USA: THE CHESAPEAKE BAY PROGRAM: APPLICATION OF WATERSHED-SCALE MODELS FOR INTEGRATED WATER QUALITY AND COASTAL RESOURCES RESTORATION (#123)

The case illustrates how a modelling framework can be applied to an entire river basin system to assist in the decision-making process of targeting pollution reduction strategies and developing regulatory guidelines for improved water quality management of the Chesapeake Bay.

ABSTRACT

Description

In the late 1970s, scientific and estuarine research on the Chesapeake Bay pinpointed three areas causing water quality deterioration that required immediate attention: nutrient over-enrichment, dwindling underwater Bay grasses, and toxic pollution. Beginning in 1980, the legislatures of Virginia, Maryland and Pennsylvania established the Chesapeake Bay Commission (CBC) to begin to address these problems and coordinate interstate planning and programs from a legislative perspective. These actions led to the historic *Chesapeake Bay Agreement* of 1983, which called on all local, state and federal agencies with jurisdictions in the Chesapeake Bay watershed to focus their existing pollution control programs on reducing nutrient loads to the Bay. The Agreement proposed a series of goals, objectives and priority commitments to establish a policy and institutional framework for continued cooperative efforts to restore and protect the Chesapeake Bay. The parties committed to specific actions to achieve the objectives, and decided to review the implementation of such actions annually with additional commitments developed as needed. Stakeholders set a major goal to reduce the nutrients nitrogen and phosphorous entering the Bay by 40% by year 2000.

Basin-wide integrated modelling activities assisted in the evaluation and monitoring of water quality changes, help stakeholders set future goals and objectives, and aid decision makers in developing new strategies and policies. As such, water quality data management, analysis, and modelling became a cornerstone in future stakeholder involvement to access data, review alternative water quality management options, and provide input to the decision making process. The use of modelling tools in the case of the Chesapeake Bay was very effective in helping implement the actions and monitor the goals set by the CBP partners. It provided decision makers with quantitative information that has assisted the restoration efforts of the Bay. The tools supplied the basis for policy makers to reach an agreement and to commit resources to work towards a common goal on an otherwise highly untenable consensus.

Lessons learned

- The public must be “educated” on the principles and use of modeling.
- Model results must be efficiently summarized in a clear and timely manner.
- Independent experts in the field must frequently review the modeling strategy and results.
- Informing stakeholders on the progress of the modelling effort enhances support for restoration efforts throughout the watershed.
- A public version of the calibrated and verified model should be made available with online or easy access.
- Models are extremely useful to assist in integrated water quality management and ecosystem protection.
- Scientific and technical advisory committees specializing in watershed modelling play an important role in helping to ensure quality and legitimacy in watershed agreements and regional action plans.

Importance for IWRM

The case shows how the use of modelling can be a cost-effective tool in helping to implement watershed restoration actions and monitor goals set by stakeholders. Computer simulation of a large number of scenarios provides a realistic look at the combined impact of a broad array of

land use activities and policies, thereby facilitating IWRM decision-making. The modelling initiative developed for the Chesapeake Bay is readily applicable to other watersheds. This case references the public-domain watershed model currently used in different parts of the world for integrated water resources management, and highlights its usefulness and availability to other managers.

Main Tools Used

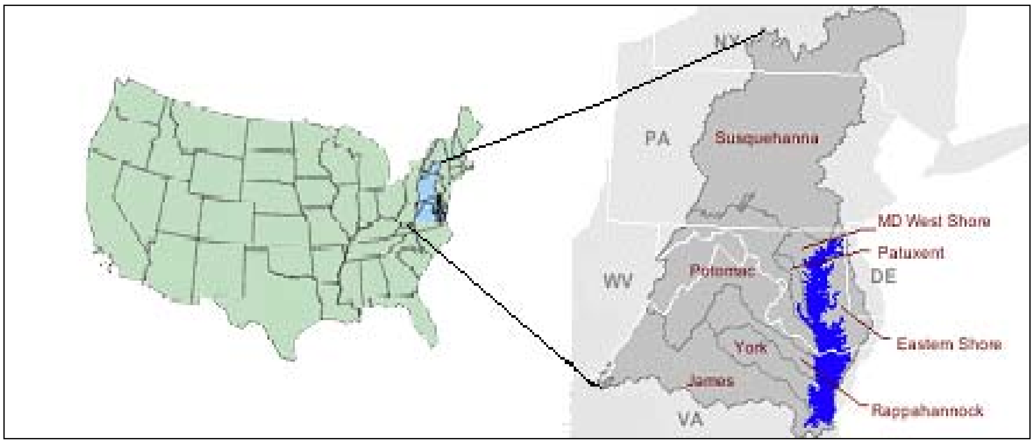
A1.2 Policies with Relation to Water Resources
C1.3 Modelling in IWRM
C2.1 River Basin Plans
C5.2 Shared Vision Planning
C6.1 Regulations for Water Quality
C8.1 Information Management Systems

