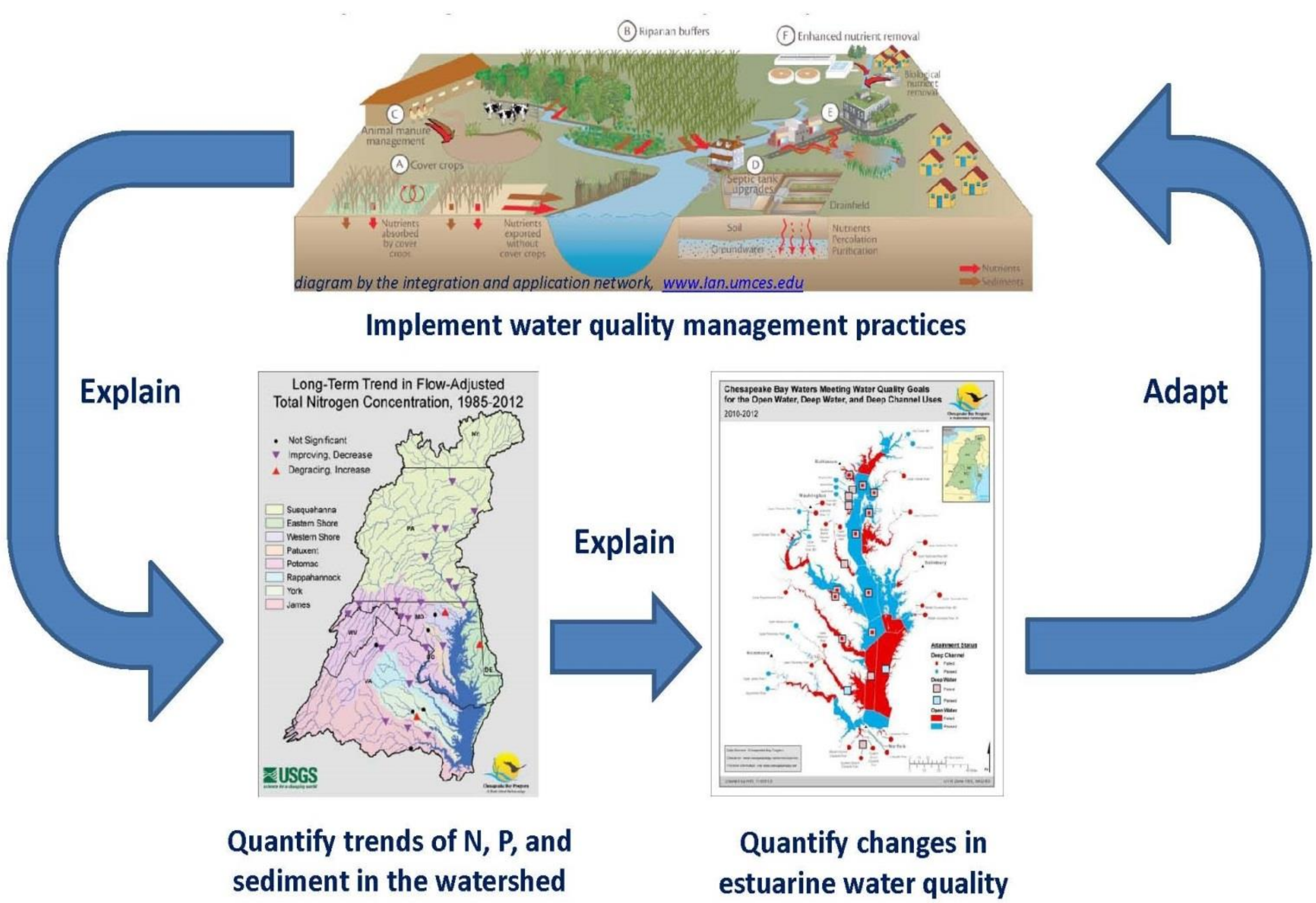
Estimating Land Management Effects on Water Quality Status and Trends



A STAC Workshop Report

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About the Scientific and Technical Advisory Committee

The Scientific and Technical Advisory Committee (STAC) provides scientific and technical guidance to the Chesapeake Bay Program (CBP) on measures to restore and protect the Chesapeake Bay. Since its creation in December 1984, STAC has worked to enhance scientific communication and outreach throughout the Chesapeake Bay watershed and beyond. STAC provides scientific and technical advice in various ways, including (1) technical reports and papers, (2) discussion groups, (3) assistance in organizing merit reviews of CBP programs and projects, (4) technical workshops, and (5) interaction between STAC members and the CBP. Through professional and academic contacts and organizational networks of its members, STAC ensures close cooperation among and between the various research institutions and management agencies represented in the watershed. For additional information about STAC, please visit the STAC website at www.chesapeake.org/stac.

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Executive Summary

Knowledge of the effectiveness of actions taken to reduce nitrogen (N), phosphorus (P), and sediment loads to the Chesapeake Bay is essential to informing the strategies developed and implemented by the Chesapeake Bay Program (CBP) Partnership to achieve the improved water quality conditions that are mandated by the Chesapeake Bay Total Maximum Daily Load (TMDL) (USEPA 2010).

Developing this knowledge for the Chesapeake Bay and its watershed will require an unprecedented integration of the latest advances in analytics and modeling with all data available on: (1) water quality, climate, landscape, and airshed characteristics, (2) demographics and land use changes, and (3) the implementation of practices that manage and reduce the transport of nutrients and sediment from land to water throughout the watershed.

In March 2014, STAC and the Harry R. Hughes Center for Agro-Ecology co-sponsored the "Management Effects on Water Quality Trends" (MEOWQT) workshop to solicit input and recommendations on the most promising analytical approaches and corresponding data needs for detecting linkages between management practices on the land and changes in water quality within the Chesapeake Bay Watershed. The workshop was designed to:

- **Share the current state of the science** on quantifying and explaining water quality trends among a broad community of watershed and estuarine researchers;

- **Identify promising technical approaches** for isolating the effects of management actions on water quality in the watershed and estuary; and

- **Promote discussion and generate recommendations** on three primary topics:

    1. Enhancing trend detection methods;

    2. Developing an integrated approach to explain observed trends in both tidal and non-tidal waters of the watershed; and

3. Identifying new information that is needed to better explain observed trends.

Major findings and recommendations identified at the workshop include:

Trend Detection

1. **Finding:** The Weighted Regressions on Time, Discharge, and Season (WRTDS) method is appropriate for estimating medium- to long-term trends (i.e., greater than 5 years) in N, P, and sediment loads at a majority of the non-tidal sites in the Chesapeake Bay watershed.

   Recommendation: The CBP should prioritize work that adds the ability to estimate uncertainty to the WRTDS method.

2. **Finding:** Methods (such as General Additive Models, or GAMs) for detecting and describing trends in estuarine waters require further development. The inability to automate interpretation of GAM results currently limits its utility.

   Recommendation: The CBP should continue to develop and apply GAMs to the appropriate response variables in tidal waters, and should develop a process of 'artificial intelligence' that enables automated application of GAMs.

Information Needed to Better Explain Trends

1. **Finding:** Incomplete and/or inaccurate reporting of the implementation of best management practices (BMPs) continues to constrain the partnership's ability to quantify BMP impact on water quality at local scales, as well as across the Chesapeake Bay watershed. Some practices (such as voluntary efforts) are not well tracked, and the reporting of other practices is suspect in some cases and lacks the geographic resolution needed to help explain trends. Furthermore, the assumptions and decision rules that must be applied in order to process these datasets constrain its interpretability.

   Recommendation: The CBP partners should continue efforts to improve reporting and tracking of BMPs. CBPO leadership and staff should ensure that any partnership-derived assumptions and decision rules applied transparently in the processing of reported BMP data.

