CHOICES
a publication of AAEA Agricultural & Applied Economics Association
The Magazine of Food, Farm and Resource Issues

3rd Quarter 2011 | 26(3)

THE CERTAINTY OF CONFRONTING UNCERTAINTY IN THE CHESAPEAKE BAY RESTORATION EFFORT

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JEL Classifications: Q00, Q01, Q20, Q28
Keywords: Environmental Restoration, TMDL, Chesapeake Bay, Adaptive Management, Uncertainty

The Chesapeake Bay is a very large complex system that no longer has the capacity to provide all of the beneficial human services it once did. Restoring some of that capacity is a consensus goal for the millions of people who live in the watershed and impact its condition. The challenges of improving the condition of such a large ecosystem lie not only in assembling the necessary resources, but also in knowing what must be done and how best to do it. These questions are at the very limits of our current knowledge and so there is inherent uncertainty in all the answers. The amount of uncertainty varies from very little—identification of the system's problem and the causes, to moderate—determination of the exact amounts of excess pollutant loads from all parts of the watershed, to significant—forecasting the performance of best management practices. Since the system will continue to degrade if nothing is done, inaction is not an option. Moving forward requires a willingness to act with less than perfect knowledge, constantly striving to reduce the uncertainty by learning and adapting as we go.

What follows is a brief review of some of the principal questions decision-makers currently confront in efforts to restore water quality conditions in the Chesapeake Bay. The answers to these questions vary significantly from "nearly certain" to "best available estimate." Understanding this circumstance is central to both designing the strategy and setting expectations.

What Is the Problem?

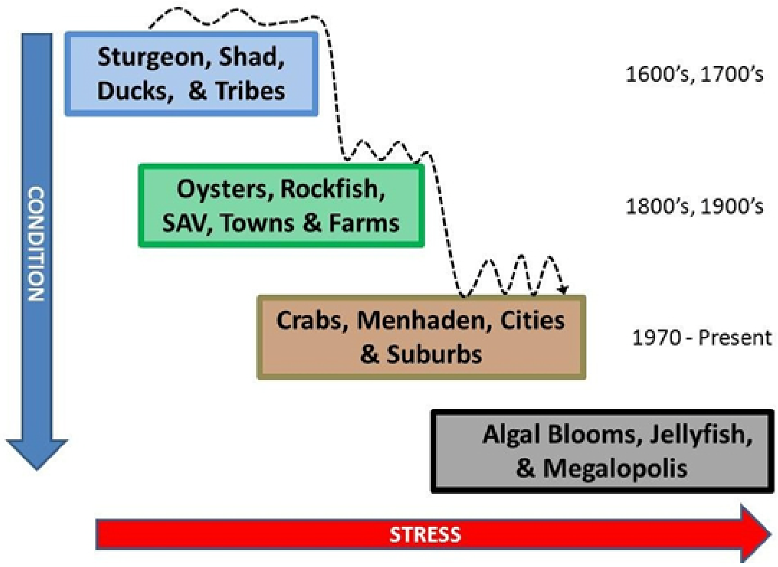
Scientists have been studying the Chesapeake Bay for decades. As the largest estuary in North America, it is both very interesting and very important. Since colonists first arrived the population living around the Bay and its tributaries have relied on it for food, transportation, recreation, and waste removal. It plays a large part in the economy of the region and its productivity and condition are of constant concern. Decreases in fisheries productivity were some of the first signs that the system was changing. Declines in finfish and shellfish harvests, particularly oysters, and changes in waterfowl populations were noted by watermen, sportsmen, and scientists as early as the end of the 19^{th} century. A dramatic decline in submerged aquatic grasses in the early 1970's was one of the factors that spurred increased interest in understanding what was happening to the system.

Current thinking among scientists describes dramatic changes in ecosystems, like the Chesapeake Bay, as "regime shifts". It is believed that, through time, ecosystems organize themselves in response to the pattern and level of stresses they experience. For example, the frequency and severity of storms will determine the opportunity for mature forests to become established or for marshes to persist along shorelines. Similarly, the amount of harvest pressure applied to a fish community will determine how many, what kind, and even what size of fish can survive in the system.

At the scale of entire systems, the ecological regime concept implies that as stress levels increase, the natural capacity of the system to resist change and/or recover from severe events is slowly overcome. There comes a point as stress levels increase, when some components of the system are no longer able to persist. When enough critical components have been affected, the system effectively reorganizes itself with a revised cast of organisms, more suited to prevalent stresses. This is referred to as a regime shift.

