or require a range of practices for all nutrient sources (primarily fertilizers and manures), to ensure N and P are applied at economically optimum rates, using efficient application methods and timing. Nutrient management plans (NMPs), with varying degrees of detail and based on University guidelines (e.g., *Nutrient Management Handbook for Delaware*; Sims and Gartley, 2012) are required of farmers in most states. State and federal advisory agencies have developed guidance documents, certification programs, and reporting and accountability systems, often linked to incentive or recognition programs to foster adoption. For example, Delaware passed a nutrient management law in 1999 that established a "Nutrient Management Commission" and defined basic requirements of NMPs, including expectations for N and P management that sustain farm profitability and protect water quality. Delaware's law requires certification of essentially all farmers, consultants, and others applying nutrients (e.g., turf, golf courses); the DNMC works closely with universities, state/federal technical agencies and the private sector to assess new practices and technologies to improve nutrient use. USDA NRCS requires adherence to Conservation Practice Standard 590, Nutrient Management[1], for farmers receiving cost-share funding and farms with CAFO permits.

While Bay health remains at risk, it is fair to say that the past 20 years have truly seen a marked increase in the agricultural community's understanding of links between nutrient management and water quality, resulting in significant economic investments by farmers into practices that mitigate N, P, and sediment losses. Farmers are interested and willing to consider adoption of innovative practices that further reduce nutrient loss: (i) new tillage equipment ("turbo-till", "subsurfers") that incorporate manures in cropping systems where no/reduced tillage is practiced to minimize soil erosion; (ii) "Greenseeker" systems that integrate on-the-go N sensors with fertilizer N application equipment, allowing for variable N rates based directly on crop N status; (iii) P "filters", containing materials with high P sorption capacities that can be placed in ditches or installed in buffers to remove P from drainage waters; and (iv) irrigation (center-pivot, subsurface drip) that moderates the effects of droughts on crop growth and yield, allowing for more efficient use of applied nutrients and greater farm profitability. Animal agriculture has also responded, by improving animal diets to reduce nutrient excretion, expanding manure storage to avoid off-season applications, investigating technologies to convert manures to fertilizers and minimize ammonia-N losses, and assessing a range of new manure-to-energy technologies.

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[1] See http://efotg.sc.egov.usda.gov/references/public/NY/nyps590.pdf for an example, from New York, of the NRCS Code 590 nutrient management standard.

Nutrient Trading: An Emerging Initiative in Chesapeake Bay Nutrient Management

Nutrient trading was recently defined, in the context of the Chesapeake Bay, as "…*a form of exchange (buying & selling) of nutrient reduction credits. These credits have a monetary value that may be paid to the seller for installing Best Management Practices (BMPs) to reduce N or P. In general, water quality trading utilizes a market-based approach that allows one source to maintain its regulatory obligations by using pollution reductions created by another source*" (MNTP, 2012). In essence, a source that cannot afford to invest in the infrastructure, technology, or practices needed to reduce its pollutant load to the Bay (typically a point source, e.g., a municipal wastewater treatment plant, WWTP), can purchase load reductions from a source that can accomplish this goal equally well and at a lower cost (typically, agriculture). Key components of a successful nutrient trading program are: (i) a reliable, consistent need to market nutrient credits, usually accomplished by mandating that nutrient reductions occur; (ii) financial incentives for both parties to enter the trade; (iii) technical feasibility of the trade and ability to certify and verify that presumed reductions in nutrient loads paid for by the original nutrient source (WWTF) are actually occurring due to the actions of the party implementing them (farmer); and (iv) trading tools and infrastructure that integrates the private sector into the process in a manner that can address current and future nutrient loads. While still in its infancy, nutrient trading is an expectation of the Chesapeake Bay Program and will be vital to meet TMDL goals by 2025. The main driver for trading programs is that point sources, often funded by local governments, lack financial capability to further invest in water treatment technologies needed to meet TMDL allocations. Nutrient trading allows the desired public good (Bay restoration) to be achieved by establishing a market-based means for point sources to provide the funding farmers need to invest in more BMPs, leading to an overall reduction in pollutant loads to the Bay.