2. **Finding:** A better understanding of BMP effectiveness requires more edge-of-field, farm-scale flow and concentration data, including a more complete inventory of all pollutant sources (such as livestock populations) encompassing a greater number and variety of watersheds.

   Recommendation: The CBP should prioritize more comprehensive and improved monitoring of BMP effectiveness. This includes assessing BMP effectiveness over time, both with and without proper operation as well as required periodic maintenance.

3. **Finding:** Although the existing body of water quality monitoring data for the Chesapeake Bay watershed and estuary is among the most robust in the world, additional continuous monitoring of water quality parameters would reduce uncertainty and improve assessment of trends in water quality. In non-tidal waters, continuous monitoring of P and sediment loads may be more valuable than that of N.

   Recommendation: The CBP partnership should implement continuous monitoring for locations, times, and constituents that maximize utility for improving assessment of effectiveness of management actions.

Integrated Approaches to Explain Trends

1. **Finding:** It is often more feasible to identify and explain the effects of management actions in small watersheds because of the limited number of influencing factors and pollutant transport processes relative to larger watersheds. In addition, explaining change at smaller scales addresses citizens' concerns regarding local water quality. Trends from larger watersheds can be used to assess the collective benefit of many different types of practices on downstream water quality. Efforts to link management actions with trends in water quality at the scale of small watersheds must incorporate and be complemented by studies that aim to discern trends and their drivers at regional and basin-wide scales. However, care must be taken in extrapolating findings from small watershed studies to explain trends in water quality at larger scales across the Chesapeake Bay watershed. Isolating the effects of management actions on water quality in the watershed and estuary within and across both spatial and temporal scales will require novel approaches and the application of new analytical techniques.

   Recommendation: The CBP partnership should engage in a concerted effort to energize the academic and federal research communities to conduct collaborative studies using the most capable and feasible techniques from among those suggested in this report. A number of techniques hold promise for application at a range of scales, or even for integrated application across scales from small watersheds to the entire Chesapeake Bay drainage basin. Multiple tools and approaches were suggested both for small watershed studies and regional analysis (see pgs.10-12). These approaches need to be evaluated to explain observed water quality changes.

The MEOWQT workshop produced an array of recommended analytical approaches for linking management actions in the Chesapeake Bay watershed to observed changes in water quality within the watershed and in the Chesapeake Bay. The challenge remains to:

1. Identify those approaches that are best suited for application to the Chesapeake Bay watershed and tidal Chesapeake Bay;

2. Identify current/ongoing studies that are already implementing some of these approaches, in particular those that will have results in time to inform the Chesapeake Bay TMDL 2017 Midpoint Assessment (MPA);

3. Distinguish a subset of studies and analytical tools that can be applied to inform the MPA from those approaches that require a longer time-frame to implement; and

4. Identify the resources, including additional monitoring, that would be necessary for pursuing the most promising approaches for informing the MPA.

Recommendations from the workshop will help guide the Partnership's efforts to better explain the effect of management practices on changes in water quality and to differentiate those changes in water quality that are due to system lags, changes in land uses, increasing population, and changing weather patterns. This improved understanding will support an adaptive management approach to restoration of Chesapeake Bay and its watershed.

Introduction and Need for Workshop

The Chesapeake Bay is a degraded eutrophic ecosystem with periodic hypoxia and anoxia, algal blooms, diminished submerged aquatic vegetation, and depleted stocks of finfish, crabs, and oysters (Kemp et al. 2005). Since 1983, the seven jurisdictions within the Chesapeake Bay watershed (Delaware, Maryland, New York, Pennsylvania, Virginia, West Virginia, and the District of Columbia) have worked with the U.S. Environmental Protection Agency (EPA) and other federal, academic, and non-governmental organizations – known collectively as the Chesapeake Bay Program Partnership ("the Partnership") – under a voluntary framework to prescribe and perform actions to restore the Chesapeake Bay. The principal actions taken were designed to lessen the amounts of N, P, and sediment to the Chesapeake Bay, as these constituents are deemed the principal drivers of the Chesapeake Bay's impairment. However, voluntary actions taken between 1985 and 2010 failed to improve conditions sufficiently to attain the water quality standards established to protect the aquatic living resources of the Chesapeake Bay and its tidal tributaries (USEPA 2003). As a result, in 2010 the EPA established the Chesapeake Bay Total Maximum Daily Load (TMDL), a historic and comprehensive "pollution diet" designed to restore the Bay's water quality (USEPA 2010).

The Chesapeake Bay TMDL – the largest ever developed by the EPA – identifies reductions in N, P, and sediment pollution across all Chesapeake Bay watershed jurisdictions that are necessary to meet applicable water quality standards (USEPA 2010). Specifically, the TMDL calls for a 25% reduction in N, 24% reduction in P, and 20% reduction in sediment from 2009 measures. These pollution limits are allocated by jurisdiction and major river basins. In order to meet these goals, the TMDL is designed to ensure that all pollution control measures necessary to fully restore the Chesapeake Bay and its tidal rivers are implemented by 2025, with management actions to achieve at least 60% of the reductions in place by 2017.

As a central part of the restoration effort, the Partnership has committed to using an adaptive management framework to define its goals, to develop and implement the requisite management strategies, to assess performance of those strategies, and to revise the strategies to improve program performance based on new insights (CBP 2011; CBP 2014). In keeping with this framework, between 2010 and 2012 jurisdictions were required to develop watershed implementation plans (WIPs) that would guide the execution of sufficient activities to meet the goals of the TMDL. Phase I and Phase II WIPs (finalized in 2010 and 2012, respectively) guide the jurisdictions' restoration activities through 2017.

In 2017, a process called the Chesapeake Bay TMDL Midpoint Assessment (MPA) will entail the review of the jurisdictions' past and planned implementation of pollution management strategies. The purpose of this review is to determine whether jurisdictions are on track to achieve the goal of implementing all management practices necessary to attain water quality standards in the Chesapeake Bay by 2025. Findings from the 2017 MPA may help jurisdictions prepare Phase III WIPs, which will guide the development of two-year milestones and installation/adoption of best management practices (BMPs) from 2018-2025.

Knowledge of the effectiveness of actions taken to reduce N, P, and sediment loads to the Chesapeake Bay is essential to the "assess performance" step of the adaptive management framework described above. Developing this knowledge for the Chesapeake Bay and its watershed will require an unprecedented integration of the latest advances in analytics and modeling with all data available on water quality, climate, landscape and airshed characteristics, demographics and land use change, and the implementation of BMPs throughout the watershed.

In March 2014, STAC and the Harry R. Hughes Center for Agro-Ecology co-sponsored the "Management Effects on Water Quality Trends (MEOWQT)" workshop to solicit input and recommendations on the most promising analytical approaches for detecting linkages between management activities on the land and changes in water quality of the Chesapeake Bay. Attendees were also asked to describe the types of data required for successfully implementing the recommended approaches.

Workshop Objectives and Format

The MEOWQT workshop focused on exploring approaches to address four primary challenges to understanding the relationship between management practices and water quality improvement:

1. **Climatic variability**: The close tie between water quality and climatic conditions creates a challenge in distinguishing real changes due to management actions from natural variations in rainfall and weather patterns.

2. **Environmental Setting**: The diversity of environmental settings across the watershed means that some areas will respond differently to management actions than others. Detecting changes due to human activity can be difficult when viewed against the backdrop of these variations. Approaches to assess the effects of management actions on water quality must take this into account.

3. **Diversity of management actions**: The management actions taken to restore the Chesapeake Bay watershed are highly diverse and distributed across a 64,000 square mile drainage basin comprising about 150 major rivers and streams and over 11,000 miles of shoreline. Assessing the effects of single management actions is usually reserved for field-scale research. However, assessing the effects of a broad ensemble of management actions across the Chesapeake Bay

watershed requires highly specific information on the location, timing, and number of a wide variety of pollution controls.

