Management Context

The Chesapeake Bay Program (CBP) Partnership carries out agreements between state and federal partners aimed at restoring and preserving the Chesapeake Bay and its watershed. These agreements date back to 1983 and are updated from time to time. To aid in decision making and tracking of commitments related to these agreements, the CBP partnership has used a system of atmospheric, land use change, watershed, and estuarine models. This system of models has been continually improved since the 1980s in accordance with management needs.

In 2010, EPA and the partnership put in place the Chesapeake TMDL, specifying nitrogen, phosphorus, and sediment levels necessary to meet water quality standards for dissolved oxygen, water clarity, and chlorophyll *a*. The 2010 agreement also specified that the states would produce Watershed Implementation Plans (WIPs), which describe the practices that will be put in place to meet the water quality standards. Both the TMDL and WIP efforts, and the annual and biennial tracking of progress towards their goals are reliant on the CBP modeling system. At the time of the TMDL, four decision dates were specified.

- 2010 – TMDL put in place and Phase I WIPs created using CBP phase 5.3 models
- 2012 – Two changes were made to the watershed model and Phase II WIPs created using CBP phase 5.3.2 models
- 2017 – Midpoint assessment. States are assessed on implementation progress made by the halfway point. New nutrient and sediment planning targets are calculated based on the CBP phase 6 models. Specific questions of climate change, reservoir filling, and growth are addressed.
- 2025 – Endpoint for the TMDL implementation. Practices sufficient to meet water quality standards should be in place by this time. It is likely that management will call for new model versions to track progress and assess water quality attainment based on the latest science.

Throughout the history of the CBP, much of the decision-making effort and modeling has been focused on Bay water quality, relating dissolved oxygen in the Chesapeake to management actions aimed at controlling nitrogen, phosphorus, and sediment. In 2014, the partners signed a new agreement that specified 31 outcomes, of which only three were related to dissolved oxygen and nutrient reduction. The CBP tracks and reports progress on all of these outcomes at http://www.chesapeakeprogress.com/, but most outcomes receive far less attention and resources than water quality outcomes. A potential model re-design for 2025 and beyond creates an opportunity to perhaps model for more outcomes.

Current models

Airshed Model **(source: https://www.epa.gov/cmaq)**

CMAQ*:* an active open-source development project of the U.S. EPA that consists of a suite of programs for conducting air quality model simulations. CMAQ combines current knowledge in atmospheric science and air quality modeling, multi-processor computing techniques, and an open-source framework to deliver fast, technically sound estimates of ozone, particulates, toxics and acid deposition.

CMAQ allows users to explore different kinds of air pollution scenarios. For example, CMAQ is often used to test the impact of future emission regulations. The interaction of meteorology and air quality, e.g. the effects of particles on solar radiation, can be explored with the two-way WRF-CMAQ system, which couples the Weather Research and Forecasting (WRF) meteorological model with the CMAQ air quality model. The Direct-Decoupled Method (DDM) can be used in CMAQ-DDM to quantify the sensitivity of air pollution predictions to model input values like emissions or reaction rates. Often, people want know more about which individual emission sources or groups of sources are contributing the most to the air pollution at a site. This can be explored using the Integrated Source-Apportionment Method (ISAM) in the CMAQ-ISAM model.

The CMAQ system is a suite of software programs that work in concert to estimate ozone, particulate matter, toxic compounds, and acid deposition throughout the troposphere. As a framework for simulating the interactions of multiple complex atmospheric processes, CMAQ requires two primary types of inputs: meteorological information, and emission rates from sources of emissions that affect air quality.

Weather conditions such as the changes in temperature, winds, cloud formation, and precipitation rates are the primary physical driving forces in the atmosphere. These conditions are represented in air quality model simulations using output from regional-scale numerical meteorology models, such as WRF. To obtain inputs on emissions, CMAQ relies on the open-source Sparse Matrix Operator Kernel Emissions (SMOKE) model to estimate the magnitude and location of pollution sources.

