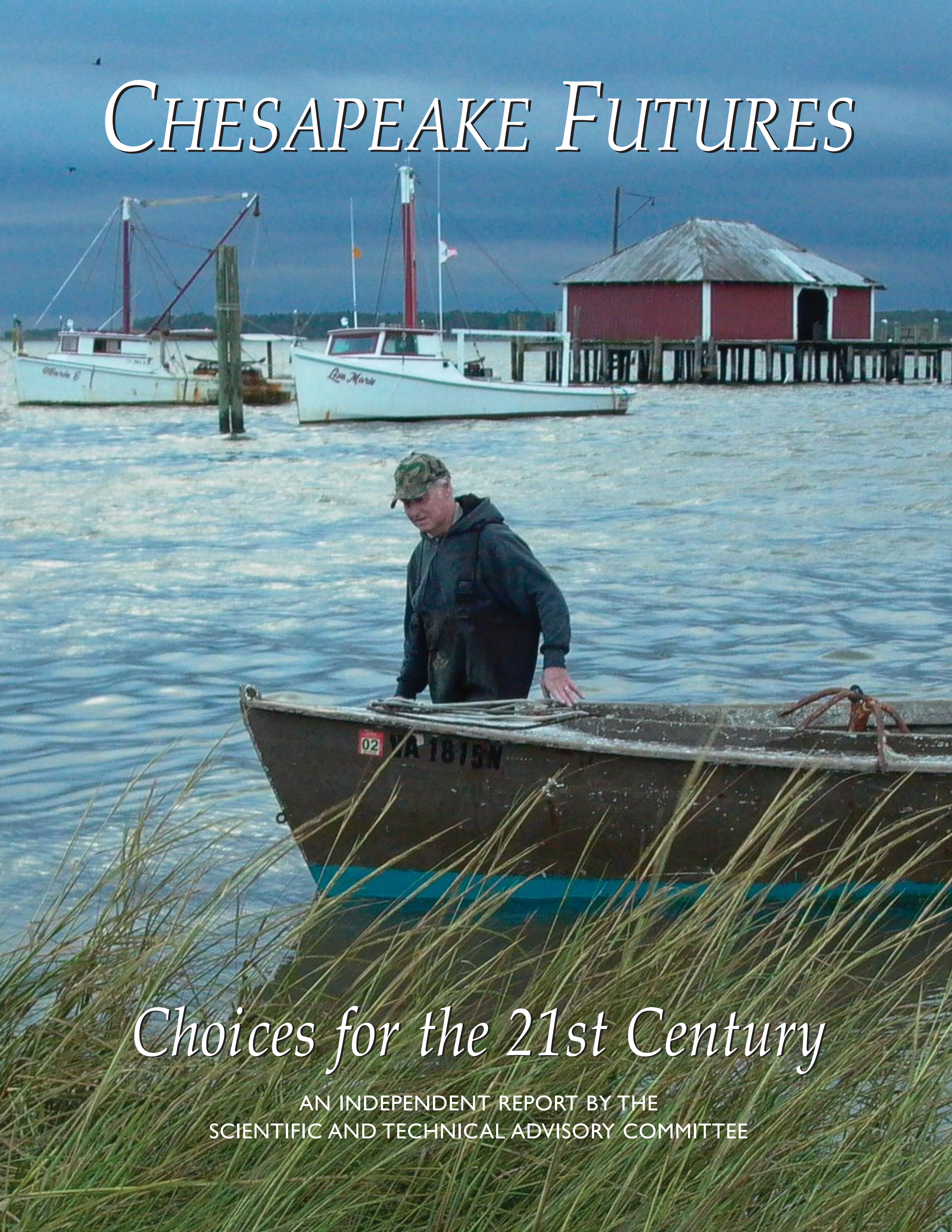
CHESAPEAKE FUTURES



Choices for the 21st Century

AN INDEPENDENT REPORT BY THE
SCIENTIFIC AND TECHNICAL ADVISORY COMMITTEE

CHESAPEAKE FUTURES
Choices for the 21st Century

edited by
Donald F. Boesch
and
Jack Greer

An Independent Report by the
Scientific and Technical Advisory Committee

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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 quarterly to the Implementation Committee and annually to the Executive Council.

STAC members come primarily from universities, research institutions, and federal agencies. Members are selected on the basis of their disciplines, perspectives, and information resources needed by the Chesapeake Bay Program.