4. **Uncontrolled changes in land use and behavior**: Many changes that occur on the landscape are related to demographic and land use shifts, including market-driven fluctuations in agriculture and land development. Determining the impact of the management actions themselves requires separating the effects of these uncontrolled changes from deliberate actions taken to improve water quality.

An implicit requirement for overcoming each of these analytical challenges is the availability of a spatially-distributed and accurate time series of data on implemented management activities, uncontrolled changes in human activities, and water quality conditions.

With these challenges in mind, the workshop was designed to:

- **Share the current state of the science** on quantifying and explaining water quality trends among a broad community of watershed and estuarine researchers;

- **Identify promising technical approaches to advance the science** of explaining effects of management actions on water quality in the watershed and estuary; and

- **Promote discussion and generate recommendations** on three primary topics:

  1. Enhancing trend detection methods;

  2. Developing an integrated approach to explain observed trends in the tidal waters and the watershed; and

  3. Identifying information that is needed to better explain observed trends.

Recommendations from the workshop will help guide the Partnership's efforts to better explain the effect of management practices on changes in water quality. This improved understanding will support an adaptive management approach to restoration of the Chesapeake Bay and its watershed.

The format of the workshop was designed around breakout discussions addressing the primary topics of trend detection, information needed to better explain trends, and integrated approaches to explain trends. Presentations were limited to: (1) five "jumpstart videos" to be viewed prior to the workshop and (2) several targeted talks given at the workshop that were intended to prime participants for the breakout discussions. The pre-workshop "jumpstart videos" described existing monitoring networks, available data on anthropogenic and natural drivers of water quality trends, and a survey of recent case studies of water quality change in response to pollution management and ecosystem restoration activities. The purpose of these videos was to provide a common baseline of knowledge without taking up valuable time during the workshop. The workshop presentations described recent research projects that have employed a variety of methods to link water quality to landscape characteristics and activities, and also presented some newly developed analytical tools with the potential to advance the science that informs watershed management. The workshop agenda as well as links to the workshop presentations can be found in Appendix A of this document. Appendix B contains a list of workshop participants and their affiliations. Appendix C contains a summary of each jumpstart video as well as links to each video.

Questions Addressed

In order to solicit multiple perspectives on each topic, workshop participants were randomly divided into four groups, and all groups were asked to consider the same set of questions:

Trend Detection

- Are existing methods adequate to describe trends to support the Total Maximum Daily Load's Midpoint Assessment (TMDL MPA)?
- What are the long-term enhancements that could be developed to estimate water quality trends in free flowing rivers and tidal waters?
- Are there additional trend methods or variables that should be considered?

Information Needed to Better Explain Trends

- What data are currently available on the physical setting in the Chesapeake Bay watershed and/or estuary to enhance trend explanation?
- What new research and information/data collection is needed about physical settings to better explain trends?
- What new or improved research and information/data collection is needed on changes in pollutant sources and associated management practice data?

Integrated Approaches to Explain Trends

- What are the most promising descriptive and/or quantitative approaches that can be applied, investigated, and/or developed to produce an integrated explanation of trends in the estuary and watershed?
- At what scale(s) can these approaches be applied (i.e., entire Chesapeake Bay watershed, major river systems, or smaller sites)?

Major Findings and Recommendations

Trend Detection:

Are existing methods adequate to describe trends to support the TMDL MPA? What are the long-term enhancements that could be developed to estimate water quality trends in free flowing rivers and tidal waters? Are there additional trend methods or variables that should be considered?

Finding: The recently developed "Weighted Regressions on Time, Discharge, and Season (WRTDS)" method, developed and presented by Bob Hirsch (USGS) and colleagues, is a promising approach for estimating medium- to long-term trends in N, P, and sediment loads at a majority of the non-tidal sites in the Chesapeake Bay watershed (Hirsch et al. 2010; Moyer et al. 2012). The WRTDS method provides a trend in load rather than concentration, which allows it to compensate for climatic variability via its flow-normalization methods. The inability to estimate uncertainty is a drawback of the current version of WRTDS. The application of more traditional methods such as seasonal Kendall and parametric trends in concentration are still useful and important tools.

Recommendation: The importance of obtaining estimates of uncertainty for simulated loads was emphasized. Developers of the WRTDS method are currently working on enhancements that will provide this feature. In the interim, statistical measures from more traditional trend methods may be used to support WRTDS results.

Finding: The GAM (General Additive Model) approach presented by Elgin Perry (EPA-CBPO) is a promising mathematical tool for detecting and describing trends in estuarine water quality parameters. It is still in a developmental phase and has yet to be fully implemented. Full implementation the GAMs technique will require incorporation of additional temporally-distributed hydrologic processes that influence mixing and flow in increasingly more saline areas of the estuary (i.e., the oligo-, meso-, and poly-haline zones).

In contrast with WRTDS, existing tools allow estimation of uncertainty for GAMs. However, the time involved in interpreting the graphs that are produced using GAMs currently limits its effective application.

Recommendation: The CBP should continue to develop and apply GAMs to the appropriate response variables (i.e., nutrients, sediments, DO) in tidal waters. Developers of the GAMs method should solicit input from the estuarine research community to guide construction of GAMs for the Chesapeake Bay. Further, in order to fully implement GAMs as a standardized method for evaluating water quality trends in the tidal waters, functionality that enables automated analysis must be developed. Hence, it is recommended that the CBP submit the GAMs technique to a rigorous peer review process before establishing it as the primary tool for estimating trends in estuarine water quality parameters.

Information Needed to Better Explain Trends:

What data are currently available on the physical setting in the watershed and/or estuary to enhance trend explanation? What new research and information/data collection is needed about physical settings to better explain trends? What new or improved research and information/data collection is needed on changes in pollutant sources and associated management practice data?

While participants were asked what data are currently available to enhance trend explanation, the MEOWQT workshop was not designed to produce a comprehensive list of existing datasets. Many existing datasets are available through websites and databases maintained by the CBP and its partner organizations, and the workshop jumpstart videos (Appendix C) summarized much of this information. As shown below, the real value that was derived from the discussion of available datasets was in sparking conversations about their utility, as well as of data gaps and additional data desired for better explaining trends.

Finding: Incomplete and/or inaccurate reporting of the implementation of BMPs continues to constrain the ability to quantify their impact on water quality at local scales as well as across the Chesapeake Bay watershed. Some practices (such as voluntary efforts) are not well tracked. Reporting of other practices is often suspect/inaccurate (J. Sweeney, repeated pleas to partners in WGs, committees over the past 2 decades, recent Devereux ref.) and lacks the geographic resolution needed to help explain trends (Sweeney 2009; National Research Council 2011; Sweeney 2012). Furthermore, complexities – such as assumptions regarding the relative efficiencies of different management practices, the temporal and spatial variability in BMP effectiveness, and other decision rules applied in the processing of reported data – constrain interpretability. The extent to which existing data are accurate and available is poorly communicated and understood, resulting in inconsistencies in access to data, as well as potentially inaccurate interpretations.

Recommendation: The CBP should continue efforts to improve reporting and tracking of management practices, and should work with partners to make currently available data more explicable. In particular, better procedures should be developed for acquiring the files of integrated, processed data that are generated by the CBP's Airshed, Land Use Change, and Scenario Builder models for input to the Chesapeake Bay Watershed Model (CBWM), in formats and with sufficient documentation to make them useful. These files are commonly referred to within the CBP as "input decks." They represent an integration of factors with the potential to affect pollutant loads that are represented in the CBWM. The CBWM is central to estimating the N, P, and sediment load reductions required to attain water quality standards in the Chesapeake Bay.

To support this end, better metadata – better reporting of the assumptions, gaps, and weaknesses of existing datasets – is critical. Examples of improved metadata include scale of reporting, level of data verification, and documentation of inconsistences and changes in sampling and/or laboratory methods for data time series.