Land Use Change Model

Chesapeake Bay Land Change Model v3a

The Chesapeake Bay Land Change Model (CBLCM) is a computer simulation model designed to forecast future urbanization across multiple counties or states based on the best data and information available at regional scales. The CBLCM relies on county and state-produced population and employment projections to determine the overall demand for growth. The model assigns a portion of that demand to infill and redevelopment based on recent county-level trends and allocates the remaining demand to the landscape in the form of residential and commercial patches (i.e., clusters of 30-meter resolution cells) of development. The U.S. Geological Survey began developing the CBLCM in 2012 and specifically designed it to inform decisions focused on restoring water quality and conserving wildlife habitat and open space throughout the 64,000-square-mile Chesapeake Bay watershed.

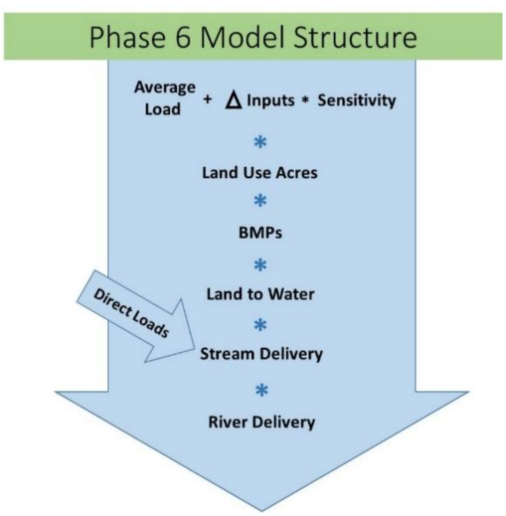
The CBLCM is capable of simulating multiple future scenarios of urbanization. Future scenarios represent unique and logically consistent sets of assumptions about future conditions. For example, a "smart growth" scenario might involve greater investments in land conservation, stronger enforcement of zoning, and incentives to promote infill and redevelopment. For any given scenario, the CBLCM simulates 101 equally-likely spatial representations of residential and commercial development. For each of the 101 iterations, the exact location of new development is randomly selected but the choice of location is influenced by probability of growth at any given location (higher close to already urbanizing areas) and by the exclusion of steep slopes, protected lands, and already developed lands. Therefore, the overall patterns of growth within a county are similar across all 101 iterations but the exact locations of patches are variable. This is done to account for the uncertainty associated with parcel-level representations of future urban growth.

Currently, over 18 million people call the Bay watershed home. By the year 2050, the watershed population will likely increase to 22.5 million. Based on historic trends, the majority of these people are expected to live and work in and around major cities (e.g., Harrisburg, Baltimore, Washington D.C., Richmond, and Norfolk) and along major transportation corridors (e.g., I-81, I-95, I-66). However, these trends could change due to changing energy prices, emerging technologies (e.g., driverless cars), more flexible workplaces and schedules, changing cultural preferences, the construction of new roads, and other factors.

Watershed Model

The primary model structure for management scenarios is a steady-state model. This steady-state model is known as CAST – the Chesapeake Assessment and Scenario Tool. The model is available for use through a web interface at cast.chesapeakebay.net. Full documentation is also available on this site. Section 1 of the documentation is encouraged for those in the watershed breakout groups.

The Phase 6 model uses a simplified structure with parameters that are well-supported by multiple lines of evidence, including observation, simple models, and complex models. This structure is chosen specifically to avoid problems with over-parameterization and over-calibration and to enhance understanding by stakeholders.



The figure at left shows the structure of the steady-state model for nutrients. The processes represented correspond to separable scales and physical domains. Each process is a coefficient determined using the available information. The factors are publicly available and calculated according to work performed under the guidance of CBP workgroups.

The steady-state model used for accounting is supported by a dynamic model that is calibrated to observed data. The dynamic model supplies estimates of river attenuation to the steady-state model, delivers hourly loads to the estuarine model, and can carry out special projects requiring a dynamic simulation. This model is documented in section 10 of the CAST documentation at cast.chesapeakebay.net.

