Review of the LimnoTech Report, "Comparison of Load Estimates for Cultivated Cropland in the Chesapeake Bay Watershed"

A report of the independent review conducted by the Chesapeake Bay Program's Scientific and Technical Advisory Committee

And prepared by the Committee for the ANPC/LimnoTech Review

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This report was prepared for the Chesapeake Bay Partnership by an independent review committee organized by the Scientific and Technical Advisory Committee (STAC) of the Chesapeake Bay Program. The Committee for the ANPC/LimnoTech Review consisted of four external reviewers and six STAC members on the review steering committee:

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The review committee thanks the lead developers of the two watershed models considered here
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Norfleet and Shenk met with the review committee to provide information and answer questions about their models.

The review committee also thanks STAC staff members Matthew Johnston and Natalie Gardner for their help in organizing and accomplishing the review.

About the Scientific and Technical Advisory Committee

The Scientific and Technical Advisory Committee (STAC) provides scientific and technical guidance to the Chesapeake Bay Program on measures to restore and protect the Chesapeake Bay. As an advisory committee, STAC reports periodically to the Implementation Committee and annually to the Executive Council. 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 conferences and workshops, and (5) service by STAC members on CBP subcommittees and workgroups. In addition, STAC has the mechanisms in place that will allow STAC to hold meetings, workshops, and reviews in rapid response to CBP subcommittee and workgroup requests for scientific and technical input. This will allow STAC to provide the CBP subcommittees and workgroups with information and support needed as specific issues arise while working towards meeting the goals outlined in the Chesapeake 2000 agreement. STAC also acts proactively to bring the most recent scientific information to the Bay Program and its partners. For additional information about STAC, please visit the STAC website at www.chesapeake.org/stac.

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Executive Summary

The LimnoTech/ANPC report *Comparison of load estimates for cultivated cropland in the Chesapeake Bay watershed* analyzed the results of two Chesapeake watershed modeling efforts. The models were the Chesapeake Bay Program's watershed model (the CBP model, which was developed to evaluate actions needed to meet TMDL requirements) and a recently published USDA-NRCS model (CB-CEAP model) developed to quantify the effects of conservation practices applied to cultivated cropland in the Chesapeake Bay watershed. LimnoTech is the consulting firm that prepared the report for its client, the Agricultural Nutrient Policy Council (ANPC), an interest group representing several agricultural trade organizations.

LimnoTech reported differences between the CBP and CB-CEAP models and their results, and then recommended suspending implementation of the Chesapeake Bay TMDL until the differences were resolved.

The Chesapeake Bay Partnership asked the Scientific and Technical Advisory Committee (STAC, an advisory board for the Chesapeake Bay Partnership) to convene an independent, expert panel to review the LimnoTech report and to make recommendations concerning the application of multiple models in environmental management of the Chesapeake Bay. This report presents the findings of the review committee.

The committee concludes that the LimnoTech analyses have poor scientific merit and promote a false set of criteria by which to judge the suitability of the CBP watershed model for use in the TMDL implementation process. LimnoTech based its recommendations on unrealistic criteria for watershed model performance, inappropriate expectations for agreement between watershed models developed for different objectives, selective interpretation of the findings of the CB-CEAP report, and errors in the interpretation of the models and their results. LimnoTech failed to acknowledge that fundamental differences in models (such as the input data, assumptions, and process representations) are unavoidable because of the different objectives of the models and differences in the data and resources available to support each effort. LimnoTech's analysis also ignores the appreciable differences between the models in purpose, history, extent of calibration, extent of validation with independent data, level of spatial discretization, and degree of stakeholder involvement in model scenario development--differences that favor the continued use of the CBP model to inform and guide the implementation of management actions to meet TMDL requirements.

When LimnoTech's errors in interpretation of model results are corrected, the results of the two models are more similar to each other than reported by LimnoTech. The corrected results indicate that the model predictions of loads are in approximate agreement despite the differences in model objectives, assumptions, input data, model frameworks, and spatial and temporal details. More importantly, the results of the two models are similar in their assessment of the need for implementing more management practices on cropland.

The CB-CEAP model and its supporting data provide new knowledge and approaches that can inform and improve the CBP model and its application to watershed management planning. The review committee commends the ongoing efforts between the CBP and USDA to compare and integrate their data and analyses, and the committee recommends many other activities that could enhance the application of multiple models in managing nutrient and sediment pollution of the Chesapeake Bay (see section on Recommendations for Integrating Models).

In summary, the review committee finds that LimnoTech's comparison of the CBP and CB-CEAP models is flawed and does not provide sufficient evidence to suspend implementation of the Chesapeake Bay TMDL.

Introduction

The LimnoTech/ANPC report (LimnoTech 2010, 2011) compared the results of two watershed modeling efforts. One effort used the Chesapeake Bay Program's Chesapeake Bay Watershed Model (hereafter called the CBP model, USEPA 2010a), which has been developed and applied to plan the watershed management actions that will be needed to meet the requirements of the Chesapeake Bay TMDL (Total Maximum Daily Load, USEPA 2010b). The second modeling effort (hereafter called the CB-CEAP model), used a suite of USDA-ARS (Agricultural Research Service) models (APEX and HUMUS/SWAT). The CB-CEAP model incorporated data from the USDA-NRCS (Natural Resources Conservation Service) National Resource Inventory (NRI) and farmer surveys from the Conservation Effects Assessment Program (CEAP) to quantify the effects of conservation practices applied to cropland in the Chesapeake Bay watershed (USDA-NRCS 2010, 2011). LimnoTech is an environmental and engineering consulting firm that prepared the report for its client, the Agricultural Nutrient Policy Council. ANPC is an interest group whose steering committee includes members of the following organizations: Agribusiness Retailers Association, the American Farm Bureau Federation, The Fertilizer Institute, the National Corn Growers Association, the National Council of Farmers Cooperatives, and the National Pork Producers Council. The LimnoTech report and its revision are contracted products delivered to a client (ANPC), not peer reviewed scientific reports.

LimnoTech observed some differences between the CBP and CB-CEAP models and their results, and then recommended suspending implementation of the Chesapeake Bay TMDL until the noted differences can be resolved (LimnoTech 2010, 2011). LimnoTech's report has been cited in the popular press, congressional testimony, and entered into evidence in lawsuits seeking to stop the implementation of TMDL requirements.

In March 2011, the Chesapeake Bay Partnership asked the Scientific and Technical Advisory Committee (STAC), an independent advisory board for the Chesapeake Bay Partnership, to convene an independent, external review panel to evaluate the LimnoTech report. The review panel was asked to address the following questions:

1. Are the LimnoTech analyses and recommendations based on reasonable expectations for watershed models and expected differences between models?
2. Does LimnoTech accurately represent the two models and their results (is the report factually correct)?
3. What future activities could be undertaken by CBP, USDA, STAC, or other interested parties to improve the application of multiple models to environmental management and regulation in the Chesapeake Bay watershed?

This report presents the findings and recommendations of the review committee. Key findings are presented in bold type throughout the text.

Realistic Expectations for Watershed Models and Agreement between Models

Apart from the specific characteristics and results of the CBP and CB-CEAP models that LimnoTech considered, their report highlights a broader issue of how alternative models should be used to inform but not derail the implementation of TMDL requirements. Unfortunately, some of the statements in the LimnoTech report are based on misinterpretation of what watershed models can do and how closely alternative models that are developed and implemented for different objectives should agree. The following section presents some basic information about watershed modeling (and models in general) to provide more realistic expectations for model comparisons for use in evaluating the LimnoTech report and in future model comparison analysis. The use of models in environmental decision making is not new. The basic principles we summarize here were more completely developed by a panel of the National Research Council of the National Academies (Box 1).