Opponents to nutrient trading do exist, primarily because of the perception that this approach allows a nutrient source to continue to pollute, unabated, because it has the financial wherewithal to invest elsewhere, with an uncertain end result – that is, will the trade lead to the presumed nutrient reductions being paid for and will Bay health improve? Other concerns include interstate trades - will governments and taxpayers in one state be content to have their local funds sent to a neighboring state where they may have no or limited control on how the funds are used? A recent economic study by the Chesapeake Bay Commission (2012) thoroughly analyzed trading and concluded "…*nutrient trading offers the potential to significantly reduce the costs of achieving the TMDL water quality goals for the Bay. If trading is successful in shifting nutrient reduction and control activities toward the most cost-effective alternatives, then the annual costs of the TMDL could be substantially reduced"* and "…*trading will be limited by: 1) transaction costs and uncertainties for buyers and sellers of credits, and 2) other regulatory restrictions and non-economic considerations (including sellers' and buyers' willingness to trade) ..federal, state, and local governments can all play a role in reducing these transaction costs by clearly defining trading rules and protocols, providing information and technical assistance, and ensuring compliance and enforcement*".

To understand nutrient trading in practice, consider the example of the recently established Maryland Nutrient Trading Program. In brief, this program creates a public marketplace for the buying and selling of nutrient credits. Goals include "…*offsetting new or increased discharges, establishing economic incentives for reductions from all sources within a watershed, and achieving greater environmental benefits than through existing regulatory programs*" (MNTP, 2012). The MNTP is an internet-based marketplace for buyers and sellers of nutrient credits. It provides a "calculation tool" to analyze technical aspects of proposed trades and allows the public to track the success of the program. The MNTP requires buyers to purchase 10% more credits than needed to cover program costs and uncertainties in the efficiency of the trade, such as due to unpredictable weather. Some agricultural BMPs where load reduction credits are approved are riparian buffers, wetlands, cover crops, tree plantings, stream fencing and animal waste management systems. Others where "technical review" is required before approval are precision feeding for dairy, water control structures, stream restoration, cropland conversion to buffers or wetlands, and precision agricultural systems.

Chesapeake Bay: Climate Change and Agricultural Nutrient Management

Global climate change is anticipated to create a wide range of effects that will likely impact efforts to restore the health of the Chesapeake Bay. The 2009 Executive Order recognized this and called for an "*…assessment of the impacts of a changing climate on the Chesapeake Bay and development of a strategy for adapting natural resource programs and public infrastructure to the impacts of a changing climate on water quality and living resources of the Chesapeake Bay watershed*" (Exec. Order 13508, 2009). Many states in the watershed have begun such assessments, usually with broader goals that extend to all economic sectors, such as Delaware's "Climate Change Vulnerability Assessment". Realistically, however, little has been done to substantively consider how climate change effects are linked to factors controlling pollution of the Bay and the nature and rate of response of the Bay's health to cleanup efforts. There is a clear consensus today, however, that climate change must be integrated soon into the many new programs (TMDLs, WIPs, etc.) launched to mitigate nutrient and sediment impacts on the Bay. At present, the Chesapeake Bay Program plans to begin incorporating climate change into model simulations used to assess how successful the WIPs are at meeting mandated TMDL goals by 2017.

It is widely recognized that many significant challenges exist to successful integration of climate change into local, state, or watershed scale efforts to restore the Bay. Foremost is the uncertainty of the nature of changes that will occur in climate, the pace of these changes, and how they will vary across this large and complex watershed. Intensive efforts are underway to develop reliable models to forecast near and long-term changes in regional climates. Despite major scientific efforts, considerable uncertainty remains in our future climate, largely due to how we will change as a global society (Fig. 5). However, the CBP Science and Technical Advisory Committee (STAC) stated three types of change are likely and must be planned for in Bay restoration: (i) *sea level rise*, will affect mixing of freshwaters draining to the Bay from its watershed and ocean waters and likely cause coastal flooding and wetlands submergence; (ii) *temperature*, generally expected to increase overall leading to hotter summers and warmer winters, and longer growing seasons, with multiple effects on land cover (forests, agriculture) and aquatic biota, increased growth of harmful algae and warm-water fish and shellfish, but greater loss of submerged aquatic vegetation; and (iii) *precipitation*, hardest to predict, especially in terms of the frequency of extreme events (droughts, hurricanes, blizzards) and of major importance because of its effect on Bay hydrology, including nutrient and sediment transport from land to water (STAC, 2008).