Finding: A better understanding of BMP effectiveness requires more edge-of-field, farm-scale flow and concentration data, including a more complete inventory of all pollutant sources (such as livestock populations) for a greater number and more diverse set of watersheds. Monitoring of groundwater is important for understanding trends in water quality parameters, and should include the use of chloride and other ions to trace groundwater sources.

Recommendation: The CBP should prioritize more comprehensive and better monitoring of the effectiveness of BMPs. This includes assessing BMP effectiveness over time, with and without proper operation and required periodic maintenance. Field-scale monitoring of hydrology, chemistry, and ortho-phosphorus should be increased. In particular, a sustained, systematic soil P sampling network and database on both agricultural and urban landscapes should be considered, as well as sampling techniques that provide a more complete assessment of sediment transport and storages throughout the landscape.

Finding: The body of existing water quality monitoring data on the Chesapeake Bay watershed and estuary is among the most robust in the world. The long-term maintenance of a water quality monitoring program in non-tidal tributaries has enabled the development of novel methods for estimating trends in loads to the estuary. However, while the existing non-tidal monitoring network (see J. Blomquist summary, Appendix C) is well suited for assessing N fluxes and trends, the large variance inherent in sediment measurements results in larger uncertainty for estimates of fluxes and trends in sediment and P. Discerning trends in such inherently variable data requires higher resolution of stream sampling than the 20 samples per year that are currently collected. More continuous monitoring of water quality parameters would further reduce uncertainty and improve assessment of trends in water quality in general, and of P in particular.

Long time series of data on key water quality indicators in tidal waters have also supported new insights regarding the Chesapeake Bay's response to reductions in pollutant loads, particularly with respect to hypoxia and submersed aquatic vegetation (SAV). However, a better understanding of the estuary's response to N, P, and sediment loads is needed. This would require improved monitoring of ecological resources including chlorophyll *a*, SAV, and speciation of plankton as indicators of ecosystem response. Detecting progress of oyster restoration efforts would also require more monitoring of oyster populations (ORET 2009); detecting the effects of climate change would require more monitoring that targets potential indicators such as the effects of pH and carbon dioxide (CO_2) on oysters. Maintenance of long-term records of dissolved oxygen, water temperature, and salinity are also critical to understanding climate change effects on the bay.

Recommendation: The CBP should implement continuous monitoring for locations, times, and constituents that maximize its utility for key WQ parameters. Continuous monitoring of the "Big 5" water quality constituents – total nitrogen (TN), nitrate, sediment, total phosphorus (TP), and ortho-phosphorus should be considered, although continuous monitoring of sediment and P species may be more valuable than of N. Tools that assist in optimal placement of continuous monitoring instruments should be exploited to maximize the value of investments in continuous monitoring.

To supplement current sampling designs and annual basin-wide, base flow synoptic sampling should be considered, perhaps to be implemented in sub-watersheds or nested watersheds (e.g., Weller et al. 2010).

In general, monitoring of living resources' response to restoration actions should follow recommendations that have been put forward in previous partnership and STAC workshops and reports. A list of STAC publications related to monitoring is provided in Appendix D.

Integrated Approaches to Explain Trends:

What descriptive and/or quantitative methods can be applied in the next 3 years to produce an integrated explanation of trends in the estuary and watershed for the TMDL MPA? What are the most

promising quantitative approaches that should be investigated / developed to explain trends after the 2017 MPA and prior to 2025? At what scale(s) can these approaches be applied (i.e., entire Chesapeake Bay/watershed; major river systems; smaller sites)?

Finding: It is often easier to identify and explain the effects of management actions in small watersheds because of the reduced numbers of influencing factors and pollutant transport processes relative to larger watersheds (e.g., Weller et al. 2010). In addition, explaining change at smaller scales addresses citizens' concerns regarding local water quality. Trends from larger watersheds can be used to assess the collective benefit of many different types of practices on downstream water quality. Efforts to link management actions with trends in water quality at the scale of small watersheds must integrate and be complemented by studies that aim to discern trends and their drivers at regional and basin-wide scales. In doing so, note that care must be taken in extrapolating findings from small watershed studies to explain trends in water quality at larger scales across the Chesapeake Bay watershed. Isolating the effects of management actions on water quality in the watershed and estuary within and across both spatial and temporal scales will require novel approaches and the application of new analytical techniques.

Recommendation: The CBP should engage in a concerted effort to energize the academic and federal research communities to conduct collaborative studies using the most promising and feasible techniques from among those suggested below. Some proposed analytical techniques are best suited to investigate the drivers of observed changes in water quality at the scale of small watersheds; other suggestions describe approaches that are more easily applied at regional scales. Finally, a number of techniques hold promise for application at a range of scales, or even for integrated application across scales from small watersheds to the entire Chesapeake Bay drainage basin.

Analytical approaches that lend themselves to investigations at the scale of a small watershed include:

- Focusing on explaining particular cases and then delving into those watersheds to understand drivers of observed patterns. Examples of such situations include:
    - Watersheds with high levels of BMP implementation;
    - Watersheds for which significant changes in loads have been quantified; and
    - Watersheds for which periods of monitoring records contain a range of outliers.

- Using fingerprinting studies (i.e., isotopic and geochemical analysis) to track nutrient transport from the land surface to a monitoring location;

- Using empirical orthogonal function analysis to decompose time series of data into distinct components (Patrick et al. 2014);

- Using U.S. Department of Agriculture-Agricultural Research Service (USDA-ARS) models to validate management practices and examine BMP effectiveness probabilities (Wang et al. 2011; Rabotyagov et al. 2014); and

- Exploiting different types of correlation analysis:

- Cross-correlation analysis is a useful tool for modeling relationships between multiple data time series. It could be used to look for correlations between trends, and could help to determine whether the parameter trends are hydrologically connected (see Guadayol et al. 2009, Cox et al. 2013, and Chen et al. 2014 for examples).

Recommended analytical approaches that lend themselves to investigating drivers of water quality change at a regional, basin-wide scale include:

- Further developing and applying the time-variable spatially referenced regressions on watersheds (SPARROW) approach (described in R. Smith's [USGS] presentation, Appendix A) to directly link changes in sources with changes in loads at a regional scale;

- Incorporating climate models to help quantify additional nutrient and sediment reductions that managers will have to implement in order to account for sea level rise and climate change effects (for example, see Johnson et al. 2012); and

- Combining groundwater models with methods designed for analyzing time series of data, to help to explain the role of lag times, with emphasis on the effects of flow, in the detection of trends in water quality. One specifically recommended time series analysis technique was the use of autoregressive integrated moving average (ARIMA) models.

Approaches that may be used to integrate explanations of trends observed at the scale of small watersheds (i.e., sub-basins within the larger Chesapeake Bay drainage area) with patterns observed at the larger scale include:

- Using the multiple paired watershed approach; encouraging additional studies that use space for time to test different management effects (Weller et al. 2010; National Research Council 2011; Jastram 2013);

- Using box models (applied on both small and larger scales) to quantify mass balance for a watershed and to estimate lag times between implementation and response in both non-tidal and tidal waters;

- Combining statistical models such as SPARROW with field-scale agricultural models such as the Agricultural Policy/Environmental eXtender (APEX) and lag time models (Garcia 2014);

- Applying GAMs within a Bayesian and/or hierarchical framework, in order to increase the statistical power of the GAMs approach (Wood 2006). However, it should be noted that doing so requires assuming that trends are similar within each branch of the hierarchy, which may not be a safe assumption in this system; and

- Using path analysis techniques. The term "path analysis" encompasses a variety of methods that can be tailored to investigate causality among variables. Some examples are factor analysis, multiple regression techniques, structural equation modeling, and latent variable modeling.