Box 1. National Research Council findings on models in environmental decision making.
The National Research Council (NRC) is a neutral non-governmental scientific body chartered to provide expert scientific advice to the Federal Government. Some highly relevant findings from their report *Models in Environmental Regulatory Decision Making* (NRC 2007) are quoted below:

Models will always be constrained by computational limitations, assumptions, and knowledge gaps. They can best be viewed as tools to help inform decisions rather than as machines to generate truth or make decisions. Scientific advances will never make it possible to build a perfect model that accounts for every aspect of reality or to prove that a given model is correct in all respects for a particular regulatory application. These characteristics make evaluation of a regulatory model more complex than solely a comparison of measurement data with model results. They suggest that model evaluation be viewed as an integral and ongoing part of the life cycle of a model, from problem formulation and model conceptualization to the development and application of a computational tool.

Models have a long history of helping to explain scientific phenomena and of predicting outcomes and behavior in settings where empirical observations are limited or not available. The use of models has resulted in great advances in scientific understanding and in improvements in a wide array of endeavors. However, by their very nature, all models are simplifications and approximations of the real world. Complex relationships are often simplified, and relationships viewed as unimportant are sometimes eliminated from consideration to reduce computational difficulties and increase transparency.

Models are always incomplete, and efforts to make them more complete can be problematic. As features and capabilities are added to a model, the cumulative effect on model performance needs to be evaluated carefully. Increasing the complexity of models without adequate consideration can introduce more model parameters with uncertain values, and decrease the potential for a model to be transparent and accessible to users and reviewers. It is often preferable to omit capabilities that do not improve model performance substantially. Even more problematic are models that accrue substantial uncertainties because they contain more parameters than can be estimated or calibrated with available observations.

Watershed models are essential tools for developing and implementing TMDL requirements. For TMDLs based on nutrient and sediment loadings, models are needed to estimate acceptable loads, quantify all relevant sources, and identify strategies that can be expected to lead to the desired load reductions. Because of the complexity of the many physical, chemical, and biological processes on the land and in the waters and because of the multitude of land-uses and point sources distributed across a large and diverse watershed, the only way to integrate the information is through the use of a watershed model that can integrate all of the relevant data and process descriptions. In order for the model to be useful to the TMDL process, the model's output must be compared with monitoring data at a large number of locations in the watershed to determine if it provides a reasonable approximation of the actual status and trends of water quality in the watershed and to better understand the uncertainties associated with the model's predictions. It must use validation[1] periods that were not used in model calibration in order to develop confidence in its ability to provide useful estimates of the water-quality outcomes of likely and proposed future changes in the watershed.

Despite their critical importance in watershed management, models are imperfect. The best models are only approximations of the real world. Model complexity is limited by computer power, input data requirements, data availability, and by the tendency for additional model complexity to increase model uncertainty. Sources of data about landscape and river characteristics all have limits of accuracy and spatial resolution, and the same is true for representations of human activities on the watershed (not only for agriculture but also for urban and industrial activities). Key data to properly represent important processes are often unavailable. It is not possible to include all the relevant processes and information in a model, and more complex representations of processes do not necessarily improve a model, particularly when the data to estimate key parameters are lacking (Box 1).

The practical limits on model complexity and available data require that modelers focus on factors important to model objectives and deemphasize or eliminate less important complexities. The choices are driven by model objectives, available data, and available modeling resources. Simplifications and approximations are a necessary and appropriate aspect of models (Box 1). It is inevitable that models with different objectives and resources will use different frameworks, make different simplifying assumptions, operate on different time scales, rely on different inputs, and produce different outputs. The resulting diversity in modeling approaches is scientifically valuable because the range of outcomes from multiple models provides a first order indication of the uncertainty in model predictions. This information can guide future model development to reduce uncertainty. When model predictions are used in making management decisions, the range of outcomes can help quantify appropriate margins of safety that account for the uncertainty in model results.

In contrast to the wisdom of the NRC experts (Box 1) and the basic principles summarized above, LimnoTech's recommendations are built upon false expectations for watershed models. Given that no model can be complete or perfect, LimnoTech's (2010, 2011) admonition to ensure that the CBP model is "correct" before proceeding with implementing the TMDL is a false expectation. Models cannot be "correct", but they can be reasonable and useful for their objectives. For water quality management models, reasonableness can only be judged by evaluation of the conceptual underpinnings of the model, the input data, and demonstration of the ability to simulate approximate water-quality conditions and changes in those conditions at watershed scale.

LimnoTech's (2010, 2011) demand that all the differences in assumptions, input data, model frameworks, time scale, etc. between the CBP and CB-CEAP models should be resolved before TMDL implementation can proceed is again a false expectation. Both of the models examined by LimnoTech are intended to determine relative impacts of different land uses and land management practices under varying climatic conditions over time. However, each has its

[1] Throughout the report we use the term "validation" to represent the activity of testing a model's ability to predict observed flow or water quality data that have not already been used in model development or calibration.

specific objectives, so the two models use different mathematical algorithms and require different input data to achieve their intended goals. A CB-CEAP model effort with the same level of effort that has been used in developing, calibrating, and evaluating the CBP model would likely take years and require hundreds of thousands to millions of dollars of additional investment that we believe could be better spent in implementing the TMDL and adaptively assessing water quality responses to implementation.

LimnoTech states that the CBP model and the EPA require "the TMDL to be accurate to a single pound." Measures of uncertainty are intrinsically reflected in the margin of safety for the TMDL, and thus imprecision is acknowledged to be present both in the models and in the statement of the TMDL. It is unclear where LimnoTech obtained the notion that the EPA expects TMDLs to be accurate to a single pound because no TMDL has or will ever likely obtain such accuracy, and most watershed modelers would concur that such a goal is folly.

Based on our review, the committee finds that the LimnoTech analyses and recommendations promote a false set of criteria by which to judge the suitability of the CBP watershed model for use in the TMDL development and implementation processes. LimnoTech's recommendations are based on false expectations about the capabilities of watershed models and how much agreement should be expected among alternative models built to accomplish different objectives as well as a misunderstanding of the role that models play in informing the TMDL development and implementation.

A major concern of the review committee is that LimnoTech failed to recognize that fundamental differences in models, (such as the input data, assumptions, and process representations) are unavoidable because of the different objectives of the models and differences in the data and resources available to support each effort. The development of multiple modeling approaches in the Chesapeake Bay watershed reflects a natural evolution of the watershed science and management activities in the region. This is entirely appropriate and can be beneficial to the TMDL process over the long term. The existence of multiple models does not impugn the utility or validity of the individual models for their intended purposes. The separate CB-CEAP and CBP modeling efforts represent an opportunity to enhance the CB modeling framework and the TMDL development and implementation processes through collaborative evaluations and further development of the models by the EPA and USDA. However, **the review committee finds that the existence of differences in the models and model predictions provides an insufficient basis for suspending the existing TMDL implementation efforts** as called for by LimnoTech.

The review committee hopes that the general information on realistic expectations for watershed models that we have summarized here will help future model comparisons avoid misinterpretations and flawed recommendations like those offered in the LimnoTech report.

Key Characteristics of the CBP and CB-CEAP Models

The CBP and CB-CEAP models were developed for different purposes (Table 1). The developers of each model chose simplifying assumptions, model frameworks, time steps, simulation periods, and data sources that were appropriate for their specific model objectives. The two models were subjected to different levels of calibration, validation, and peer review. Key characteristics of the development and application of the two models to the Chesapeake Bay watershed are summarized in Table 1 and presented in more detail in the succeeding text.

Table 1. Overview of differences between the CBP and CB-CEAP models.