In 2011, CBP STAC convened a workshop to review progress in addressing climate change impacts on Bay restoration (STAC, 2011). Large-scale action items identified were: (i) *Embed climate change in decision making*: avoid "siloing" climate change discussions, goals, and policies within and between states and federal partners; (ii) *Focus on solutions to specific problems:* initially, seek to identify specific problems that will arise as climate changes and develop/modify solutions; (iii) *Identify, prioritize vulnerabilities and adaptive opportunities:* develop specific criteria to recognize vulnerabilities to new climates and consider how to revise WIPs to address them and/or adjust TMDL goals; (iv) *Build capacity*: train professional staff in Bay states and agencies in climate science and its implications to policy, management, engineering, and BMP; (v) *Prioritize research*: Accelerate research efforts to reduce uncertainty in predicting future climates, integrate climate science into Bay models, and support social science and communications research on climate change.

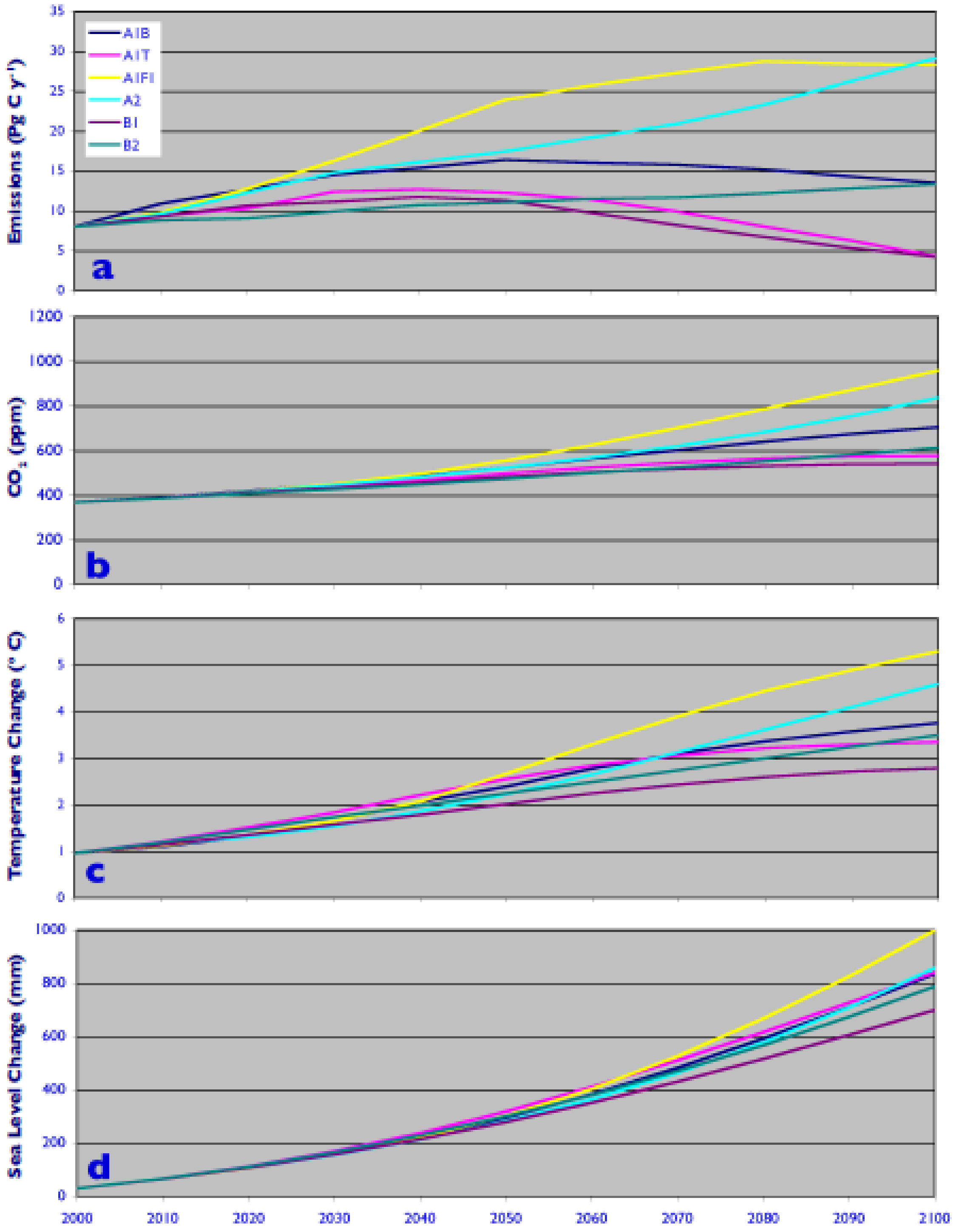

Figure 5. Projected long-term climate changes relevant to Chesapeake Bay restoration, for six scenarios: (A1: rapid economic growth, introduction of new technologies; population peaks by mid-21st century then declines; energy from A1F: fossil fuels; A1T: new, non-fossil sources; A1B: balance of both; A2: continuous population increases, fragmented and slower economic growth, technological change; B1: global convergence on solutions to climate change, population trend similar to A1, less material intensive society, cleaner energy and technologies; B2: similar to B1 but more emphasis on local/regional solutions, slower economic and technological change; (*Source*: Nakicenovic and Swart, 2000).

How climate change will affect agriculture in general and nonpoint pollution of the Bay by agricultural nutrients and sediments is also quite uncertain. It is important to recognize that these impacts could occur both at the farmstead and in the field. Some changes that could occur and thus need to be planned for, assuming a warmer climate with more extreme weather events and more unpredictable precipitation patterns, include:

- ✓ Increased losses of ammonia-N (and potentially fine particles, dusts, odors) from animal production facilities due to higher temperatures, which will increase volatilization and the need for increased ventilation within production houses to protect animal health. Ammonia-N has both air and water quality impacts, thus greater costs will be faced by animal agriculture to prevent higher emissions.
- ✓ Potential for direct losses of nutrients to water by runoff from farmsteads and manure storage areas, including liquid storage facilities (e.g., dairy effluent tanks), may increase should there be periods of intense or prolonged precipitation, high winds, or other extreme weather events.