MAIN TEXT

1 Background of Issues and Problems

The Chesapeake Bay (Figure 1) is North America's largest, most ecologically diverse estuary that constitutes a resource of extraordinary productivity worthy of the utmost levels of protection and restoration. The watershed basin covers about 165,000 square kilometers (64,000 square miles) with a population of 15 million people. It is home to more than 3,600 species of plants, fish and animals. For over 300 years, the Bay and its tributaries have sustained the region's economy and defined its traditions and culture.

Figure 1 Location Map of the Chesapeake Bay Watershed



The Formation of Governing Bodies and Stakeholder Groups

In the late 1970s, scientific and estuarine research on the Chesapeake Bay pinpointed three areas causing water quality deterioration that required immediate attention: nutrient over-enrichment, dwindling underwater Bay grasses, and toxic pollution. In 1980, the legislatures of Virginia and Maryland established the Chesapeake Bay Commission (CBC) to begin to address these problems and coordinate interstate planning and programs from a legislative perspective; Pennsylvania later joined the Commission in 1985. The CBC was created to advise the members of the General Assemblies of Maryland, Virginia, and Pennsylvania on matters of Bay-wide concern. Twenty-one members from three states define the Commission's identity and its work. Fifteen of the members are legislators, five each from Maryland, Virginia, and Pennsylvania. Completing the ranks are cabinet secretaries from each state who are directly responsible for managing their states' natural resources, as well as three citizen representatives who bring with them a unique perspective and expertise.

These actions led to the historic *Chesapeake Bay Agreement* of 1983, which evolved as the means to restore the exceptionally valuable resources of the Bay. The Agreement called on all local, state and federal agencies with jurisdictions in the Chesapeake Bay watershed to focus their existing pollution control programs on reducing nutrient loads to the Bay, since this issue was identified as the main cause of Bay degradation.

Considered a national and international model for estuarine research and restoration programs, the Chesapeake Bay Program (CPB) was thereby established as a partnership led by the Chesapeake Executive Council[1]. The members of the Executive Council are the governors of the states of Maryland, Virginia and Pennsylvania; the mayor of the District of Columbia; the administrator of the U.S. Environmental Protection Agency (EPA); and the chair of the Chesapeake Bay Commission. The Executive Council meets at least annually to establish the policy direction for the Bay Program and is advised by the Principals' Staff Committee. An Implementation Committee and nine thematic subcommittees are responsible for executing policy decisions and conducting technical studies.

In addition, a body called the Citizens Advisory Committee (CAC) provides assistance to the Executive Council, Implementation Committee and all subcommittees as needed in implementing the Chesapeake Bay Agreement. The Citizens Advisory Committee (CAC) is composed of 25 members representing a cross-section of individuals and organizations with interests and concerns about the Bay. Such interests include conservation, business and industry, agriculture, recreation, seafood, and development. Members of the CAC are appointed by the Executive Council. This group has provided a non-governmental perspective on the Bay cleanup effort and on how Bay Program policies affect citizens who live and work in the Chesapeake Bay Watershed. Members communicate with their constituencies to increase understanding of the program to restore and protect the Bay. Information on the CAC and its by-laws can be found at http://www.chesapeakebay.net/cac.htm.

The 1987 Chesapeake Bay Agreement: Goals and Priority Commitments
In 1987, a second Agreement refined the goals, objectives, and interventions under the CBP. The Agreement proposed a series of goals, objectives and priority commitments to establish a policy and institutional framework for continued cooperative efforts to restore and protect the Chesapeake Bay. The parties committed to specific actions to achieve the objectives, and decided to review the implementation of such actions annually with additional commitments developed as needed. Objectives under the water quality area were set in the 1987 Agreement as follows:

- Provide timely construction and maintenance of public and private sewerage facilities to assure control of pollutant discharges;
- Reduce the discharge of untreated or inadequately treated sewage into Bay waters from such sources as combined sewer overflows, leaking sewage systems, and failing septic systems;
- Evaluate and institute, where appropriate, alternative technologies for point source pollution control, such as biological nutrient removal and land application of effluent to reduce pollution loads in a cost-effective manner;
- Establish and enforce pollutant limitations to ensure compliance with water quality laws;
- Reduce the levels of non-point sources of pollution;
- Reduce sedimentation by strengthening enforcement of existing control regulations;
- Eliminate pollutant discharges from recreational boats;
- Identify and control toxic discharges to the Bay system, including metals and toxic organics to protect water quality, aquatic resources and human health through implementation and enforcement of the states' National Pollutant Discharge Elimination System permit programs and other programs;
- Reduce chlorine discharges in critical finfish and shellfish areas;
- Minimize water pollution incidents and provide adequate response to pollutant spills;
- Manage sewage sludge, dredged spoil and hazardous wastes to protect the Bay system;

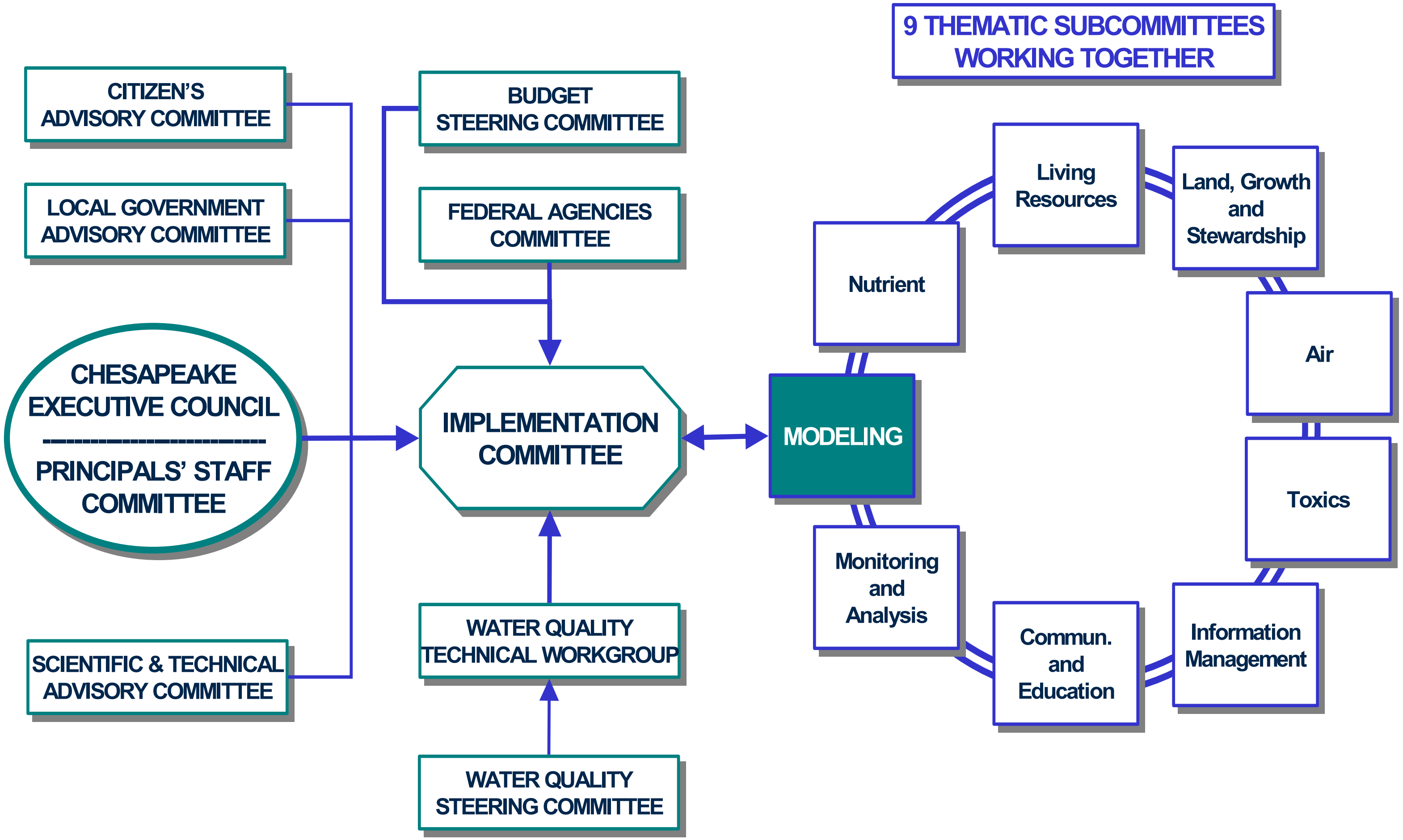
[1] The Chesapeake Bay Executive Council (CEC) is a separate body from the Chesapeake Bay Commission (CBC). The CBC is a legislative body serving MD, PA, and VA, and predated the CBP Executive Council by three years until Virginia, Maryland, Pennsylvania, the District of Columbia, the U.S. Environmental Protection Agency and the Chesapeake Bay Commission formally established the CEC and signed the first Chesapeake Bay Agreement for a cooperative approach in 1983.