	CBP Model	CB-CEAP Model
Purpose	Quantify and improve our understanding of the contributions of all point and nonpoint source loadings of pollutants to the Chesapeake Bay with an ultimate goal of developing comprehensive strategies that can be expected to improve Chesapeake Bay water quality such that it meets agreed-upon goals.	Quantify the effects of conservation practices commonly used on cultivated cropland in the Chesapeake Bay region, evaluate the need for additional conservation treatment in the region, and estimate the potential gains that could be attained with additional conservation treatment.
History	A succession of models developed and improved over a period of 30 years, with many publications of model description and performance information over that time frame	The application of this suite of models to the Chesapeake Bay was first made available for public review in October, 2010 and in final form in February, 2011
Peer review	Components of the model have been published in the peer-reviewed literature. External scientific panels have published reviews and recommendations on the complete model system (Band et al. 2005, 2008) and the land use (Pyke et al. 2008, Pyke 2010) and BMP (Pease et al. 2007, 2008) components	Components of the model have been published in the peer-reviewed literature. Individual external reviewers examined draft versions (e. g., USDA-NRCS 2010) of the initial report on applying the complete model system to the Chesapeake Bay watershed (USDA-NRCS 2011)
Model oversight and technical team	Chesapeake Bay Partnership: USEPA, USDA, USGS, Maryland, Virginia, Interstate Commission on the Potomac River Basin, and universities	USDA and universities
Simulated time period and time step	21-year simulation period of which 10-years is used as TMDL baseline. Time step is hourly	47-year simulation period. Time step is daily
Calibration and validation[1]	Locations throughout the Chesapeake Bay watershed (237 locations for flow, 215 for total phosphorus, 200 for suspended sediment, 115 for total nitrogen, 216 for ammonium-nitrogen and 219 for nitrate-nitrogen, (USEPA 2010a, Table 11-1)	5 locations within the Chesapeake Bay watershed (Kannan et al. 2011)

[1]We use the term "validation" throughout the report to represent the activity of testing a model's ability to predict observed flow or water quality data that have not already been used in model development or calibration.

The CBP model

The current Phase 5.3 version of CBP model (USEPA 2010a) was developed over a 30-year period and the current version meets the needs of the TMDL development process. The CBP model is linked to the estuarine water quality model that is used to identify impairments in the Bay and to evaluate whether nutrient and sediment reductions from proposed management actions can remove those impairments. The CBP model has been developed by the collaboration of USEPA Chesapeake Bay Program, the U.S. Geological Survey (USGS), the Interstate Commission on the Potomac River Basin, the Maryland Department of the Environment, the Virginia Department of Conservation and Recreation, and the University of Maryland. Through an interactive and iterative process of development, testing, review, and improvement; each successive version of the model has added more detail, more process representation, better input data sets, and finer temporal and spatial representation of the watershed. Technical direction has come from several groups within the Chesapeake Bay Program structure: The Water Quality Goal Implementation Team, the Modeling Workgroup, and the Agricultural Nutrient and Sediment Reduction Workgroup, the Urban Stormwater Workgroup, the Forestry Workgroup, and the Wastewater Workgroup. The current co-chair of the Agricultural Nutrient and Sediment Reduction Workgroup works for the USDA.

The model is spatially complex and has 1185 spatial segments in the Chesapeake watershed. Those segments average 54 square miles in area. The model simulates rainfall, runoff, subsurface flows, and evaporation from landscapes including forest, agricultural and urban lands. It models soil erosion and pollutant loadings from the land to the rivers and considers the role of a wide range of BMPs in reducing these sediment and pollutant inputs. Expert panels have been convened to develop the appropriate reduction factors based on available studies. The CBP model simulates the downstream movement, deposition, and transformation of sediment and pollutants through lakes, rivers and reservoirs. These simulations use an hourly time step. The calibration period is 21 years, and simulations for TMDL analyses are run for ten years. The model produces time series of concentrations and loadings to the Bay, which are processed by the estuary model to estimate impacts on water quality and ecological outcomes in the Bay.

The model is calibrated and validated at water-quality monitoring sites throughout the basin (Table 1). A number of key parameters are adjusted in this process to improve the match between observed and predicted fluxes at these monitoring locations.

Components of the CBP model, such as the HSPF model (Hydrologic Simulation Program FORTRAN), have been the subject of many peer-reviewed publications, and the complete CBP model system has been peer reviewed by independent committees (Band et al. 2005, 2008). Independent peer reviews have also examined the land use and land cover data (Pyke et al. 2008, Pyke 2010) and the efficiency estimates of best management practices (Pease et al. 2007, 2008) used in the model.

The CB-CEAP model

The CB-CEAP model of the Chesapeake Bay watershed was developed recently as part of a nationwide effort to assess the effects on conservation practices on nutrient and sediment losses from cultivated cropland. Although the CB-CEAP model incorporates a number of agricultural and hydrologic process simulation models that have been developed over many years, the full analysis of the Chesapeake Bay watershed was first released for review in August 2010, a revised draft was released for further comment in October 2010 (USDA-NRCS 2010), and the final version was released in February 2011 (USDA-NRCS 2011). The CB-CEAP model was used to explicitly quantify the effects of conservation practices commonly used on cultivated cropland in the Chesapeake Bay region, to evaluate the need for additional conservation treatment in the region, and to estimate the potential gains that could be attained with additional conservation treatment (USDA-NRCS 2010, 2011).

The CB-CEAP effort used a suite of models to extrapolate results from field level crop surveys to the entire Chesapeake Bay watershed. Field level crop data for the years 2003-2006 were obtained at 771 NRI sample areas (averaging approximately 0.5 square mile in area) within the Chesapeake Bay watershed. Sets of unique cropland hydrologic response units (HRUs) were then aggregated within each of the four 4-digit HUCs in the Bay watershed (averaging approximately 16,000 square miles) and simulated with the APEX model. The SWAT model was then applied to the cropland HRU per-acre loads from the APEX model together with cropland distribution data and data from the HUMUS database to simulate cropland HRU loads within each of the fifty-five 8-digit HUCs in the Bay watershed (averaging approximately 1,160 square miles). The temporal resolution of the model was daily. The duration of the simulation was a 47-year period, but the baseline land use and land management conditions reflect the years 2003-2006. Soil processes were modeled in detail for agricultural lands.

Observed annual flux estimates for sediment, total phosphorus, and total nitrogen were compared with model output at five sites (three on the Susquehanna River and one each on the Potomac River and the James River).

The component parts of the model (SWAT, HUMUS, and APEX) appear in many peer reviewed publications. Drafts of the report on the integration of the component models and their application to the Chesapeake Bay watershed (USDA-NRCS 2010) were examined by individual external reviewers before the report was published in final form (USDA-NRCS 2011). We are aware of no external review publications that evaluate the application of the model to the entire Chesapeake watershed.

One major concern with comparing the CBP and CB-CEAP model results is that the sample size of the CB-CEAP survey of farmer practices on cultivated cropland is too small to allow reliable and defensible reporting of results for areas smaller than a 4-digit hydrologic unit code (HUC) subregion (USDA-NRCS 2011, page 19). There are four 4-digit HUCs (numbers 0205, 0206, 0207, and 0208) within the CB watershed with an average area of 16,000 square miles. They are the Susquehanna River Basin, the Potomac River Basin, the Upper Chesapeake Eastern and Western Shores, and the Lower Chesapeake (which includes the Rappahannock, York, and James Rivers and other minor tributaries of the lower eastern and western shores of the Bay).

Differences between the models

These brief descriptions of the CBP and CB-CEAP models reveal some important differences between the two models. The CBP model was developed specifically as a tool for understanding and managing all major sources of pollution in the Chesapeake Bay watershed. The CBP model is designed to assimilate the best available knowledge to account for nutrient or sediment sources and possible reductions in the loads from all source sectors (not just cultivated cropland). In contrast, the CB-CEAP model was developed to estimate the effects of conservation practices that were applied to cultivated cropland during the period 2003 to 2006 (USDA-NRCS 2011). Consequently, the CB-CEAP model emphasizes cropland and does have more field-scale detail for cropland than the CBP model. However, CB-CEAP contains less detail than the CBP model for other nutrient and sediment sources, and CB-CEAP does not consider BMPs for non-cropland sources.