- ✓ Severe weather or periods of prolonged and intense precipitation will increase loss of sediments and sediment-bound nutrients to surface waters via erosion and runoff.
- ✓ Structural best management practices now in place may fail or be damaged in extreme weather events, i.e., buffer strips, grassed waterways, controlled drainage structures, manure storage facilities (including field storage), and constructed wetlands.
- ✓ Application of organic nutrient sources may be delayed or made more difficult should wet conditions and/or flooding occur as a result of extreme weather events. Poorly timed applications or major precipitation events after application can lead to increased losses of nutrients and other constituents (e.g., bacteria).
- ✓ Warmer temperatures increase the risk of N loss by volatilization from ammonia-based fertilizers commonly used in the Bay Watershed.
- ✓ Mineralization of organic N from manures, biosolids, and composts may increase, decreasing their value as “slow-release” fertilizers and leading to higher concentrations of nitrate-N in soils earlier in the growing season.
- ✓ Drought conditions may cause inefficient uptake of applied N and decrease the depletion of P from high P soils via crop removal. Rainfed crops will be most susceptible, leading to greater potential for accumulations of nitrate-N in soil profiles after crop harvest and higher likelihood of nitrate leaching to ground waters in winter.
- ✓ Longer growing seasons (warmer temperatures year-round) will lead to greater growth of winter annual cover crops, making them more effective at recovering nutrients remaining in soils after harvest of crops.

Future Challenges, Research and Policy Needs

Restoration of the Chesapeake Bay has entered a new phase with the advent of the TMDL and Watershed Implementation Plans. Key factors that are likely to affect these renewed, and more regulatory, approaches to “saving the Bay” include: (i) Ensuring that the funding and infrastructure needed to implement WIPS is in place and sustained in the long run so that existing BMPs, and new policies, such as nutrient trading, can be expanded throughout the watershed; (ii) Prioritizing and supporting the multi-disciplinary research needed to develop new and more efficient BMPs that can further increase the efficiency of N and P use by agriculture; (iii) preparing for the impacts of expanded land use conversion (agriculture and forests to development) as the US economy rebounds; and (iv) aggressively addressing the potential impacts of climate change on the agricultural practices and policies in-place, and planned, to mitigate N,P, and sediment losses to the Bay.

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