Estuarine Model

The following is summarized from draft documentation which is available for download at this site: ftp://ftp.chesapeakebay.net/Modeling/WQSTM/ . Participants in the estuarine breakouts are encouraged to read through the introduction of this document for more details.

The structure of the estuarine water quality model was established nearly 30 years ago and subjected to continual revision since then. The CH3D model supplies the hydrodynamics and is unchanged from the 2010 model version. The biogeochemical model CE-QUAL-ICM was designed to be a flexible, widely-applicable eutrophication model. Initial application was to Chesapeake Bay in 1994. Subsequently it has been applied multiple times in the Chesapeake Bay and in several other estuaries.

Labile and refractory state variables are defined in the water column for carbon, nitrogen, and phosphorus. The sediment diagenesis model is formulated with three classes of organic matter: labile, refractory, and slow refractory material and has been updated for the current model with improved nitrate flux.

A relatively simple wetlands model is included to reflect low dissolved oxygen concentrations observed in open waters adjacent to extensive tidal wetlands and to address the need for estimating nutrient reduction due to wetlands restoration. Shoreline Erosion derived from long-term shoreline recession rates adds nutrients and solids to the Bay. Phosphorus, especially, contributed by erosion is a significant portion of the system total phosphorus load. Protocols have been developed to provide nutrient and sediment mass reduction credits for shoreline management projects that include restoration of vegetation.

The inclusion of bivalve filter feeders reflects the general interest in living resources as well as a specific mandate to investigate the impact of a ten-fold increase in oyster population on Bay water quality. The filter feeder module incorporated two freshwater bivalve groups as well as oysters.

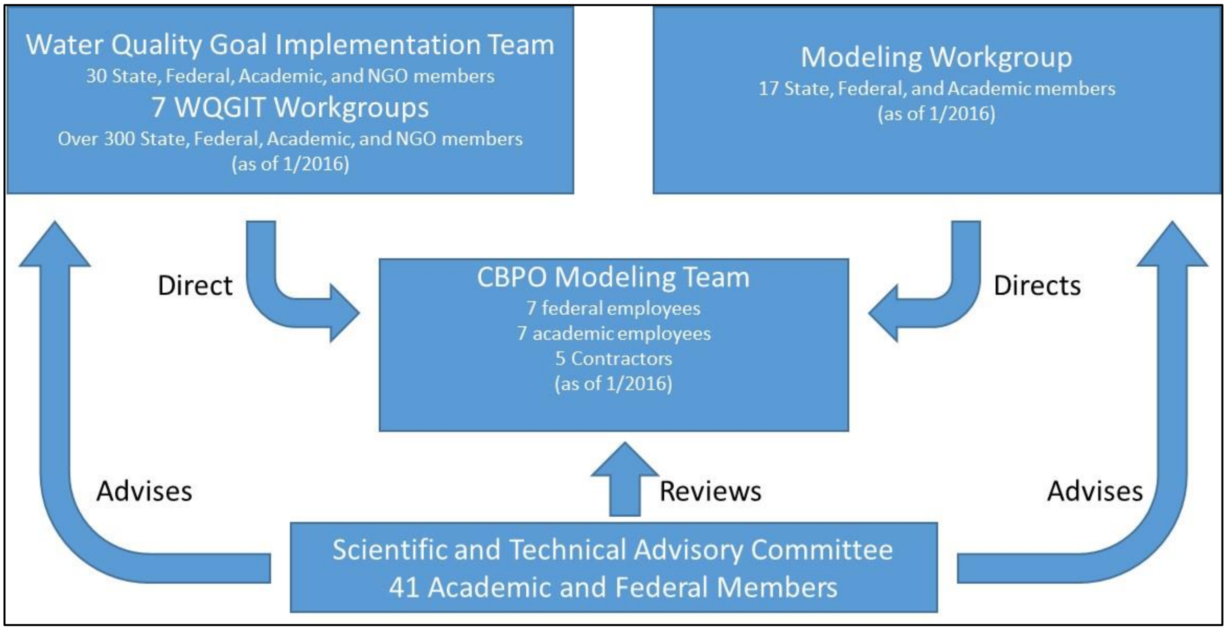
Light Attenuation is simulated through a partial-attenuation model. Submerged aquatic vegetation (SAV) was added to the 2002 model version along with other living resources. The model is a representation of SAV production and loss on a unit-area basis. The current model specifies bed area based on annual surveys. This specification enhances the computation of total SAV biomass and ensures the correct representation of mass fluxes between SAV and the Bay water column.