In their report and recommendations, LimnoTech ignored differences of more than an order of magnitude in the level of discretization of subwatersheds. The CB-CEAP watershed discretization for its SWAT watershed modeling was done at the 8-digit HUC scale. There are 55 8-digit HUCs within the Chesapeake Bay watershed, so the CB-CEAP simulates the 64,000 mi^2 Chesapeake Bay watershed as 55 subwatersheds averaging 1,160 mi^2 each. In contrast, the CBP model is discretized at a much finer scale—it has 1,185 subwatersheds (river segments) averaging 54 mi^2 each. Consequently, the spatial scale for reporting the results from the CB-CEAP model is much coarser than the scale applied in the CBP model to support the TMDL allocation process. LimnoTech also ignored the differences in the calibration and validation efforts of the two modeling approaches. The CBP model was extensively calibrated and validated to stream monitoring data at locations throughout the Chesapeake watershed (Table 1) while the CB-CEAP model was only calibrated and validated at five locations in the watershed. The differences in levels of calibration and validation are significant concerns in the comparison of model output. The review committee is not criticizing the CB-CEAP effort for its level of discretization, calibration, and validation. The levels of discretization, calibration, and validation of the CB-CEAP program were appropriate for the purpose of the CB-CEAP effort. However, we are critical of LimnoTech's report and recommendations because they fail to acknowledge that the scale of information and levels of calibration and validation in the CBP model were chosen for the model's purpose in supporting the TMDL implementation effort.

The review committee finds that LimnoTech's comparison of the two modeling efforts and the resulting recommendations are unrealistic because the two modeling efforts were developed for different purposes and because the levels of hydrologic discretization, calibration, and validation differed by more than order of magnitude between the two models. Consequently, the review panel concludes that it is scientifically unreasonable to expect the two modeling efforts to be in agreement to the extent suggested by LimnoTech.

LimnoTech also ignores the appreciable differences in the history and purposes of the use of two modeling systems in the Chesapeake Bay Watershed. **The review committee finds that LimnoTech ignores the attributes of the CBP model that favor its continued use to inform and guide the TMDL process.** These attributes include the long-term linkages of the CBP watershed model to the estuarine model and their coupled association in developing the Chesapeake Bay TMDL, the long standing peer review and evolution of the CBP watershed model, stakeholder involvement in model reviews and the selection and evaluation of a broad range of pollution management scenarios (i. e., point and nonpoint reductions), and the extensive use of measurements from up to 237 stream and river monitoring sites in the Chesapeake watershed to calibrate and validate the model (Table 1). These attributes of the CBP modeling process stand in stark contrast to those of the relatively new CB-CEAP model, which has a more limited focus, a much shorter history, much less calibration and validation with stream and river measurements, and less independent peer review or stakeholder evaluation of the model results at the Chesapeake Bay watershed level.

Box 2. Modeling BMP effectiveness.

To predict how nutrient and sediment loadings respond to possible watershed management actions, a watershed model must integrate physical, chemical, biological, ecological, economic, and social processes. For many pollution control practices (conservation or best management practices, BMPs), knowledge of the outcomes is always imperfect. Key difficulties in quantifying nutrient or sediment reductions arise from several difficult problems:1) identifying how BMPs perform in "the real world" versus a very carefully controlled research environment, 2) how the BMPs perform over time, 3) how multiple BMPs applied to a given parcel of land interact with each other, 4) how the BMPs influence not only the direct surface delivery of nutrients to streams, but also their delivery over periods of years to decades through the groundwater system (which ultimately may deliver those nutrients to the streams at a substantial distance from the fields where the practice is applied), and 5) how many BMPs are actually implemented in the watershed and whether they are being well maintained over time. Evaluating effectiveness is a daunting challenge that needs the expertise of many disciplines and long-term monitoring of the actual water-quality outcomes of BMPs in the modeled watershed. Enhancing the reliability of any watershed model for use in TMDL analysis requires verifications of actual improvements in water quality due to changes in practices and sources at many scales over many years.

The CBP model deals with these questions through the use of expert panels that incorporate information from the best available research studies and modeling analysis to describe the anticipated outcomes of a wide range of BMPs. The results of many USDA studies are included in CBP model estimates of BMP effectiveness, and the new results from the CB-CEAP analysis can be useful additions to this body of knowledge. But, it must be stressed that estimation of the water-quality benefits of conservation practices is still highly uncertain and needs to be further informed by many sources of information, especially by comparisons between predicted changes in water quality and water quality observations integrated over large areas and long time periods.

The CB-CEAP analysis does not, and was not intended to verify the in-stream effects of conservation practices, because the approach does not include any analysis of observed water quality before and after BMP implementation (USDA-NRCS 2011). Instead, the conservation-related changes in water quality as described in the CB-CEAP model report are simply the results of model simulations that switch conservation practices "on" and "off", based on knowledge of the types and locations of practices from CEAP survey data and model assumptions about the effects of these practices on nutrient and sediment losses from cultivated lands.

Critique of Specific LimnoTech Report Analyses

LimnoTech listed several specific concerns about differences between the two models, related to assumptions about cropland area and the effects of conservation practices, the model frameworks and process representations (hydrology, time step, and simulation time period), and model load predictions. LimnoTech argued that the differences in these attributes of the models are sufficient to warrant a delay in implementing the Chesapeake Bay TMDL requirements until the models can be fully reconciled. The review committee assessed the factual basis for the model statistics as reported by LimnoTech to determine whether the model comparisons were conducted in a fair manner (or were misrepresented) and whether the comparisons used the best available information reported for each of the models. Several of the most significant errors in the LimnoTech report are described below.

Differences in load estimates

The review committee finds that LimnoTech committed notable errors in their comparisons of the loads of both models, such that the load values reported in the LimnoTech report tables and figures are not accurate (Tables 2-4). LimnoTech used CBP model predictions for 2009 land use and land management conditions rather than results that are available for 2005, which are more comparable to the 2003-2006 conditions considered by the CB-CEAP model. In addition, LimnoTech compared controllable nutrient or sediment loads from the CB-CEAP model to total nutrient or sediment loads from the CBP model. The total load from crop fields can be divided into two components, the background load that would be expected if the fields were in a non-agricultural use (like grassland or forest) and the additional load (the controllable load) generated by agricultural activities (tillage, fertilization, manure application, etc.). One could legitimately compare controllable loads from the CBP to controllable loads from CB-CEAP, or CBP model total loads to CB-CEAP total loads. However, the comparison of CB-CEAP controllable load to the CBP model total loads as presented in the LimnoTech report is an "apples to oranges" comparison.

The review committee finds that when errors in LimnoTech's interpretations of the CB-CEAP nutrient and sediment loads are corrected, the simulated nutrient and sediment loads from the two modeling efforts are closer to each other than reported by LimnoTech. For nitrogen and sediment (Table 2), the committee calculates that differences between the total agricultural loads of the two models for nitrogen and sediment are 15% and 29%, respectively. By contrast, the differences in loads as reported by LimnoTech (28% and 67%, respectively) were about twice as large as the corrected estimates. Even without the corrections, the review panel believes that, given the uncertainties associated with the predictions of the two modeling efforts (and watershed models in general), the predictions are within the likely margins of error of the two models and are therefore probably not significantly different. The difference between the corrected load estimates of the two models for phosphorus (28%) is similar to that reported by LimnoTech (26%). Corrected estimates of the differences between the two models in the estimated fractions of the total agricultural load entering the Chesapeake Bay from four major regional basins (Table 3) are within about 6% for nitrogen for all but one basin (Upper Chesapeake) and within 10% for phosphorus for two basins, with differences of about 40% observed for phosphorus in the other two basins (Susquehanna, Lower Chesapeake). For sediment, differences in model predictions range from about 10% to 20% for all but one basin (Upper Chesapeake).

Table 2. LimnoTech (2011) and corrected estimates of total agricultural loads delivered to the Bay.