- Manage groundwater to protect the water quality of the Bay; and
- Quantify the impacts and identify the sources of atmospheric inputs on the Bay system.

Based on these objectives, the Executive Council set a major goal to reduce the nutrients nitrogen and phosphorous entering the Bay by 40% by year 2000. Achieving a 40% nutrient reduction would ultimately improve the oxygen levels in Bay waters and encourage aquatic life to flourish. To achieve these water quality goals, the parties agreed to the following complete set of commitments and time schedule as part of the 1987 Agreement:

- By July 1988, to develop, adopt and begin implementation of a basin-wide strategy to equitably achieve by the year 2000 at least a 40 percent reduction of nitrogen and phosphorus entering the main stem of the Chesapeake Bay;
- By December 1991, to re-evaluate the 40 percent reduction target based on the results of modelling, research, monitoring and other information available at that time;
- By December 1988, to develop, adopt and begin implementation of a basin-wide strategy to achieve a reduction of toxics consistent with the Water Quality Act of 1987, which will ensure protection of human health and living resources;
- By July 1988, to develop and adopt, as required by the Water Quality Act of 1987, a basin-wide implementation strategy for the management and control of conventional pollutants entering the Chesapeake Bay system from point and non-point sources;
- By July 1988, the EPA, acting for the federal government, will develop, adopt and begin implementation of a strategy for the control and reduction of point and non-point sources of nutrient, toxic and conventional pollution from all federal facilities.

To help achieve the goals established under the 1987 Agreement, and implement its commitments, resulting decisions, and future Program adjustments, it was decided to intensify the use of computer-based modelling as a tool for integrated water quality assessment and prediction. Hence, basin-wide integrated modelling activities were sought to assist in the evaluation and monitoring of water quality changes, help stakeholders set future goals and objectives, and aid decision makers in developing new strategies and policies. As such, water quality data management, analysis, and modelling was to become a corner stone in future stakeholder involvement to access data, review alternative water quality management options, and provide input to the decision making process. Figure 2 presents the relationship and interaction of the Modelling Subcommittee within the overall CBP organization and functions.



The Modeling Subcommittee interacts and collects information from all thematic areas based on the requirements of the Implementation Committee and the stakeholders. The Modeling Subcommittee then evaluates various management options and scenarios, and communicates the results to the decision-makers.

It was recommended to use watershed and water quality modeling to support and achieve the following objectives within the CBP:

- Establish a nutrient reduction goal amenable to the Bay's restoration;
- Quantify the nutrients contributing to Bay eutrophication;
- Assess the existing nutrient loading conditions;
- Quantify and track the progress towards the restoration of the Bay;
- Help identify and establish priorities in the Bay cleanup effort; and
- Assess the response of water quality within the Bay to various nutrient management controls.

2 *Description of actions taken*

Basin-wide Integrated Models: A Management and Decision-Support Tool for Bay Restoration

In the early stages of the restoration effort, watershed modeling was identified as a key instrument to provide essential information to guide decision-makers in Bay restoration. The Bay system is exceedingly large and complex to conduct extensive field experiments. Environmental models were deemed essential for simulating the Bay's aquatic and atmospheric conditions. A modeling framework was needed for the entire Bay system to provide a quantitative tool to assist in the decision-making process for the restoration of the Bay, and to enhance the understanding of Bay water quality processes and their sensitivity to external nutrient loads.

Models are not only less expensive than massive data collection and monitoring campaigns, but are also an ideal tool to simulate a large number of possible management scenarios (Thomann et al. 1994). Model parameters can be changed rather easily which makes it possible to examine the simulated changes in an ecosystem due to, for instance, changes in population, land use, fertilizer or manure application on agricultural land, or improved sewage treatment. These scenario simulations allow engineers and scientists to predict changes within the ecosystem due to alternative management options.