Silica has been eliminated from the current model due to a lack of observations and a finding that phosphorus is the predominant limiting nutrient during the spring bloom. Zooplankton have also been eliminated for a similar lack of data and finding of low importance in the model.

Model Governance

The 2010 TMDL greatly increased the partnership and public interest in model development, which has led to greater partnership resources available for modeling, particularly in the watershed.

The Phase 6 watershed model was developed with extensive partnership input and direction. The figure below illustrates the modeling governance structure within the CBP. These groups are part of the larger CBP organizational chart.



The Modeling Team is a cross-disciplinary group at the Chesapeake Bay Program Office (CBPO) working on development, analysis, research, calibration, and operation of the CBP modeling suite including the Land Cover Model, Watershed Model, and Estuarine Water Quality and Sediment Transport Model (WQSTM). The team takes direction from decisions of the CBP Partnership, particularly the Modeling Workgroup (MWG), and Water Quality Goal Implementation Team (WQGIT), as well as expert guidance from the Workgroups of the WQGIT. The independent Scientific and Technical Advisory Committee (STAC) advises the partnership through recommendations from workshops and reviews, and through direct communication. The MWG and WQGIT also receive considerable input from stakeholders and other interested parties that participate in regular meetings.

Modeling Resources

As the CBP is a distributed partnership, the resources available to the CBP for modeling are also distributed. The CBP office has dedicated staff to handle software development, model development of some models, and model application. Much of the data that drives these models are created through funded and unfunded partnership processes. Much of the research that is built into the models is funded externally to the partnership.

Atmospheric modeling through CMAQ is supported by EPA externally to the CBP. The EPA CBP contributes minor amounts for specific scenario analysis.

Land use change modeling is currently supported by approximately 4 USGS employees at the CBPO. These positions are paid for by EPA CBP. Data collection is through the Chesapeake Conservancy which is also paid for by EPA CBP.

CAST is supported by approximately 8 CBPO employees including EPA, UMCES, UMd, CRC, and contract staff. All positions are currently paid for by EPA CBP. Workgroups of the WQGIT conduct significant analysis that feeds into the development of CAST and supply input data for CAST through an automated database application. Additional ad hoc groups, for example the Poultry Litter Subcommittee, are formed on a volunteer basis to address specific issues. Expert Panels supported by a grant from EPA CBP to Virginia Tech develop recommendations for effectiveness of management practices.

The dynamic watershed model is supported by approximately four CBPO employees including PSU, UMCES, USGS, and computer administration support. All CBPO positions are currently paid for by EPA CBP. MDE has also supported an additional employee with the Interstate Commission on the Potomac River Basin. Self-funded collaborations with academic and federal researchers supply much of the data and analysis needed for the modeling. Prominent recent collaboration include extensive and wide-spread interaction with USGS and targeted interactions with academic modelers at Johns Hopkins, UMCES, Virginia Tech, Penn State, and other institutions. Exelon and the state of Maryland contributed to research used to simulate the Conowingo reservoir.

The estuarine model has been developed by approximately 2 employees at the US Army Corps of Engineers. Scenario analysis and other research is carried out by one UMCES employee at the CBPO. All three positions have been paid for by EPA CBP. In the past, EPA CBP has made limited funds available for targeted research related to priority processes in the estuarine model.