	Nitrogen (1000 pounds)			Phosphorus (1000 pounds)			Sediment (1000 tons)		
Analysis	CB-CEAP	CBP	Ratio*	CB-CEAP	CBP	Ratio*	CB-CEAP	CBP	Ratio*
LimnoTech	142.1	111.1	1.28	5.4	7.3	0.74	850	2585	0.33
Corrected	148.5	128.7	1.15	5.8	8.1	0.72	2018	2850	0.71

*Ratio of CB-CEAP to CBP predicted load.

Table 3. Corrected fractions of the total agricultural loads delivered to the Bay from major basins.

	Nitrogen (percent of total load)			Phosphorus (percent of total load)			Sediment (percent of total load)		
Basin	CB-CEAP	CBP	Ratio*	CB-CEAP	CBP	Ratio*	CB-CEAP	CBP	Ratio*
Susquehanna	53.1	55.3	0.96	34.8	24.6	1.42	37.8	34.0	1.11
Upper Chesapeake	16.1	12.4	1.30	19.6	18.3	1.07	12.4	7.0	1.77
Potomac	20.6	22.0	0.94	28.6	29.9	0.96	28.4	32.3	0.88
Lower Chesapeake	10.2	10.3	0.98	17.0	27.2	0.62	21.4	26.7	0.80

*Ratio of CB-CEAP to CBP percentage.

Based on the corrected CB-CEAP loads (Table 2), predictions of the percentages of the total loads delivered to the Bay that are attributed to agriculture by the two models (Table 4) show close agreement for nitrogen and phosphorus. For nitrogen, cropland represents 31% and 32% of the total loads from the CB-CEAP and CBP model simulations, respectively, whereas total agricultural loads (from crop, hay, and pasture lands and from animal feeding operations) represent 48% and 47%, respectively. For phosphorus, cropland represents 25% of the total loads in both models, whereas agricultural loads represent 39% and 45%. The agricultural sediment loads show much larger differences—i.e., 15% and 35% reflect cropland contributions to the total loads, whereas 30% and 66% reflect agricultural contributions for the CB-CEAP and CBP models, respectively.

Table 4. Corrected predictions of the percentage of the total load attributed to cropland and total agricultural sources.

	Nitrogen (percent of total load)			Phosphorus (percent of total load)			Sediment (percent of total load)		
Agricultural Source	CB-CEAP	CBP	Ratio*	CB-CEAP	CBP	Ratio*	CB-CEAP	CBP	Ratio*
Cropland	31	32	0.96	25	25	1.01	15	35	0.44
Total agriculture#	48	47	1.02	39	45	0.87	30	66	0.45

*Ratio of CB-CEAP to CBP percentage.
#Loads from crop, hay, and pasture lands and from animal feeding operations.

The review committee finds that the differences in the loads attributed to cropland and total agriculture between the CBP and CB-CEAP models are small, especially in view of the acknowledged differences in the characteristics and purposes of the two modeling efforts. This offers encouragement that, at least over very large spatial scales, the models display many similarities in nutrient and sediment loadings. **More importantly, the results of the two models are similar in their assessment of the need for implementing more management practices on cropland.** The similarities in load estimates are generally consistent with CB-CEAP and CBP modeling reports of model calibration and validation results, which show evidence of approximate agreement between the predictions of both models and monitored loads (monthly and annual) for several of the largest watershed outlets in the Chesapeake Bay region (Kannan et al. 2011, USEPA 2010a, Phase 5.3 Model Calibration). However, the review committee cautions that these comparisons alone provide an insufficient basis for evaluating differences in the performance of the two models. More systematic evaluations (such as those already initiated by the USDA and the CBP) are needed to assess differences in the dynamics of the models and the load response to a range of key processes, including hydrology and agricultural practices. Evaluations are also needed of the performance of the models, particularly CB-CEAP, against available stream monitoring data across a wider range of spatial scales.

LimnoTech also argues that differences exist between the two models in their assumptions about current agricultural practices and the magnitude and location of managed load reductions that are likely to be attainable to satisfy the TMDL requirements. The review committee finds it unremarkable that the models evaluate the outcomes (downstream effects) of different management scenarios differently given that the two modeling efforts clearly have different objectives. These differences in scenario outcomes are not indicative of weaknesses or inconsistencies in the models, but instead reflect the different intended uses and designs of the models. For example, the CB-CEAP management scenarios were designed to illustrate potential environmental benefits based on model assumptions about the controlling processes and the effectiveness of agricultural BMPs. The USDA acknowledges that their scenarios were not designed to represent actual options for the Chesapeake Bay region (USDA-NRCS 2010, 2011). In contrast, the CBP model scenarios are based on stakeholder input and reflect a summary of state and local governmental choices about feasible pollution management actions. The CBP model scenarios are based on the development of watershed implementation plans (WIPs) by state and local stakeholders that describe how each jurisdiction will meet its share of the TMDL-related nutrient and sediment reductions. The review committee's understanding is that these stakeholders (not the CBP) proposed how much of the necessary load reduction will be achieved by the agricultural sector and what type of management practices were included in each state's WIP to meet their target TMDL loads. Therefore, the assumed 20% change in cropland acreage (conversion of cropland into other land uses) that is cited as a concern by LimnoTech actually reflects the integrated outcome of a mix of state and local choices and serves to represent the aggregate effects of this collection of management activities in the model.

Finally, LimnoTech argues that there is an inconsistency in the nutrient and sediment yields between the two models at the field scale that may relate to differences in the scale of the CBP model calibration and the information used to inform the estimates in the CB-CEAP suite of models. LimnoTech suggests that the CBP model yields for cropland are not accurate because there is no calibration at the "edge-of-field", and that the larger scale calibration can lead to field-scale estimates that are too high or low, relative to the approach used in the CB-CEAP model to represent field-scale export. However, the CB-CEAP study did not conduct edge-of-field calibrations and validations either, and CB-CEAP makes no claims of edge-of-field accuracy. Instead, the CB-CEAP report states that the statistical sample used to estimate BMPs for cultivated cropland is too small to allow reliable and defensible reporting of results for areas smaller than a 4-digit hydrologic unit code subregion (USDA-NRCS 2011, page 19). These regions average about 16,000 square miles in area. It is also important to note that the USDA APEX model applications to the Chesapeake Bay regions were not calibrated to field data for the region. Instead, USDA APEX predictions of runoff from cropland are based on field studies that reflect farm runoff under a range of climatic and soil conditions and conservation practices nationwide; these conditions may not be fully representative of those in the Chesapeake Bay region. The lack of formal calibration of the CB-CEAP model (SWAT), except at the 4-digit HUC scale, to monitored load data for Chesapeake Bay streams raises questions about how well the CB-CEAP predictions of nutrient and sediment runoff from croplands reflect actual conditions. It is the opinion of the review committee, that despite the recognized shortcomings of the CBP and CB-CEAP models, the extensive use of stream monitoring data to calibrate the CBP model is an informative modeling practice that helps provide equitable and balanced local and regional predictions of nutrient and sediment export from cropland and other land uses and delivery to downstream waters. Evaluations of the performance of both models against commensurate measurements of water quality should be conducted across a wide range of locations and conditions in the watershed to provide a more informed understanding of model differences. The Committee is concerned that LimnoTech failed to consider or discuss this more appropriate method for evaluating model performance.

Differences in drainage areas

LimnoTech noted a 2.1% difference between the CBP and CB-CEAP models in the estimated total area of the CB watershed (LimnoTech 2011). Such a difference could arise from differences in the topographic data, stream maps, or analysis procedures used to map watershed outlines. The review committee did not pursue the difference in watershed areas, but believes it is an appropriate topic to consider in the follow-up efforts of USDA and EPA model comparisons (see the section on Recommendations for Integrating Models).