When a regime shift occurs, the system's composition and energy pathways are altered, and the reorganized system typically has a reduced capacity to provide traditional services to human users. In the case of the Chesapeake Bay, declining condition resulted in losses in the system's capacity to provide suitable habitat for some species of birds and fish, support some commercial and recreational fisheries, buffer storm impacts, and provide recreational and aesthetic opportunities for a variety of users as seen in Figure 1.

Figure 1:Chesapeake Bay regime shifts



The Chesapeake Bay ecosystem is hypothesized to undergo changes in structure andfunction as stresses increase. The changes are called regime shifts and represent a reorganization of the system as major components are lost. Recovery to a previous regime with higher values for humans can require reduction in stress beyond the point at which the system was first degraded.

The problem in the Chesapeake Bay is that stresses have increased sufficiently to cause significant changes in the nature of the system. While it remains an incredibly productive system, the production no longer occurs in forms we tend to prefer. Instead of ending up in oysters and large fish, most of the production is now found in plankton, algae, and bacteria. Preventing further unwelcome change in the system requires that we reduce the stressors that are causing its degradation.

Therefore the answer to the question regarding what is the problem may be found in the system stress level leading to a condition that is not optimal or even desirable. This is certain.

What Is Causing the Problem?

Scientists recognized that the primary stresses on the Bay ecosystem are generated by the millions of people who live in and use the watershed. While overharvesting of fish stocks, shellfish diseases, and rapid coastal development all played roles in the system's decline, scientists concluded that decreased water quality was a primary factor in many of the unwelcome changes. Too many nutrients—nitrogen and phosphorus compounds—and too much sediment have found their way into the system as a result of development, farming, forestry, and industrial practices of the past several centuries.

This understanding was derived from a combination of direct observation and experimentation. For both nutrients and sediments, monitoring stations at the fall lines of the principal Bay tributaries provide direct measurements of the modern loads coming from the watershed. Scientists also used well established methods to date the sediments already in the Bay and its tributaries. This allowed them to calculate the historic loads, documenting the impacts of land clearing and land disturbing activities since the time the first colonists arrived. Experimental evidence provided the primary explanation of the impact nutrients were having on the system. In controlled conditions, scientists conclusively demonstrated that the small floating plants, which are naturally found in estuarine systems like Chesapeake Bay, respond to increased nutrients just like any other plant – they grow and reproduce faster. In fact, it became clear that at the levels of nutrients found in the Bay, these plants frequently grew far faster than they could be eaten by the animals that feed on them. The results are the phytoplankton and algal blooms that often color the water and keep light from reaching the bottom.

Through both monitoring and experimentation, the impact of large phytoplankton blooms was discovered to include the depletion of oxygen in the deep waters of the Bay. Phytoplankton that is not successfully grazed by zooplankton, dies and sinks to the bottom. There it is decomposed by bacteria, which use up all the oxygen available in the surrounding water in the process. The result is hypoxia—very low oxygen levels—or anoxia—no oxygen, making the area unsuitable for other higher life forms such as fish, clams and worms. The end result is a “dead zone”, an area in which few if any organisms can survive. And this all starts with excess nutrients added to the system.

The answer to the question “what is causing the problem” is therefore also certain. Through direct observation and extensive experimentation, excess sediment and nutrients have been unequivocally identified as primary factors in the degradation of water quality conditions in the Bay and its tributaries.

How Do We Fix It?

The answer to this question would seem patently obvious. If the problem is excess sediments and nutrients, the solution is to reduce the loads. However, this leads to the questions of 1) how much nutrient loads must be reduced and 2) how to accomplish this.

The magnitude of required nutrient load reduction is estimated based on two primary types of information. The first is the many years of monitoring that have been undertaken to understand how the Bay responds to nutrient and sediment loads. The second type of information is the controlled experiments that have been undertaken in laboratories to investigate the response of individual organisms or small communities to different pollutant loads. These two lines of information are combined to predict the response of the Bay system to large scale changes in the loads coming from the watershed. Managers, scientists, and stakeholders identify the conditions we would prefer to have in the Bay and that is then matched to the nutrient and sediment loads that would allow those conditions to persist.

Clearly this is not a precise undertaking. The available evidence strongly supports the presumption that managing pollutant loads to the identified levels will result in restoration of the desired conditions. But at the bottom line, this is forecasting behavior of a very complex and organic system. Relatively constant behavior by the human components of the system is modified by variable weather conditions from year to year and the result is a fluctuating response in Bay conditions. Averaged over many years however, we are confident we can see the impact of management changes—reduced pollutant loads lead to improved ecosystem conditions.