During initial efforts under the CBP, modeling was used to confirm the direct cause-and-effect relationship between anoxia (concentrations of dissolved oxygen is less than 1 milligram per litter) and nutrient enrichment. To estimate the impact of nutrient loads on the main stem of the Bay, a water quality modeling effort was completed in 1987, and supported the overall targets established in the 1987 Agreement. Modeling results indicated that a 40% reduction in nutrient loads would eliminate anoxia in the main stem of the Bay. Furthermore, to confirm and refine estimates of anoxia reduction due to nutrient load reduction, work began in 1987 on integrating the set of Chesapeake Bay models as described below.

Chesapeake Bay Modelling Framework

The CBP through the modelling sub-committee identified and applied an integrated set of air and water models to track changes in the watershed and airshed. Three models have been developed and linked to get an integrated simulation of the Chesapeake watershed, airshed and estuary. The models are: the Regional Acid Deposition Model (RADM) (Dennis 1996), the Chesapeake Bay Water Quality Model (CBWQM) (Cerco 1993), and the Chesapeake Bay Watershed Model (CBWSM) (Linker 1996). These models are briefly described in Box 1. Each of these Chesapeake Bay Basin models performs specific types of evaluations. When combined, they provide decision-makers with a quantitative framework for predicting the response of water quality and living resources within the Bay to nutrient management controls in the Bay Watershed and Airshed.

Problems Encountered During Implementation of the Modeling Framework and How They Were Resolved

Credibility and Integrity of the Modeling Effort

In the early stages of the CBP, modeling was not perceived as an essential tool for the restoration of the Bay. This was due to the fact that few of the stakeholders had a basic knowledge of the modeling concept. The CBP through the modeling subcommittee and the Scientific and Technical Advisory Committee engaged in a series of presentations focused on educating and familiarizing the stakeholders in the role of modeling as an integral part of the restoration effort. Technical and non-technical versions of the presentations were prepared that clearly showed how modeling can be used effectively.

To give a strong credibility to the modeling effort, the Modeling Subcommittee created a Modeling Evaluation Group (MEG) composed of top experts in the field. The role of the MEG was to review and validate the modeling results during its quarterly meetings. In addition, the modeling subcommittee scheduled monthly public meetings where simulation results are presented and discussed.

Gathering Essential Data Needed for the Calibration Process

During the initial phases of the modelling effort, some organizations and individuals were reluctant to share information needed for model calibration for fear of its inaccurate or unfavorable interpretation. They expressed concern that inappropriate conclusions could be drawn, or that blame for poor results would be assigned unfairly. Given the consensus-based nature of this intergovernmental effort, the implications of any mistakes could carry a high political cost. However, frequent and open interaction with the stakeholders and the public at large helped resolve this key difficulty.

BOX 1: DESCRIPTION OF CHESAPEAKE BAY MODELS

The Regional Acid Deposition Model (RADM)

The RADM is used to simulate atmospheric processes within the Bay airshed and provides an estimate of nutrient deposition of emissions from point and mobile sources to the watershed and estuary. The RADM was developed in 1990 and is the model used to simulate the Chesapeake Bay airshed, which is defined as the area surrounding the Bay from which a significant percentage of air emissions of nitrogen from both mobile and stationary sources are delivered to the Bay through atmospheric deposition to land and water surfaces.

The Chesapeake Bay Water Quality Model (CBWQM)

The CBWQM is a three-dimensional model simulating the hydrodynamics, water quality and living resource processes that take place from the tributary fall lines to the ocean shelf outside the mouth of the Bay. The CBWQM, also referred to as the 3-D Model, the Estuarine Model and, in its most recent form, the Tributary Model, was developed in 1990, and was refined for use in the 1997 Re-evaluation. When linked with the RADM and CBWSM models, the CBWQM is used to determine the Chesapeake Bay water quality response to different degrees of nutrient load control.

The Chesapeake Bay Watershed Model (CBWSM)

The CBWSM is an adaptation to the Chesapeake Bay watershed of a computer model called the Hydrologic Simulation Program, Fortran (HSPF) (Bicknell, et al.1996). HSPF simulates the hydrology, nutrient and sediment exports from pervious and impervious land uses, as well as the transport of these exports in rivers and reservoirs. Major land use categories used in the model include: forest, conventional tillage cropland, conservation tillage cropland, hay land, pasture, manure acres, pervious and impervious urban lands. Nutrient inputs to these land uses include: atmospheric deposition to all pervious land uses, manure applications to croplands and pasture, and fertilizer applications to croplands and pervious urban land.