Conclusions and Next Steps

The MEOWQT workshop produced an array of recommended analytical approaches for linking management actions in the Chesapeake Bay watershed to observed changes in water quality. The challenge remains to:

1. Identify those approaches that are best suited for application to the Chesapeake Bay watershed;

2. Identify current/ongoing studies that are already implementing some of these approaches, in particular those that will have results in time to inform the 2017 MPA;

3. Distinguish the subset of studies and analytical tools that can be applied to inform the MPA from those approaches that require a longer time-frame to implement; and

4. Identify the resources, including additional monitoring, that would be necessary for pursuing the most promising approaches for informing the 2017 MPA.

Recommendations from the workshop will help guide the Partnership's efforts to explain the effect of management practices on changes in water quality and to distinguish from those changes due to system lags, land uses, population, and weather patterns. This improved understanding will support an adaptive management approach to restoration of the Chesapeake Bay Watershed.

The following is a preliminary effort to summarize previously identified activities that should be targeted for implementation prior to 2017, and some recommendations for supporting longer-term efforts.

For the 2017 Midpoint Assessment:

1. Further develop and apply existing trend detection techniques for estuarine waters. GAM techniques should be implemented as a complement to the application of the WRTDS method for non-tidal waters;

2. Report results of trend detection analyses, including estimates of uncertainty, for analyses conducted with both the WRTDS and GAM approaches;

3. Identify projects already under way that can provide findings in time to inform the MPA and post-MPA Phase III WIPs;

4. Select a small number of pilot watersheds where accurate reporting of BMPs, existing knowledge of land use changes, and a robust water quality time series can support an immediate effort to apply one or more of the recommended analytical approaches for explaining the drivers of observed trends in water quality;

5. Conduct targeted SPARROW modeling activities to help inform development of the Phase 6 CBWM; and

6. Commit partners to a plan for making data compiled by the CBP Modeling Team more accurate and accessible.

Longer-Term Enhancements for Explaining Trends by 2025:

1. Improve quality of, and access to, BMP data needed to help explain trends;

2. Implement more continuous monitoring of nutrients and sediment to improve the capacity to detect and explain trends in water quality;

3. Determine support for collection of additional parameters (such as tracking groundwater sources) critical to linking landscape characteristics to water quality; and

4. Develop and apply the most promising statistical techniques recommended above to better distinguish effects of BMPs in river basins and downstream estuary waters.

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Appendix A: Workshop Agenda

Enhancing Approaches to Explain Management Effects on Water Quality Trends
Tentative Workshop Agenda
A STAC Responsive Workshop
Dates: March 25-26 2014
Location: Westin Hotel, Annapolis, MD

Workshop Introduction

The Chesapeake Bay Program (CBP) decision framework for adaptive management has these components: articulating program goals, describing factors influencing goal attainment, assessing current management efforts and gaps, developing a management strategy, developing the monitoring program, assessing performance, and revising these components to improve program performance based on new insights.

With the goal of improving approaches to the "assessing performance" step of the decision framework, the workshop addresses the following questions:

(1) "How do we better understand the degree to which management practices are improving water quality in the Bay and its watershed?", and
(2) "How do we use the knowledge gained from asking this question to guide the actions we take to continue to improve the water quality and ecosystem health of the Chesapeake Bay and its watershed?"

The purpose of the workshop is to identify improved technical approaches for explaining the effect of management actions, and the degree to which they are influencing, water quality changes in the watershed and estuary. The purpose of the breakout sessions is to promote discussion and generate recommendations on three primary topics:

- Enhancing trend detection methods;
- Identifying information that is needed to better explain trends; and
- Suggesting quantitative approaches for an integrated approach to explain trends in the tidal waters and watershed.

Recommendations from the workshop will help guide CBP partner efforts to better explain the effect of management practices on water quality change. The improved understanding will support an adaptive management approach to restoration of the Chesapeake Bay and its watershed.

There are two primary challenges to better understanding the relation of management practices to water quality improvement:

1) The influences of climatic variability and environmental setting will both affect water quality and ecosystem changes. Climatic variability, especially the size and timing of precipitation events,

has a profound effect on water quality and ecosystem conditions. Thus, being able to observe the changes due to human activity can be difficult when viewed against the backdrop of those variations. The environmental setting will influence the residence time of nutrients and sediment in the watershed and circulation of nutrients in the estuary, thus causing a "lag time" between implementation of management practices and water quality and ecosystem response. There is a need to better integrate the effect of lag times in explanation of water quality and ecosystem changes.

2) The management actions taken across the watershed are highly diverse and distributed across this very large area. They are further made complicated by the many other changes that happen on the landscape related to demographic and land use shifts and by market-driven changes in agriculture and land development. Determining the impact of the management actions requires the availability of distributed and accurate time series of these human activities in the watershed. These data sets can be very difficult to obtain and need to be improved to explain changes.

Pre-workshop jumpstart videos will be required viewing of workshop participants, focusing on the anthropogenic and natural drivers of water quality trends. Videos will also be available for viewing during registration:

- Anthropogenic Drivers: Pollution sources and BMPs - Jeff Sweeney (EPA CBPO)
- Anthropogenic Drivers: Land use changes – Peter Claggett (USGS CBPO)
- Introduction to the Environmental Setting and Climate Variability Underlying Water Quality Trends – Joel Blomquist (USGS)
- Historical Patterns in Chesapeake Bay Health Indicators – Peter Tango (USGS CBPO)
- New Insights: Science-based evidence of water quality improvements, challenges, and opportunities in Chesapeake Bay Restoration – Christina Lyerly (UMCES)

Tuesday, March 25 Morning Session

9:00 am **Workshop registration opens**

10:00 am **Overview of workshop management questions – *Gary Shenk (EPA-CBO) and Jeni Keisman (USGS)***

Presentations:

- **Gary Shenk -** http://www.chesapeake.org/stac/presentations/231_Intro%20MEOWQT%20STAC%20gshenk.pdf
- **Jeni Keisman -** http://www.chesapeake.org/stac/presentations/231_Intro%20Presentation%20Keisman%20Final.pdf

10:30 am **Using the USGS' WRTDS (Weighted Regressions on Time, Discharge, and Season) to describe water quality trends – *Bob Hirsch (USGS)***

Presentation:

- http://www.chesapeake.org/stac/presentations/231_Hirsch%20WRTDS%20Trends%28small%20size%29.pdf

11:00 am **Using GAMs to describe water quality trends in estuarine and freshwater systems– *Elgin Perry (Independent Consultant to EPA-CBO)***

Presentation:

- http://www.chesapeake.org/stac/presentations/231_PerryTrendWS.pdf

11:30 am **Plenary Discussion on quantitative approaches to explain water quality trends in the watershed and estuary – *Gary Shenk (EPA-CBPO) and Jeni Keisman (USGS)***

Presentation:

- http://www.chesapeake.org/stac/presentations/231_Discussion%20Questions%20Plenary.pdf

12:00 pm **Lunch**

Tuesday, March 25 Afternoon Session

This session will focus on some examples where linkages of activities on the landscape and natural forcing have had demonstrable impact on large water bodies.