So, we know generally how to fix the problem. There is a great deal of certainty that the system will respond positively to the management efforts. The uncertainty that remains in knowing how to fix the system arises from the fact that pollutant loads are not the only factor determining the condition and/or ecological regime for the Bay. Other factors, such as fishing pressure, are also important and must be managed effectively along with the efforts to restore water quality conditions. Still other factors, like climate change, will potentially affect our management efforts in a variety of ways that will only be determined through time.

How Do We Decide Who Does What?

The biggest challenge in restoring the Bay arises from the fact that there is such a large area in which activities generate impacts to the system. The 64,000 square mile watershed for the Bay covers areas that are relatively remote from the Bay shorelines. And yet it is the cumulative actions across this entire land surface that created the loads that have reduced Bay conditions. There is no single type of activity, nor any small portion of the watershed that can be modified sufficiently to restore the target conditions. Success requires targeting management efforts to the sources of the pollutant loads throughout the watershed.

The complication arises from knowing exactly where the loads are generated and how they are transmitted to the Bay. This is where the first bits of significant uncertainty begin to arise.

We think of load sources in the Bay system in two broad categories: point sources and nonpoint sources. Our knowledge about how much of the pollutant loads are derived from each of these sources is not perfect.

Point sources are discrete, easily identified discharges to the Bay system. They include things like municipal and industrial wastewater facilities, sewer overflows, confined animal feeding operations, and stormwater system discharges. Point sources are largely regulated, and the permits for these discharges typically require some monitoring of the delivered loads. As a result, point sources, at least those large enough to require permits, are well documented and there is relatively little uncertainty associated with their contribution to the total loads entering the Bay.

Nonpoint sources are basically everything else. Pollution that finds its way into the Bay system through runoff, seepage, precipitation, air deposition, shoreline erosion, or tidal influence are all considered to arise from nonpoint sources. Some of our information about the loads generated by nonpoint sources comes from monitoring and some comes from a mix of inductive and deductive reasoning, most of it facilitated by rather sophisticated models.

The process used to generate landuse load estimates for the entire Bay watershed allow us to have a high degree of confidence in the average performance of farms, developments, forests, and so on. The uncertainty that is inherent in these estimates only becomes important as the size of the area being evaluated shrinks. The smaller the watershed modeled with the general load estimates, the higher the uncertainty that the modeling is accurate.

The model used by the Bay Program is an enormously complex, state-of-the-art tool. It has been used to estimate nutrient and sediment loads generated in all parts of the Bay watershed, providing a rational basis for planning restoration efforts. But, it is just a model, and according to the oft repeated phrase generally attributed to George Box—“all models are wrong, some are useful.”

The Bay program model has been very useful. It has supported the analyses that established load reduction targets for the restoration effort. It is now being used to determine where reductions must occur and to assess the consequences of various management strategies. While the model has been carefully and purposefully developed to support these activities, everyone recognizes that these last tasks are at the limits of its abilities to provide spatial resolution of responses. It is not perfect because it was designed to simulate the performance of the entire system, not all the individual parts. As a consequence, it is not being treated as the definitive answer for design of restoration strategies. It is, however, being used to establish the ground rules for the current iteration of the restoration effort.

How Sure Are We It Will Work?

As noted in preceding sections, there are multiple sources of uncertainty in the effort to restore the Bay. All the activities that will be necessary to maintain and improve conditions in the system are not known, and to some degree cannot be known at this time. Things we do not fully understand at present, like climate change, will undoubtedly affect our ongoing efforts to manage the system. These factors will require adaptation as our knowledge increases. At present, however, we are confident that we have identified a primary factor degrading the system’s condition—water quality. We are quite certain about this, and we are certain about what needs to be done to manage that factor.

Changing long–standing land use practices to mitigate the deleterious effects they generate will not be easy. No one seriously proposes cessation of farming and no one expects a decrease in human populations in the watershed. So reducing pollutant loads requires incorporation of best management practices that allow uses to continue while directly addressing the potential negative consequences.

There are a lot of best management practices available for implementation. All of them have been demonstrated to have the capacity to reduce one or more of the pollutant loads necessary for the restoration effort. They vary widely, however, in their efficacy and capacity to generate long-term benefits. This is the predominant source of uncertainty in restoration planning.