Differences in agricultural land area

LimnoTech also notes that the CBP and CB-CEAP models differ in the amounts of agricultural land, including USDA's reporting of additional acreage in conservation tillage. The acres of conventional-tilled acres versus conservation tilled acres vary considerably between the two reports and this concern is legitimate. The Chesapeake Bay Program (CBP) estimates of the two types of cropland were derived from state inventories of cost-shared BMPs and the latest distributions between the two types by county from the Conservation Tillage Information Center (CTIC, Gary Shenk, USEPA-CBP, personal communication). Unfortunately the latest data from CTIC was in 2002, so these data are not reflective of recent shifts between the two. While the percentage of conservation tillage varies from county to county, the cited overall average of 50% gives the impression that this was some arbitrary value. The CBP also acknowledges that these values are low and do not include acreages of conservation tillage implemented on a voluntary basis, which could be substantial. The NRC Review Committee concluded that "a consolidated regional BMP program to account for voluntary practices and increase geo-referencing of BMPs presents opportunities to improve the tracking and account process (NRC 2011). CBP is currently working with the states to incorporate verified voluntary conservation tillage acreages in their annual inventories. The review committee finds that agricultural areas are closer in size when Conservation Reserve Program areas (CRP) and hay/pasture rotations are treated equivalently. Currently the CB-CEAP model counts CRP land as agricultural land, whereas the CBP model does not. Therefore, the inclusion of CRP and hay areas may explain the higher agricultural land area in the CB-CEAP model (Lee Norfleet, USDA-NRCS, personal communication).

Differences in BMP acreage

The CB-CEAP report states that producers use some kind of residue, tillage, or structural management practices on 94% of cropped acres. The LimnoTech report quotes CB-CEAP as saying that producers use residue, tillage, structural practices on 96% of cropped acres. In the CBP model, about 90% of cropped acres have at least one conservation practice applied to them.

The CBP model scenario builder

LimnoTech acknowledges that the CBP model has been tested and reviewed, but expresses concerns that the "scenario builder" component has not been reviewed and its accuracy is unknown. LimnoTech states that "Scenario Builder is not a complete agricultural model and it has significant limitation. It was not designed to be full crop growth model ... [and] is used to represent farm scale operations." The review committee agrees that the scenario builder is a key component of the CBP modeling framework and is important in representing the level of implementation and effectiveness of BMPs in the CBP model. However, scenario builder is not a simulation, but a tool for assembling the inputs needed to represent particular scenarios (USEPA 2010a, Scenario Builder Documentation). Those inputs are in turn supplied to the CBP watershed simulation model, which handles the crop simulation. It is the opinion of the review committee that the scenario builder and its role in the CBP model have been extensively reviewed by stakeholders in several workgroups within the Bay program, and it has been judged adequate for its intended purpose at the current time. The underlying BMP efficiency data have been examined by external peer review committees (Pease et al. 2007, 2008). We agree that the scenario builder should evolve over time to better represent BMPs in the CBP model system, and we believe that the CB-CEAP modeling approach may provide useful insights for achieving those improvements.

Modeling agricultural practices

The committee is concerned that LimnoTech is misinformed about how the CB-CEAP and CBP models characterize agricultural practices. First, LimnoTech asserted that the CBP model lacks temporal variability in agricultural practices. This is not the case as both the CB-CEAP and CBP models account for temporal variations in a variety of practices, including crop rotations and management practices. Second, LimnoTech cites differences in how animal manure sources are simulated in the two models. These differences are explained by fundamental differences in the structure of the two models and the importance assigned to these sources by the model developers. The CBP model includes estimates of manure nutrient runoff from animal feeding operations, which are considered to be an important agricultural source of nutrients that must be evaluated as part of the TMDL process. In contrast, the CB-CEAP model divides all manure into a recoverable fraction (which is applied to cropland, hayland, and pasture) and a non-recoverable fraction, which is assumed to be dispersed onto pasture land (Lee Norfleet, USDA-NRCS, personal communication). CB-CEAP's simulation of nutrient runoff from animal feeding operations is less explicit than the treatment in the CBP model because the primary purpose of the CB-CEAP model is to evaluate the effectiveness of farm conservation practices on cultivated cropland. The review committee agrees with LimnoTech that the CB-CEAP model includes many realistic details about agricultural operations and management (e. g., crop rotations, more levels of tillage [no-till, mulch till, conventional till], actual nutrient management practices, etc.) that are not considered in the CBP model. However, comparisons to observed nutrient and sediment loads must still be done to determine if the additional model detail actually yields better predictions of nutrient and sediment loads.

Recommendations for Integrating Models

The existence of multiple models for the Chesapeake Bay watershed can help to inform science and management efforts to reduce nutrient and sediment pollution. Although the new CB-CEAP analysis does not provide information to delay TMDL implementation, the CB-CEAP model framework does provide valuable information that can inform and improve the CBP model and its future application to the TMDL. CBP and USDA modelers have already begun integrating their two approaches. The modelers began talking informally in the summer of 2010 (before the publication of both the CB-CEAP and LimnoTech reports to compare results and consider possible collaborations. Those efforts have matured into a formal agreement to undertake a range of cooperative activities to identify where information from the two activities can be effectively harmonized and where NRI and CEAP results can inform TMDL modeling with the CBP model (see Appendix). The review committee commends the two agencies for undertaking these collaborative activities, and offers suggestions for additional integrative and collaborative activities below.

The CBP to CB-CEAP comparison does not support delaying TMDL implementation

The review committee finds no reasonable scientific basis to support LimnoTech's admonition to delay the implementation of the Chesapeake Bay TMDL. The existence of differences between the CBP and CB-CEAP models does not support a delay. Differences are expected because the two models were developed for different purposes and exploited different approaches and data sources that were appropriate for their individual objectives. Delaying the TMDL to resolve all the differences and build a so-called "correct" model will only delay Chesapeake Bay restoration. The CBP and CB-CEAP models both indicate that additional agricultural conservation practices for cropland are needed, and there is little risk that initial management actions will go farther than is needed.

Implement TMDL requirements in an adaptive management framework

Adaptive management (not delay or inaction) is the proper response to uncertainty in knowledge, including differences between models. Adaptive management (Box 3) arose from the recognition that uncertainty is inherent in natural systems, yet management actions cannot be indefinitely delayed until knowledge is complete and uncertainties are resolved (NRC 2011). TMDL plans should use adaptive management methods (e. g., NRC 2011) to ensure that programs are not halted for lack of information, but rather progress while better information is collected (NRC 2001). That new information will reflect changes in the watershed and new understanding gained from ongoing water quality monitoring and modeling and from new research on water quality responses to management actions. With adaptive management, knowledge of the effects of BMPs on water quality and the modeling of those effects will evolve in parallel with regulations and management actions.

The Chesapeake Bay TMDL offers some adaptive management flexibility through its two year milestones and its planned recalibration of the model and reevaluation of progress and goals in 2017. To fully implement adaptive management, the NRC (2011) recommended that the CBP refine its understanding of adaptive management, better analyze the uncertainties relevant to nutrient and sediment reduction efforts and water quality outcomes, implement targeted monitoring programs, and ensure sufficient flexibility in accountability and regulatory and organizational structures.

Box 3. Adaptive management.

Adaptive management arose from the recognition that uncertainty is inherent in natural systems, yet management actions cannot be indefinitely delayed until knowledge is complete and uncertainties are resolved (NRC 2011). USDA scientists have reviewed the adaptive management literature (Stankey et al. 2005), and concluded that effective approaches to adaptive resource management involve a structured, iterative process of decision making that attempts to reduce uncertainty through the use of continuous feedback from new knowledge and understanding. The Chesapeake Bay TMDL's pollutant load allocations and required reductions represent the CBP's current best professional judgment of reductions that will meet the Clean Water Act's requirements. With adaptive management, the goal is the attainment of water quality standards and not the attainment of specified waste load reductions. As the Bay TMDL is implemented, the effects of implementation efforts will be continuously assessed for their impacts on water quality, and the TMDL requirements should be adjusted as more knowledge is gained about the effectiveness and social/economic feasibility of alternative implementation approaches. For example, over time and in response to implementation of BMPs and to improved data and models, water quality monitoring results may indicate that one sector has more or less responsibility for pollutant loadings in a particular watershed than was originally thought. If so, the TMDL load allocations would be refined to reflect this new information and reallocation would follow to meet water quality goals.