1:00 pm **Tracking and Understanding Change in San Francisco Bay – Jim Cloern (USGS, Menlo Park, CA)**

Presentation:

- www.chesapeake.org/stac/presentations/231_2014CBP-STAC.pdf

1:45 pm **Case Studies within the Chesapeake Bay estuarine system – Walt Boynton (UMCES)**

Presentation:

- http://www.chesapeake.org/stac/presentations/231_Walt-Trends%20STAR%20March%202014%20v3.pdf

2:30 pm **Moderate-complexity models for the Gulf of Mexico, Lake Erie, and the Maumee River – *Dan Obenour (University of Michigan)***

Presentation:

- http://www.chesapeake.org/stac/presentations/231_Obenour_ResearchTalk_STAC3.pdf

3:15 pm **Break**

3:30 pm **Breakout Session #1: Use of existing methods and information to support the TMDL Mid-Point Assessment in 2017**

4:45 pm **Overview of Day 2/Organize dinner plans –** ***Gene Yagow (Virginia Tech)***

5:00 pm **Recess**

Wednesday, March 26 Morning Session

This session will focus on scientific approaches that have been successful or that might be successful in linking water quality trends to anthropogenic or natural drivers

8:00 am **Introduction to the morning session –** ***Scott Phillips, USGS***

Presentation:

- http://www.chesapeake.org/stac/presentations/231_WORKGROUP%20presentation_Phillips.pdf

8:15 am **Importance of changing atmospheric deposition to nutrient trends in the Chesapeake Bay watershed –** ***Keith Eshleman (University of Maryland – Appalachian Lab, Frostburg, Maryland)***

Presentation:

- http://www.chesapeake.org/stac/presentations/231_Eshleman%20et%20al.%20STAC%20March%202014.pdf

8:45 am **Mid-bay dissolved oxygen trends as a function of nutrient loads –** ***Bill Ball (Johns Hopkins University)***

Presentation:

- http://www.chesapeake.org/stac/presentations/231_Ball_2014-03-25_CBP-STAC%28from%20AEESP2011%29REVISED.pdf

9:15 am **Time dependent version of the SPARROW model –** ***Dick Smith (USGS, Reston, VA)***

Presentation:

- http://www.chesapeake.org/stac/presentations/231_smith.STAC14.final.pdf

9:45 am **Using spatially explicit models to estimate the impacts of changing agricultural practices –** ***Ana Garcia (USGS – Raleigh, North Carolina)***

Presentation:

- http://www.chesapeake.org/stac/presentations/231_GARCIA.CBP_WORKSHOP_March26.pdf

10:15 am **Break**

10:30 am **Understanding water quality trends in urban watersheds – *Claire Welty (UMBC)***

Presentation:
- http://www.chesapeake.org/stac/presentations/231_Welty%20STAC%203-26-14.pdf

11:00 am **Small watershed and sub-estuary studies link drivers and management practices to system responses – *Don Weller (SERC) and Tom Jordan (SERC)***

Presentation:
- http://www.chesapeake.org/stac/presentations/231_SERCtalkv15fixes.pdf

11:30 am **National Nonpoint Source Monitoring Program (NNPSMP) Long-Term Monitoring Projects:** Statistical approaches to documenting water quality improvements from BMPs **– *Jean Spooner (NC State University)***

Presentation:
- http://www.chesapeake.org/stac/presentations/231_Spooner_Corsica_STAC%20 2014.pdf

12:00 pm **Lunch**

Wednesday, March 26 Afternoon Session

12:30 pm **Breakout Session # 2:** New or enhanced methods, datasets, and studies to inform management actions over the longer term (i.e. 2017-2025).

2:00 pm **Wrap-up discussion**

3:00 pm **Adjourn**
Steering committee meets to begin the report outline and assign tasks.

Appendix B: Workshop Participants

Workshop Steering Committee

Brinsfield	Russ	UMD Wye Center
Ellis	Matt	STAC-CRC
Gardner	Natalie	STAC-CRC
Keisman	Jeni	USGS
Kemp	Michael	UMCES
Miller	Andy	UMBC
Phillips	Scott	USGS
Shirmohammadi	Adel	UMD
Staver, Jr.	Ken	UMD Wye Center
Yagow	Gene	Virginia Tech

Workshop Presenters

Ball	Bill	JHU
Boynton	Walt	UMCES
Cloern	Jim	USGS
Eshleman	Keith	UMCP-Appalachian Lab
Garcia	Ana	USGS
Hirsch	Bob	USGS
Jordan	Tom	SERC
Obenour	Dan	University of Michigan
Perry	Elgin	Consultant, EPA-CBPO
Shenk	Gary	EPA-CBPO
Smith	Richard "Dick"	USGS
Spooner	Jean	NC State University
Weller	Don	SERC
Welty	Claire	UMBC

Workshop Participants

Ator	Scott	USGS
Batiuk	Rich	EPA-CBPO
Bennett	Mark	USGS
Berger	Karl	MWCOG
Blankenship	Karl	Bay Journal
Boomer	Kathy	TNC
Bukaveckas	Paul	VCU
Chanat	Jeff	USGS
Currey	Lee	MDE
Devereux	Olivia	Devereux Consulting
Easton	Zack	Virginia Tech

Fisher	Tom	UMCES
Forrest	Quentin	MDE
Garcia	Ana	USGS
Hill	Bob	UMD
Hively	Dean	USGS
Hyer	Ken	USGS
Johnston	Matt	CBPO-UMD
Jordan	Tom	SERC
Karrh	Renee	MD-DNR
Keisman	Jeni	USGS
Langland	Mike	USGS
Law	Neely	CWP
Linker	Lewis	EPA-CBPO
Mandel	Ross	ICPRB
Meisinger	Jack	USDA-ARS
Michael	Bruce	MD-DNR
Miller	Andy	UMBC
Montali	Dave	WV-DEP
Moyer	Doug	USGS
Patrick	Chris	SERC
Phillips	Scott	USGS
Pruzinsky	Amanda	CBPO-CRC
Robertson	Tish	VA-DEQ
Rubin	Lea	CBPO-CRC
Sabo	Robert	UMCP-Appalachian Lab
Sanford	Ward	USGS
Sellner	Kevin	CRC
Stewart	Steve	Balt. Co. Dept. of EP&S
Testa	Jeremy	UMCES
Tian	Richard	CBPO-UMCES
Vadas	Peter	USDA-ARS
Wang	Ping	CBPO-VIMS
Weller	Don	SERC
Welty	Claire	UMBC
Wilusz	Dano	JHU
Williams	Michael	UMCES
Zhang	Qian	JHU

Workshop Video Presenters

Blomquist	Joel	USGS
Claggett	Peter	CBPO-USGS
Dennison	Bill	UMCES
Lyerly	Christina	UMCES-IAN
Sweeney	Jeff	EPA-CBPO
Tango	Peter	USGS

Appendix C: Video Summaries

Introduction to the Environmental Setting and Climate Variability Underlying Water Quality Trends – Joel Blomquist (USGS)

Video: https://www.youtube.com/watch?v=RD9dCzoi32U&feature=youtu.be

Blomquist's video presentation focused on three main topics: environmental setting and climatic factors and how they affect our ability to assess trends; overview of selected recent trends results; and a review of the current state of the Chesapeake Bay watershed monitoring network. Environmental settings and climatic factors include: river-flow variability; source changes and BMPs; and watershed properties (in-stream loss and geochemical processes; groundwater; residence time and storage; "lag times"). Climatic effects refer to the standard climate variability within the Chesapeake Bay watershed. Lag times describe the process of a land-based change causing an observable response in water quality.

The Chesapeake Bay watershed ranges from forested uplands, to high steep ridges and incised valleys, and the Great Valley region to the Piedmont and finally, coastal plain sediment areas. Water quality responses can differ from one setting to another. This is due in part to different river and streamflow variations across the different physio- and geographic landscapes. It is natural to have a series of drought and flood years within a decade and these variations influence river flow. The spring season brings the largest freshwater inflow to the Chesapeake Bay, with the lowest inflow rates occurring in the summer months. In-stream processes and functions have a major impact on the amount of nutrient/sediment load delivered to the Chesapeake Bay.

Groundwater also plays a prominent role in obscuring the true amount and movement of nutrient loads from streams and rivers through the subterranean landscape. The amount of time it takes for that water to cycle from the stream to groundwater and back to the surface is known as residence time, but the uncertainties associated with these times and transport create unknown lag times. Variation within the Chesapeake Bay watershed landscape will induce varied responses in sediment storage and transport. Blomquist explained that areas of high sediment yields exist predominantly in the Piedmont physiographic region, and in lands with agricultural and urban land uses.