Figure 2

Key questions and answers for restoration of the Chesapeake Bay.

1. What is the problem? Degraded habitat conditions
2. What is causing the problem? Too many nutrients and sediments
3. How do we fix it? Reduce pollutant loads
4. How do we decide who does what? Use the model
5. How sure are we that the effort will succeed? Certain the effects will be positive. Less certain about precisely achieving the goal
6. What are the options? Monitor and learn–adaptive implementation

What this means for the restoration effort is that we do not know exactly how many, or which, best management practices it will ultimately take to achieve the goal. For some, this is a dispiriting reality. The absence of certainty in the outcome is seen as an argument against committing the enormous resources necessary to undertake current plans. Two things are overlooked from this perspective. First, doing nothing will not improve the system, but rather permit further unchecked degradation. Increasing human populations simply increase the potential loads of nutrients and sediments to the system, and so merely maintaining the status quo requires ever increasing efforts at mitigation. Second, while knowledge of the precise end point for achieving restoration is elusive, every reduction in pollutant loads reduces stress on the system, and thus decreases the likelihood of an unwanted regime shift to an even less desirable state.

What are the options?

In the face of the uncertainties detailed above, the development of strategy is challenging, but not daunting. There are at least five possible options:

1. Do nothing
2. Implement the easy actions—voluntary actions and incentives
3. Change expectations—shift the end point towards current standards
4. Try the hard things—mandatory actions and retrofitting existing development
5. Commit to learn while doing—adaptive management

The first option has long ago been discarded as unacceptable.

The second option was effectively the strategy for the past three decades in Bay management. Voluntary efforts and incentive based strategies failed to achieve the goals of the Bay program partners. This was most distressingly clear in the case of water quality for the Bay. Having set the criteria for water quality necessary to support the designated uses of the Bay and its tributaries, the program partners were forced to admit those criteria could not be met and list the waters as impaired.

The third option, to change expectations, is technically still a possibility. However, conditions are currently undesirable, failing to support designated uses of the system. The Clean Water Act, which motivates the ongoing water quality improvement efforts, prohibits changes in designated uses before it is clearly demonstrated that the criteria for those uses cannot be attained. In other words, restoration must be seriously attempted and fail before a change can be considered.

So the Bay partnership finds itself working on option four–try the hard things. These include practices like comprehensive management of storm water, capping nutrient loads from all sources, and requiring limit-of-technology treatment of waste water. The strategies currently being developed and implemented are difficult and expensive, and they confront multiple sources of uncertainty. With few exceptions, the uncertainties are unavoidable and cannot be addressed without taking the actions planned and observing the outcomes.

The Bay program partnership and all the stakeholders in the system are left with a need to act at a large scale, while there is significant uncertainty regarding efficacy of all the possible activities.

A solution for the seeming conundrum is a more phased implementation that allows learning to occur. Sometimes referred to as adaptive implementation, this is a means of reducing the investment risk in restoration efforts, without backing off from the commitment. Instead of wholesale implementation of best management practices that may or may not prove economical, targeted implementation is undertaken, allowing discovery of efficacy and more strategic application of limited public resources.

The trade–off in acceptance of an adaptive implementation approach is lengthening of the restoration time line. Discovery of the most effective and economically efficient means of restoring the Bay will require some time. Implementation can be immediate for those actions that enjoy relatively high surety of effectiveness. But for other actions, admitting the knowledge base is limited and the risk for investment is high, could be the rationale for a more strategic approach to implementation.

Concluding Comments

The Bay program partnership has embarked on a difficult but essential task of reducing the stress on a highly valuable natural system. The certainty of success in restoring the system to a more desirable state is not absolute. The strategy being implemented is founded on extensive and well-vetted knowledge. But the sheer size and complexity of the system prevent precise, spatially explicit understanding of behavior and potential response to management efforts. This factor, combined with the imprecise knowledge of the efficacy of many of the practices that will be used to effect restoration, limits ability to forecast outcomes. Despite these limitations, there is little doubt about the type of actions that must be taken, nor the scope of those efforts. The challenge for program managers is how to minimize the impact of inherent uncertainty on the progress and achievements of the restoration effort. Adaptive implementation of the management practices with the greatest attendant uncertainty is suggested as a practical alternative to blanket, hopeful implementation.

For More Information

Bay TMDL development and implementation. Available online: http://www.epa.gov/chesapeakebaytmdl/

Chesapeake Bay Program. Available models online:http://www.chesapeakebay.net/modeling

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