Key Implementation Issues

Dissemination and Distribution of the Modeling Results

Because of the large volume and complexity of the output generated by the models and the large size of the watershed, the distribution and presentation of the modeling results in a clear and timely manner was a real challenge. In the late 1980s, the Modeling Subcommittee initiated the development of an automated output postprocessor to summarize and tabulate nutrients and sediment loads on a State, Country, and Model segment levels.

Without this effective model output postprocessor, the goals and progress of the modeling effort could not have been transmitted in a clear and efficient manner to the decision-makers and the public. The model output post-processor is analogous to the Decision Support Process within the IWRM Decision Support System (DSS).

3 *Outcome: Modelling Results Guided the Decision Making Process*

This section discusses specific examples of the use of model results in the decision making process, and the performance of the modelling effort within the Chesapeake Bay Program. The use of modelling tools in the case of the Chesapeake Bay was very effective in helping implement the actions and monitor the goals set by the CBP partners. It provided decision makers with quantitative information that has assisted the restoration efforts of the Bay. Since 1983, but more extensively after the 1987 Agreement, modelling efforts supported specific actions that were initiated by the CPB including a watershed-wide phosphate detergent ban, the introduction of best management practices in agriculture, and biological nutrient removal at wastewater treatment plants.

Estimating Nutrient Reduction Goals

One of the initial uses of the modelling framework was to quantify the nutrient reduction level necessary to restore the Chesapeake Bay. Simulation of a large number of scenarios indicated that a 40% reduction in nutrients entering the Bay would result in increasing dissolved oxygen to the levels that can protect and replenish aquatic resources. The decision makers managing the cleanup effort adopted this reduction target in the 1987 Chesapeake Agreement indicating the importance placed in the models. In this case, modelling was used to provide the necessary supporting information to the decision making process. The tools supplied the basis for policy makers to reach an agreement and to commit resources to work towards a common goal on an otherwise highly untenable consensus.

Assessing Existing Nutrient Load Conditions

Following an extensive calibration of the CBWSM, the 1985 reference loads were generated. The reference loads were input in the CBWQM to generate the 1985 baseline water quality conditions in the Bay. 1985 was chosen as the reference year because hydrologic conditions were relatively normal, and it was the first year with extensive monitoring data in the watershed and tidal waters. The 40% nutrient reduction target and all future nutrient load reductions are measured against the 1985 reference loads.

Decisions makers reviewed nutrient loads from each tributary and land use categories and the resulting water quality conditions. This snapshot of the Bay showed that agricultural practices, point sources, and urban sources were the dominant loads. This helped target the restoration effort and implement a wide-ranging program in nutrient management promoting reductions in fertilizer application; less invasive agricultural practices such a low tillage; and use of biological nutrient removal at wastewater treatment plants.

This is another example where the application of models helped environmental managers and practitioners in selecting best management solutions to improve the health of the ecosystem. Model results supplied useful information to scientist and engineers who supported decision makers prioritize actions and optimize the use of available resources.

Quantification of Controllable Loads and Allocation of Nutrient Reduction Goals for each Tributary

Simulation results helped quantify the controllable loads, answering a key question needed by decision makers: “how much can be controlled/reduced”. Controllable loads are defined as the total point source loads from the states signatory to the Bay Agreement, as well as nonpoint source loads greater than the loads estimated from an all-forested watershed condition. The controllable loads were deemed to be those that can be affected by nutrient management actions to be undertaken by the partners of the CBP. This information provided the basis for states and local communities to develop strategies at the state and tributary level.

The Bay partners agreed to reduce controllable loads of nitrogen and phosphorous delivered to the Bay by 40% of the 1985 levels by year 2000. Based on this goal, Bay models were used to develop tributary nutrient reduction allocations for each of the nine major tributaries in the Chesapeake watershed. In the 2000 Agreement, tributary allocations were converted into caps not to be exceeded even with future increases in population and growth. With the nutrient caps in place, Bay models are used to assess nutrient loads to ensure the caps are not exceeded.