In addition, streamflow intensity determines transport and storage of N, P, and sediments. When tracking restoration progress throughout the Chesapeake Bay watershed, scientists and modelers use flow-adjusted trends. Blomquist presented a map showing various monitoring networks throughout the watershed.

Over the past ten years, there have been decreasing N concentration in 25 of 43 selected monitoring sites, 20 other sites showing insignificant to no change, and only one site in Virginia showing any degradation (rising N concentration). In terms of flow-adjusted P concentrations, results are not so obvious. Only 9 sites out of 43 showed improvements, 27 sites showed no change, and 7 sites were degraded. Flow-adjusted suspended sediment concentrations showed even more disparity, with only 4 out of 39 sites improving, 19 sites showing no change, and 16 sites degrading.

Blomquist then described the evolution of the CBP Monitoring Network showing both non-tidal and tidal sites. The River Input Monitoring Program is a tributary-based network of 9 sites in total that have been operating from 1985 to the present. To that, the CBP added 21 partner-operated monitoring stations, with data going back to at least 1985, to create a long-term monitoring network. In 2004, the CBP expanded to incorporate a coordinated network of 56 new sites across all partner jurisdictions by adding storm sampling gauges, quality assurance programs, and a consistent sampling framework and protocols. More recently, the network expanded to include 40 more sites to target land uses in small watersheds.

Land Use/Land Cover Trends and Data – Peter Claggett (USGS)

Video: https://www.youtube.com/watch?v=UObeoTmyjwM

The Chesapeake Bay Watershed is 64,000 square miles in area and has the highest land area-to-water volume ratio of any coastal estuary in the world, so what happens on the land has more impact on Chesapeake Bay water quality than anywhere else. Population growth has grown steadily and the watershed is expected to support 20 million people by 2030, an increase from approximately 8 million in 1950.

Spatial development trends are best understood by examining shifting housing densities beginning in 1940. Most future growth is expected to occur around the Baltimore-Washington and other interstate corridors, similar to 20th century trends, but there is also significant growth expected to occur away from urban sectors, leading to forest and farmland loss.

Annual impervious surface data were recently acquired for all of Maryland and Delaware. Across the Chesapeake Bay watershed, satellite confusion between low-density residential land, pasture, and farmland led to major discrepancies between the reported Landsat Land Cover Change from 1984-2006 and the CBP Modeled Land Use Change from 1985-2005.

New land use categories have been proposed for the CBWM Phase 6 to reduce confusion and refine land uses with unique nutrient and sediment characteristics needed for local implementation and reporting of BMPs. Land uses such as riparian areas, floodplains, and connected impervious surface have differential impacts for water quality.

Developed land uses, which were previously separated into impervious and pervious developed lands, have been broken into subcategories: impervious developed (residential, non-residential, roads, construction); pervious developed (turf grass, tree canopy <1 acre). Each of those subcategories is further refined to assess whether the lands are (1) connected to streams, (2) regulated based on density, storm surge, etc., (3) federal or non-federal, and (4) fertilized or non-fertilized pervious developed lands. Natural land uses (forests, wetlands, beaches, open water) have been expanded as well. Forest land uses now include upland, floodplain, and riparian (non-floodplain) subcategories. Wetlands now include tidal, riverine, and palustrine/lacustrine subcategories, and each of the subcategories are further separated into categories to assess disturbance, seral stage or type (herbaceous/woody), and whether or not the land is harvested (does not apply to tidal, beaches, and open water).

Agricultural land uses proposed for the CBWM Phase 6 include farmsteads, crops (grain and forage, grass or legume hay, vegetables), pasture, nurseries (covered or uncovered), orchards, sod farms, and idle/fallow land. Farmsteads are categorized by impervious and regulated lands, and all agricultural land uses are organized by federal or non-federal lands. The CBP uses the CropScape Cropland Data Layer to spatially identify where the agricultural land use areas exist.

The CBP is also conducting a phased local land use data request, which began in February 2013. Phase 1 provides one year to collect readily available land use and related datasets from localities, and evaluate similarities and differences among received datasets. Phase 2 will be used to identify gaps in the types and locations of data received, and solicit local agencies directly for data. The final phase, scheduled for a July 2014 start, will solicit and accept updates to data received from localities.

Anthropogenic Drivers: Pollution Sources and BMPs – Jeff Sweeney (EPA-CBPO) and Matt Johnston (UMD-CBPO)

Video: https://www.youtube.com/watch?v=g1dOzWGxVKY

Sweeney's presentation focused on root pollutant sources and BMPs, and how they affect nutrient and sediment loads to the Chesapeake Bay. In a previous version of the CBWM (Phase 5.3.2), watershed modelers divided total N in two ways: land use source and root sources. The three primary models used at the CBP are the atmospheric deposition, watershed, and estuarine models.

In terms of atmospheric deposition of N, ozone seasonal NO_x emissions have decreased significantly from 1990-2011. Nitrate concentrations showed the same long-term decreasing trend as NO_x emissions, and this translates to decreasing flux and deposition to the watershed. These trends were gathered from both monitored and modeled atmospheric deposition data, wet and dry data, and both oxidized and reduced forms of N.

Sweeney then discussed pollution sources from manure and chemical fertilizer nutrients. The CBP uses different nutrient species (Nitrogen as NH_3, Organic N, Mineralized N, and NO_3; Phosphorus – PO_4, Organic P, and Mineralized P) in Scenario Builder to further refine manure mass and nutrient loads. Within the Chesapeake Bay watershed, poultry populations (measured in animal units, AU) increased from 1982-2012 while livestock units decreased. In that same time-frame, manure N and P crop application rates (not including additional chemical fertilizer applications) increased steadily.

Nutrient application rates and timing for over a hundred different crops are governed by temperature variations, agricultural practice data, actual yield history, and allowances for variation among planting and harvest dates. Chemical fertilizer application has decreased from 1982-2012, but when combined with rising manure application, results show that there has been little decrease in the amount of manure/fertilizer N applied to crops. Fertilizer application rates are kept constant for turf grass land cover (i.e., do not vary from year to year).

Nearly 85% of all sediment loads to the Chesapeake Bay come from agriculture erosion and urban/suburban runoff. BMPs to reduce loads can differ mechanistically. For instance, Sweeney described BMPs that alter nutrient flux to the land by encouraging diet and feed changes, manure transport, and ammonia emissions reductions in agricultural sectors, and increasing nutrient management in both agricultural and urban lands. Other BMP types involve land use conversions, variable nutrient and sediment reduction efficiencies, and practices with both land use conversions and reduction efficiencies (riparian forest and grass buffers, wetland restoration).

Chesapeake Bay Health Patterns and Trends – Peter Tango (USGS-CBPO)

Video: https://www.youtube.com/watch?v=vdKEYCsNLqs

Tango reviewed long-term water quality time series data that exist for physical, chemical, and biological parameters in the Chesapeake Bay and tidal tributaries; available linear and non-linear trend assessment results; significant trends for Chesapeake Bay health indicators at local, regional, and bay-wide scales; trends that exhibit seasonality; system-specific syntheses that have been published and could be leveraged for further analyses; consideration of upstream, in-bay, and global influences for explaining trends; and exploration of sensitivity and use of complementary variables to detect change and explain effects of management actions.

Tidal water quality time series exist for an array of individual water quality metrics, multi-metric assessments, variable-length time series, state level and tributary level metrics, salinity zones, segments, strata, and stations. These data are available for a range of geographic scales. A suite of physical, chemical, and biological parameters are assessed for trends on an annual basis. The trends are evaluated for a variety of seasons and water column layers, and seasonal Kendall (S-K), blocked S-K, and non-linear trends tests are applied for parameters from 1985-2012, as applicable.