The concept of adaptive management involves systematically testing assumptions, not a trial and error process. It involves adaptation as new information challenges current assumptions and suggests improved interventions. It involves learning as a fundamental process that reduces uncertainty. The committee views the introduction of new modeling perspectives as part of the process of adaptive resource management, and we commend the EPA and USDA for implementing a constructive dialog to arrive at the best way forward to meet the Clean Water Act's requirements. The applicability of adaptive management to Chesapeake Bay restoration was explicitly considered in a full chapter in the recent report of the National Research Council's Committee on the Evaluation of Chesapeake Bay Program Implementation for Nutrient Reduction to Improve Water Quality (NRC 2011). The review committee agrees with the NRC findings, which are summarized in the following quote from their report summary (NRC 2011, page 6): "Effective adaptive management involves deliberate management experiments, a carefully planned monitoring program, assessment of the results, and a process by which management decisions are modified based on new knowledge. Learning is an explicit benefit of adaptive management that is used to improve future decision making."

Apply a multiple modeling strategy

The review committee believes that having a suite of models built on different representations of processes, different spatial and temporal resolutions, and different approaches to calibration and validation with observational data is useful and yields better predictive capability in the long run than relying on a single model. For nearly two decades, the CBP model was the only modeling effort that attempted to comprehensively model the entire Chesapeake Bay watershed. SPARROW (Preston and Brakebill 1999) was built in 1997 using a very different spatial, temporal, and process construct; and it has added new insights that have led to improvements in the CBP model. In the last year, the CB-CEAP model has emerged as a third model of the Chesapeake watershed, and it brings new approaches to modeling land use and agricultural practices. This third model can continue the pattern of improving predictive modeling of the Chesapeake Bay Watershed through model comparison and integration. The review committee commends EPA and USDA for already undertaking model inter-comparison, and we recommend that those efforts be enhanced as described below. The review committee emphasizes that recommending analyses of multiple models does not undermine the use of the existing CBP model or provide a rationale for halting TMDL implementation.

Integrate knowledge from the CB-CEAP project into the CBP model

The CB-CEAP effort provides new knowledge about the way that BMP implementation can be expected to reduce nutrient and sediment loads from cultivated cropland. That knowledge can enhance the CBP model and its application to the TMDL. CB-CEAP's use of site-specific data from the NRI and from additional farmer surveys to characterize cropland management is an important development. For example, CEAP's farmer surveys suggested that voluntary conservation practices are implemented at much higher levels than previously accounted for (USDA-NRCS 2010, 2011). CEAP also provides new data and statistical summaries of the amounts of cropland with conventional tillage or conservation tillage. This approach should also be considered for non-cultivated cropland land uses. These results would be very helpful in identifying other spatial and temporal factors that cause variation in practice effectiveness. The review committee recommends that the CBP, USDA, and state and local partners continue their ongoing collaborative efforts to assemble better data on verified voluntary BMPs and other BMPs on agricultural lands (Chesapeake Bay Executive Order Strategy http://executiveorder.chesapeakebay.net/ and Joint CBP-USDA agreement, Appendix) and to incorporating the new information into the CBP model. Those efforts will implement and exploit the consolidated program for tracking and geo-referencing BMPs recommended by the NRC (2011).

Enhance comparability and improve all Chesapeake Bay watershed management models

Standardization of data where appropriate. As noted above, models created for different purposes must often use different, conceptualizations, algorithms, or data sources. Despite those necessary differences, there are opportunities for greater standardization among models. For example, CBP and USDA could adopt the same Chesapeake watershed boundary data set for their two modeling efforts. The review committee recommends that the CBP and USDA work together with other organizations interested in the Chesapeake to identify and implement such opportunities for standardization.

Estimation of prediction uncertainties. The review committee recommends that both models attempt to estimate uncertainties in key predictions (NRC 2001, Band et al. 2005, 2008) in order to help decision makers understand the variability of natural systems and to provide them with additional information for their analyses. Model uncertainty estimates will facilitate objective assessment of the significance of differences between models.

Improved access to critical data. The review committee notes that the CB-CEAP model relies on confidential USDA data from the NRI (National Resources Inventory) and from confidential farmer surveys. Such information has not been available for use by the CBP because of restrictions established by the US Congress on the use of site specific agricultural data. Restricted access to USDA data has limited their past use in developing the CBP model and continues to limit independent analysis and critical review by academic and other non-USDA scientists. The review committee recommends that USDA and the CBP work together to relax restrictions on the use of site-specific farm data by the CBP and for other water quality management planning purposes, while maintaining protection of individual farmer confidentiality. The committee also recommends that USDA report data at the highest spatial resolution that will not violate mandated confidentiality restrictions. We understand USDA's desire to only publish statistically significant cropland characteristics at the resolution of 4-digit

HUCS (USDA-NRCS 2010, 2011), but the ranges and spatial distributions of the cropland characteristics at higher resolution could inform many other analyses and management efforts.

Improved model accounting for lag times associated with BMPs. Both models assume actions have immediate impact, but there are groundwater, soil response, and instream lag times associated with BMP implementation and hydrologic transport that neither model represents as well as is it could. Both models overestimate the immediate impact of BMPs. The review committee recommends development of modeling approaches that can account for groundwater lag-time, sediment deposition and remobilization, and nutrient cycling in soils and aquatic environments in future revisions of each modeling framework.

More extensive calibration, validation, and discretization of CB-CEAP. If the CB-CEAP model is to become a more useful component of the suite of Chesapeake Bay management models, it should be recalibrated and revalidated with a larger subset of the water quality monitoring stations at which the CBP model has been calibrated and validated (Table 1). CB-CEAP could also provide output at the level of spatial resolution as the CBP model for all land uses. This would allow a more direct comparison of the results of the two models and help better define uncertainties in the models' predictions and in the Chesapeake Bay TMDL.

Utilization of CB-CEAP submodels to estimate field/watershed specific BMP effectiveness. The CB-CEAP model could be analyzed to yield effectiveness estimates for different BMPs or systems of BMPs. These CB-CEAP efficiency estimates could be compared to the scientific literature and to the estimates used in the CBP model. These CB-CEAP simulations could help identify the spatial and temporal factors that cause variation in practice effectiveness, which could inform future refinements of the CBP model.

Continued model development. Models used in the Chesapeake Bay restoration efforts/TMDL should not be static. They should evolve as our knowledge of the Chesapeake Bay watershed increases and there are roles for use of additional models such as CB-CEAP.

Subject Chesapeake Bay Watershed management models to regular peer review

The review panel recommends that all models used in making Chesapeake Bay management decisions should be periodically independently reviewed to identify model shortcomings and to improve the predictive abilities of the models. Peer review is an important tool for improving the quality of scientific products and is basic to all stages of model evaluation. The CBP and CB-CEAP models both contain components (such as the HSPF, APEX, or SWAT models) that have been extensively peer-reviewed in the scientific literature. The CBP model (Band et al 2005, 2008) and some of its components (Pyke et al. 2008, Pease et al. 2007, 2008; Pyke 2010) have had several independent peer reviews and those reviews should continue at regular intervals. The CB-CEAP implementation is new and could benefit from similar regular, independent, external reviews of the complete modeling system and its application to the Chesapeake watershed.

Compare models to observed data as well as to other models

Comparing the predictions of models (e. g., LimnoTech 2010, 2011) is useful to help understand modeling uncertainty, but real assessment of model performance requires comparing model predictions to observed data. Comparing how well the CBP and CB-CEAP models simulate the observed status and trends in water quality across the watershed as influenced by cultivated cropland could help guide future enhancements of the both models and help characterize uncertainties associated with model outputs.