Nutrient Contribution from Point and Non-point Sources and the Ban on Phosphate Detergents

The ratio of point to non-point source loads changes from dry years to wet years. In a dry year point sources account for the majority of nutrients entering the Bay. On the other hand, in a wet year, the relative contribution of point sources decreases. Models were used to assess the load ratio of point and non-point sources over a period of many years. The results helped decisions makers realize that it is more economical and less politically-charged to ban phosphate detergents entering the bay through the sewage system than force farmers to use less fertilizer. This information helped support the ban of phosphate detergents in 1988, and the initiation of a cost-share program offering an incentive to farmers to implement agricultural best management practices.

The models are now used to track the effects of the ban. Also, it provides information to assess the economic impact of this regulatory action and the farmers incentive program.

Achievement of Project Objectives

It is clear that in the case of the Chesapeake Bay, the introduction of models helped shape the restoration efforts, and provided a common basis for stakeholders to build consensus and reach agreements. Successive agreements were adopted as more information was collected and decision makers relied on modeling results to track progress and adjust goals. It was proven that integrated basin-wide models might be the key to alleviate much of the subjective judgment, especially in large complex watersheds involving varying levels of jurisdiction, control, and interest.

For the Bay restoration efforts, although nutrient loads have declined significantly since 1987, reductions fell short of the 40% goal by 2000. In the areas most impacted by excessive nutrient loads, the Potomac River and points north, phosphorus reduction goals were achieved. Nitrogen reduction goals for those areas are expected to be met once tributary strategies are fully implemented in 2003. A significant portion of nutrient reductions can be attributed to improved technology at wastewater treatment plants, while additional gains have been achieved through the banning of phosphate detergents and the implementation of new technologies, such as biological nutrient removal. A variety of best management practices, such as forest and other buffer strips and nutrient management plans on farms, also helped reduce the amount of nitrogen and phosphorus entering the Bay.

Impact on Bay Ecology

The nutrient reductions that have been achieved, although not meeting the targeted nutrient reductions for 2000, have had a positive impact on the ecology and productivity of the Bay. As a result of the aggressive nutrient reduction program in the Bay and its tributaries, the total acreage of bay grasses has increased since the lowest point in 1984 of 38,000 acres to more than 69,000 acres in 2000. The Bay Program's aim is to achieve 114,000 acres by 2005. In 2001, the distribution of Chesapeake Bay submerged aquatic vegetation (SAV), or bay grasses, reached the highest levels since tracking began in 1978 to an estimated 85,252 acres bay-wide, according to data released by the Chesapeake Bay Program in October 2002. Data gathered from the annual aerial survey shows that in areas surveyed in both 2000 and 2001, bay grass abundance increased by 27 percent in one year. When compared to areas surveyed in 2000, the data show a 10 percent increase in the upper Bay, a 49 percent increase in the middle Bay and a 7 percent increase in the lower Bay.

Bay grasses are critical to the overall health of the Chesapeake Bay ecosystem, as they produce oxygen, provide food for a variety of animals, provide shelter and nursery areas for a variety of fish and shellfish, reduce wave action and shoreline erosion, absorb nutrients such as phosphorus and nitrogen, and trap sediments. Improved water clarity from drier than normal conditions beginning in 2001 and improvements in water quality contributed to the highest levels since the bay-wide survey began in 1978, surpassing the previous record of 73,000 acres set in 1993.

This case shows that models are extremely useful to assist in integrated water quality management and ecosystem protection. It is however up to the stakeholders to make decisions on sensible actions and commitments to reach shared goals within the realm of sustainable development.

Impact at the National Level

Since modelling was clearly recognized as a long-term sustainable tool, a model development effort was set in place at the CBP to support the development, upgrade, and refinement of future versions. As a result, the CBWSM model is currently widely disseminated and used in the United States due to the continuous support of the model by the Chesapeake Bay Program. In addition, the EPA is recommending the use of the model in all aspects of watershed-scale pollution control issues. The models are updated frequently and can be accessed at the EPA Modelling Support Website: (http://www.epa.gov/ceampubl/swater/hspf/index.htm).

Winners and Losers as a Consequence of the Action/Program

The use of modelling at the Chesapeake Bay was a win-win situation. In fact, stakeholders are now extremely familiar with the modelling concept in general and with the Chesapeake Modelling Framework in particular. They actively participate and provide input in the periodic review meetings. In addition, stakeholders have access to all data, maps, and they can even conduct their own scenario modelling to assess and validate possible actions at the local and regional level. More information on the sustainability of the modelling support tools is provided below.