Tango presented dissolved oxygen (DO) time series from the Water Quality Standards Criteria Attainment for All Tidal Waters in which DO standards attainment improved from the mid-1980s to the early 2000s before declining to levels similar to starting levels. Water clarity exhibited a long-term decline from the mid-1980s to 2012. In comparison, SAV abundance has fluctuated in that time-frame with a peak in 2002; SAV acreage in the Chesapeake Bay remains well below the 200,000 sq. acre goal.

Tango discussed the extended time series for regional chlorophyll *a* in the Chesapeake Bay, which dates back to 1950, and even longer data sets, such as the 113-year time series for summer DO in the Potomac River.

Multi-metric assessments of Bay health such as the CBP Bay Health (i.e., Water Quality Standards Achievement) indicator and the Benthic Index of Biotic Integrity (BIBI) have shown relatively little inter-annual variability from 1985-2012. However drilling down into the patterns in both the composite and the individual metrics can provide further insights regarding regional signals in water quality parameters over time.

Tango presented examples of case studies conducted at local, regional, and bay-wide scales that can be leveraged and synthesized to inform analysis for explaining trends in water quality. Small-watershed scale studies (such as the Gunston Cove and Mattawoman Creek studies) have provided insights into responses to local point-source reductions. On a bay-wide scale, time series of DO data extending from present time back to the 1950s have supported multiple studies and syntheses of long-term patterns in hypoxia. Recent multi-model analyses have integrated multiple factors potentially affecting Bay hypoxia.

Water quality behavior integrates climate, landscape, and biology to help explain trends. For example, in the Magothy River, a dark-false mussel population explosion produced some of the clearest waters in years, but a Mahogany Tide (harmful algal bloom) diminished that improvement a few years later.

New Insights: Science-based evidence of water quality improvements, challenges, and opportunities in the Chesapeake – Christina Lyerly (UMCES)

Video: https://www.youtube.com/watch?v=5ltQliYXeFM

New Insights Report:
http://www.chesapeakebay.net/documents/New_Insights_Executive_Summary_FINAL.pdf

Lyerly provided an update of the CBP New Insights Report. UMCES reviewed 40 case studies and developed 7 lessons that were categorized into three themes: What's Working?; Challenges; and Opportunities.

Lesson 1: Upgrades in both N and P wastewater treatment result in rapid local water quality improvements. Lyerly presented a case study from the Upper Patuxent River in Maryland. Upgrades to wastewater treatment plants and a 1985 ban on P in laundry detergents reduced nutrient loads to the Upper Patuxent. Decreasing N loads from wastewater treatment plants contributed to a resurgence of SAV growth in the Upper Patuxent.

Lesson 2: Improvements in air quality led to reductions in atmospheric nitrogen deposition. In the past 20 years, atmospheric nitrogen deposition declined by nearly a third in the Chesapeake Bay watershed. Lyerly cited research conducted by Keith Eshleman (UMCES-Appalachian Laboratory) showing that decreases in atmospheric point source emissions (from power plants) and nitrogen deposition are directly linked to improved surface water quality in 9 mostly-forested sub-watersheds in the Appalachian region. In addition, tighter regulations have decreased vehicle emissions, but the majority of nitrogen oxide (NO_x) emissions continue to originate from mobile sources.

Lesson 3: Reductions of agricultural nutrient sources result in improved stream quality. The New Insights report focused on three main practices: Cover crops, excluding livestock from streams, and animal waste management. In the Wye River drainage basin, cover crops planted during winter significantly reduced groundwater nitrate concentrations in two agricultural fields.

Lesson 4: Many practices provide initial water quality improvements in runoff; however, full benefits to stream conditions can be delayed. The delays between BMP implementation and observable water quality improvements are known as lag times. Lag times present one of the first challenges in the New Insights report. Lag times are driven by a number of factors like groundwater age (the time it takes water to recharge in the water table to the time it discharges from streams – this can range from less than a year to more than a hundred years), and storage of P in sediments (even if P loads are reduced to the estuary, unknown amounts of P already stored in sediments can be discharged to the Chesapeake Bay). Unknowns like this create uncertainty in tracking BMP effectiveness and water quality improvements.

Lesson 5: Improvements in water quality can be counteracted by changes in nutrient sources and land use practices. For instance, upgrades to wastewater treatment plants have reduced nutrient loads from Easton and Cambridge wastewater treatment plants on Maryland's Eastern Shore, but water quality remains poor in the upper and middle tidal Choptank River which flows between both towns. Agriculture is the primary driver of poor water quality in the non-tidal Choptank River. As agricultural land coverage increases, nitrate concentrations also increase in nearby streams due to increased fertilizer application and loss of local forest and wetland buffers that protect larger waterways.

Lesson 6: Observable water quality responses are more likely to occur if: (a) location-specific sources of pollution are identified and (b) targeted practices are implemented. This lesson presents the first opportunity for improvement within the New Insights Report. Lyerly focused on one Centreville, Maryland case study in which improvements in non-tidal water quality in the Corsica River were observed after aggressive implementation of multiple nutrient reduction practices. That study showed decreasing concentrations of total N and P in the Three Bridges Branch and Gravel Run waterways two years after the implementation of the nutrient reduction plan.

Lesson 7: An array of practices (rain gardens, impervious surface installation, etc.) to promote stormwater infiltration and retention are needed in expanding urban and suburban areas. Currently, there are approximately 17.5 million people in the Chesapeake Bay watershed, and that number is expected to rise to 20 million by year 2030. In Baltimore, Maryland, constructed wetlands have already demonstrated the potential to reduce nitrate entering streams through stormwater runoff. Constructed wetlands received water primarily from direct stormwater outflows, and other types of wetlands received overflow water from nearby streams during high precipitation events. Constructed wetlands can potentially be just as effective at reducing nitrates in streams through the denitrification process.

Overall, many practices are working. The Clean Water Act, Clean Air Act, and practices to reduce agricultural nutrient loads have proven effective so far, but challenges remain. Delays in observable water quality improvements necessitate patience and persistence, and increased population pressures and unsustainable changes to the landscape can hinder efforts. Despite these counteractive issues, opportunities for improvement have arisen from the ongoing research in the Chesapeake Bay watershed. Scientists and policymakers have learned that implementation location is crucial for success. Nutrient sources must be accurately identified and BMPs must be properly targeted. Expected BMP outcomes must be effectively monitored and measured to track progress and implement adaptive management as necessary. With population growth, innovative and proven practices in the field of stormwater management should be implemented while further testing is conducted.

Appendix D: STAC Publications with Emphasis on Monitoring

1. STAC (2007) Submerged Aquatic Vegetation Reproductive Ecology: Evaluating the State of Knowledge and Assessing Future Research Needs
2. STAC (2007) Developing Environmental Indicators for Assessing the Health of the Chesapeake Bay Watershed
3. CRC-NCBO (2006) Baywide and Coordinated Chesapeake Fish Stock Monitoring
4. STAC (2005) Evaluating the Design and Implementation of the Chesapeake Bay Shallow Water Monitoring Program
5. STAC (2005): Assessing Progress and Effectiveness through Monitoring Rivers and Streams: Report of the Task Force on Analysis of Non-tidal Water Quality Modeling Results
6. STAC (2005) Recommendations for Refinement of a Spatially Representative Non-tidal Water Quality Monitoring Network for the Chesapeake Bay Watershed
7. Maryland Sea Grant (2004) Estuarine and Watershed Monitoring Using Remote Sensing Technology: Present Status and Future Trends Workshop
8. STAC (2004) Scientific and Technical Needs for Fulfilling Chesapeake 2000 Goals: 2004 Update
9. STAC (2000) The Technical Review of the CBPs Basin-wide Monitoring Program
10. STAC (1997) Watershed Response to Changes in Nutrient Loads: The Best Uses of Modeling and Monitoring
11. STAC (1996) Integrated Analysis of Chesapeake Bay Monitoring Data