Promote a realistic understanding of the uncertainties associated with watershed models

Use of multiple models and model comparisons. The CBP partnership could host workshops and subsequent activities to better define how multiple models and model comparison can be more effectively used in managing the Chesapeake Bay.

Improved public understanding of models and their uncertainties. The CBP could sponsor a social science workshop on how models, differences in models, and model uncertainty are perceived by non-scientists, and on how these issues can be better communicated to decision makers and to the public.

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List of Acronyms

ANPC	Agricultural Nutrient Policy Council
ARS	Agricultural Research Service
BMP	Best Management Practice
CBP	Chesapeake Bay Program
CEAP	Conservation Effects Assessment Project
CRP	Conservation Reserve Program
CTIC	Conservation Tillage Information Center
EPA	United States Environmental Protection Agency
HRU	Hydrologic Response Unit
HUC	Hydrologic Unit Code
NRC	National Research Council
NRCS	Natural Resources Conservation Service
NRI	National Resources Inventory
STAC	Scientific and Technical Advisory Committee
TMDL	Total Maximum Daily Load
USDA	United States Department of Agriculture
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
WIP	Watershed Implementation Plan

List of Model Names

APEX	Agricultural Policy Environmental EXtender
CB-CEAP	model of the effects cropland conservation practices in the Chesapeake watershed
CBP model	Chesapeake Bay Program watershed model
HUMUS	Hydrologic Unit Model for the United States
SPARROW	Spatially Referenced Regressions on Watershed Attributes
SWAT	Soil and Water Assessment Tool

Appendix: EPA-USDA Collaborative Agreement

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

JUN 28 2011

OFFICE OF CONGRESSIONAL AND
INTERGOVERNMENTAL RELATIONS

The Honorable Glenn Thompson
Chairman
Subcommittee on Conservation, Energy, and Forestry
Committee on Agriculture
U.S. House of Representatives
Washington, D.C. 20515

Dear Chairman Thompson:

At the Subcommittee on Conservation, Energy and Forestry hearing about the Chesapeake Bay in March, the USDA and the EPA stated their intention to continue efforts to refine and increase the level of data available for understanding the implementation of conservation practices by farmers in the Chesapeake Bay Region. To ensure that the work continues to progress, the EPA and the USDA scientists have developed a plan of work for the key activities that are expected to be accomplished. A copy of the plan of work for that effort is enclosed.

The additional data and refinements will serve a set of key purposes that will:

- Account for agricultural conservation practices implemented throughout the Chesapeake Bay watershed, including those practices funded solely by the farmer (not funded by federal or state cost share funding).
- Develop, as appropriate and feasible, a consistent estimate of pasture and hay land acres for use by the EPA and the USDA.
- Develop, as appropriate and feasible, a consistent approach for estimating fertilizer and manure applications for use by the EPA and the USDA.

In addition, there is ongoing work to 1) update and refine current conservation practice effectiveness estimates; and 2) credit new conservation practices as they are applied in the field. These efforts are intended to reflect our long term commitment to ensuring the best possible data is available. As a result of this work, we hope to increase our understanding of the impact of conservation practices and of the contribution farmers are making to restoration of the Bay.

We appreciate your interest in this important issue and will be glad to provide additional information that you may request.

Sincerely,

Arvin R. Ganesan
Associate Administrator

Enclosure

U.S. Department of Agriculture (USDA) and U.S. Environmental Protection Agency (EPA) Chesapeake Bay Conservation Data Collaboration

In December 2010, the EPA released the final Total Maximum Daily Load (TMDL) for the Chesapeake Bay. TMDL nutrient and sediment load allocations for the Bay Watershed States were developed using water quality monitoring data and a suite of models, including the Chesapeake Bay Program Watershed Model.

In March 2011, the USDA released its Assessment of the Effects of Conservation Practices on Cultivated Cropland in the Chesapeake Bay Region, a document known familiarly as the Chesapeake Bay Conservation Effects Assessment Project, or CEAP report. The USDA's CEAP effort is based on a combination of farmer surveys and modeling used to estimate the impact of conservation practices on the landscape.

There is a lot of interest from Chesapeake Bay stakeholders and within the USDA and the EPA to ensure consistency between the two modeling efforts and that they are informed by the best data available describing implementation of conservation by farmers in the Chesapeake Bay region. Below are commitments by the two agencies to that end.

Improve tracking and reporting of conservation practices in the Chesapeake Bay Program (CBP) Watershed Model
As called for in the May 12, 2009 Executive Order 13508 - *Strategy for Protecting and Restoring the Chesapeake Bay Watershed,* The USDA and the EPA are working with state agricultural agencies, conservation districts, and other key agricultural groups to ensure that non-cost shared practices are tracked, verified, and reported for credit in the CBP Watershed Model.

Additionally, the USDA is surveying approximately 1,400 producers through the National Resources Inventory (NRI) in 2011 to estimate the level of conservation practice implementation and to refine the spatial scale of available data. Combined with the similar work conducted from 2003-2006 (presented in the 2011 CEAP report), the results of this survey will provide an estimate of additional on-the-ground implementation of conservation practices between the two survey time periods.

Commitments:
The USDA and the EPA will work with state agricultural agencies, conservation districts, and other key agricultural groups to develop a mechanism for tracking, verifying and reporting non-cost shared conservation practices on agricultural lands for use in the CBP Watershed Model.
Timeframe: Complete by July 2012.

Using CEAP results from 2003-2006 and the pending 2011-12 analysis, the USDA and the CBP Partnership will explore inclusion of the additional practices identified in these surveys into the CBP Watershed Model.
Timeframe: Begin in 2012.

Develop consistent estimates of pasture and hay land use in both models
The CBP Watershed Model and CEAP Model use different approaches for estimating pasture and hay land in the Chesapeake Bay watershed. The U.S. Geological Survey developed a methodology for estimating land use for the CBP modeling effort in which the pasture and hay land use is based on the USDA census of agriculture data rather than satellite imagery.

Commitment:
The Natural Resources Conservation Service (NRCS) and the CBP will work together to investigate the appropriateness of using a common approach for estimating pasture and hay land in both models.
Timeframe: Begin in 2011.

Coordinate fertilizer and manure nutrient input assumptions in both models
The NRCS and the CBP independently developed databases to estimate nutrient applications to cropland and arrived at similar figures for total application. However, differences likely exist in application timing and amounts applied by region, crop, and management system. A consistent approach for fertilizer and manure nutrient inputs that is informed by the significant work by the USDA and the CBP partnership would likely improve both models.

Commitment:
The NRCS and the CBP will work together to investigate the development of a single database to estimate nutrient applications to cropland that would drive both modeling efforts, building on the experiences of both. Alternatively, given the different temporal and spatial scales of the modeling, the NRCS and the CBP can work together to standardize assumptions across databases.
Timeframe: Begin 2012 and continue thereafter. Results may be used in CEAP on an ongoing basis and may be used for the CBP management decisions in 2017.

Develop comparable scales for reporting nutrient/sediment loads in CEAP & CBP Models
Commitment:
Currently the two models track and report loads on different geographic scales. Development of common reporting scales will allow a more effective comparison of model findings and increase watershed model data and technique sharing capabilities. As the technologies of the two models advance, opportunities to collaborate should be explored.
Timeframe: Begin 2012 and continue thereafter.

There are two further tasks that are already in progress to ensure that the CBP Watershed Model is informed by the latest scientific data:

Updating current conservation practice effectiveness estimates based on the latest science. The NRCS and the CBP will work with the Agriculture Workgroup to determine the most appropriate way to inform updates to conservation practice effectiveness estimates in the CBP Watershed Model, with a particular focus on characterizing spatial variability in practice effectiveness.
Timeframe: Ongoing

Crediting new conservation practices. The EPA will provide resources to help coordinate the effort to credit new conservation practices in the CBP Watershed Model, in accordance with the established protocols. The USDA will provide relevant data on effectiveness estimates of the new conservation practices to inform assessment by expert panels that evaluate practice effectiveness.
Timeframe: Ongoing