Sustainability

The Modelling Subcommittee of the CBP recognized that the transparency of the modeling efforts was the key to its success and sustainability. To empower all stakeholders and allow open access to the modeling assets, the Chesapeake Bay Program implemented the Community Watershed Model (CWM). At its core is a calibrated model of the Chesapeake Bay watershed that can be modified relatively easily using pre-processing and post-processing tools available from the CBP Modeling Subcommittee. Using this model, a group can determine the nutrient and sediment loads delivered to the Bay under various management strategies. Running the model with the necessary data on management practices, land-use, and other relevant factors, users can determine the loads that result from alternative actions.

By widely disseminating the modeling tools, and providing training and access for their use, the CBP has achieved a great deal to ensure the sustainability of this effort, and build capacity at the local community level. This helped improve the participation of local groups, NGOs, the scientific community, and governmental agencies at all levels. Stakeholders have open access to available data and model results. Their ability to independently validate such information using the CWM enhanced the overall consensus building process, and allowed agreements to be reached more efficiently.

4 Lessons Learned

Lessons learned were developed based on an evolving process that started over two decades ago. It is important that other water managers consider these as recommendations that should be tried as soon as politically, culturally, and technically feasible.

- The public must be “educated” on the principles and use of modelling. This can be done through non-technical presentations.

- Model results must be efficiently summarized in a clear and timely manner. An automated model output post-processor is essential for summarizing and disseminating the information to decision makers, stakeholders, and the public.
- Independent experts in the field must frequently review the modeling strategy and results. Modeling phases should not be implemented without their approval. This improves the public confidence and trust in the process and its outcomes.
- Informing stakeholders on the progress of the modelling effort enhances support for restoration efforts throughout the watershed. Modellers must frequently present the progress and the preliminary results of the modelling effort, and model input and output are widely distributed to stakeholders. As a result, stakeholders are now extremely familiar with the modelling concept in general and with the Chesapeake Modelling Framework in particular. They actively participate and provide input in the periodic review meetings. In addition, stakeholders have access to all data, maps, and they can even conduct their own scenario modelling to assess and validate possible actions at the local and regional level. More information on the sustainability of the modelling support tools is provided below.
- A public version of the calibrated and verified model should be made available with online or easy access. Training on the use of this "community watershed model" should be available online, or through conventional classrooms.
- Models are extremely useful to assist in integrated water quality management and ecosystem protection. Computer simulation of a large number of scenarios is a cost-effective way to evaluate the impact of a broad array of land use activities and policies. It is, however, up to the stakeholders to make decisions on sensible actions and commitments to reach shared goals within the realm of sustainable development.
- Scientific and technical advisory committees (Figure 2) specializing in watershed modeling play an important role in helping to ensure quality and legitimacy in watershed agreements and regional action plans. The use of scientific models in guiding decision making processes by stakeholders and legislative bodies has broad applicability to river basins worldwide.

Replicability

The main advantage of the CBWSM and related tools is the ability to simulate the transient, dynamic or the steady state behavior of both the hydrologic and water quality processes in a watershed. The model can represent the hydrologic regimes of a wide variety of streams and rivers with reasonable accuracy. Thus, the potential applications and uses of the model are numerous and include: non-point source loadings, flood mapping, urban drainage studies, river basin planning, studies of sedimentation and water erosion problems, and in-stream water quality planning. The main limitation of the CBWSM is that it requires a large amount of data to build the input files needed for the simulations (Figure 3). However, such effort is intensive only at the beginning of a modeling program.

The modelling initiative developed for the Chesapeake Bay is readily applicable to other watersheds. The public-domain watershed model is currently used in different parts of the world for water resources management, as well as integrated watershed modeling (Ball et al 1993; Johanson 1989; Walton et al 1997). The CBWSM is an open-source computer software package, and copies, along with pre- and post- processors are available on-line at http://www.chesapeakebay.net/temporary/mdsc/community_model/index.htm .

The Chesapeake Bay program invested enormous resources in the upgrade and refinements of the different versions of the model. The model is thoroughly documented, resulting in a great potential for application in watersheds around the world.

Importance of Case to IWRM

The case shows how the use of modeling can be a cost-effective tool in helping to implement watershed restoration actions and monitor goals set by stakeholders. Computer simulation of a large number of scenarios provides a realistic look at the combined impact of a broad array of land use activities and policies, thereby facilitating IWRM decision-making. The modeling initiative developed for the Chesapeake Bay is readily applicable to other watersheds. This case references the public-domain watershed model currently used in different parts of the world for integrated water resources management, and highlights its usefulness and availability to other managers.

5 *Links to Additional Information*

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Organizations and People

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