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The production of Chesapeake Futures was very much a team effort. Donald Boesch and Jack Greer were the principal writer/editors for the report as a whole, but several workgroups, listed here, drafted and contributed the report's many sections. Time given by the workgroup members and other participants was entirely voluntary. STAC offers its appreciation to all who donated their time and effort to produce this ambitious report.

Key to the production of Chesapeake Futures was the extensive help of several assistants and contractors: Caryn Boscoe helped serve as coordinator of the Futures project; Catherine Schmitt filled many information gaps in the report; and Nina Fisher has been central in bringing the project to completion and preparing it for publication. Listed here are the individuals who made up the core group for the Chesapeake Futures project, including the Steering Committee and each Task Force group.

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Foreword

The Chesapeake Bay—heart of the Mid-Atlantic seaboard—faces enormous challenges in the coming decades. While the Bay has faced the onslaughts of waste dumping and heavy sediment loads in the past, a rapidly increasing population and an even more rapid rate of development have raised the stakes and presented us with many curcial choices. *Chesapeake Futures* outlines the likely consequences of some of the choices we are now making, and their implications for the future of the nation's largest and historically most productive estuary.

This report represents the work of many scientists and technical experts gathered under the auspices of the Chesapeake Bay Program's Scientific and Technical Advisory Committee. The projections and estimates emanate from several data and information sources and do not rely on any one methodological tool or approach. For example, although the Chesapeake Bay Program's Watershed Model was used to estimate past and current nutrient loadings, different assumptions and methods were applied for the projections in this study. Researchers drew upon their own knowledge and examined several models and assessments, including Mid-Atlantic climate models and other regional projections for agriculture, forestry, and land development.

The assumptions and conclusions in *Chesapeake Futures* capture the state of knowledge as viewed by the authors of the report, and do not represent the official position of the Chesapeake Bay Program, the U.S. Environmental Protection Agency, or any other private, state, or federal agency.

While *Chesapeake Futures* presents a series of likely outcomes, or "scenarios," based on current knowledge and projected trends, it does not propose direct policy recommendations. The authors offer this report as constructive advice from a wide-ranging team of technical experts in the hope that the information will assist policymakers, resource managers, and citizens alike as they weigh the choices confronting them in the coming decades. Clearly, every participant in *Chesapeake Futures* has an interest in the restoration and productivity of the Chesapeake Bay, as well as deep concern for the landscape that forms the Chesapeake's drainage basin. Many have spent much or even all of their careers studying issues central to the estuary and its watershed.

In the spirit of open discussion and debate, all of the participants in *Chesapeake Futures* welcome further questioning and analysis as we make our way through the 21st century. We also urge the continued use of environmental science and technology—combined with a strong sense of personal environmental stewardship—to guide our choices as we shape the future of the Chesapeake Bay in the face of constant and inevitable change.

Tim McCabe, USDA NRCS

Highlights

Chesapeake Futures, an effort undertaken by scientists and technical experts under the auspices of the Chesapeake Bay Program's Scientific and Technical Advisory Committee, developed three scenarios for the Bay and its watershed, timed to the year 2030. This exercise focuses on long-term possibilities and long-term choices. The three scenarios are for Recent Trends (essentially the status quo), Current Objectives (accounting for current baywide agreements and commitments),[1] and Feasible Alternatives (innovative technologies and aggressive approaches). While all projections and future outcomes presented in this report should be read in context, with an understanding of specific background and assumptions, the following highlights outline some of the key findings of this effort.

The Chesapeake Bay faces an uncertain future. If sediment and nutrient loads continue at levels witnessed at the end of the 20th century, multiplied by a growing population and new development, water quality will worsen. Water clarity and oxygen levels will slide back toward conditions not seen since the 1980s. Specifically, total loadings of nitrogen to the Bay would grow by about 30 million pounds—about 10 percent over current levels—by 2030 representing the loss of more than half of the load reductions achieved between 1985 and 2000. Total phosphorus loadings would grow by about 3 million pounds, nearly 15 percent, losing one-third of the load reductions achieved within this same time period.

Escalating nutrient and sediment loads would result not only from a population expected to reach about 19 million by the year 2030, but also from poor land use planning, with continued rapid loss of farm and forest lands, and only modest improvements in agricultural methods and wastewater treatment.

These additional loads would largely defeat current efforts to restore underwater grasses, cause further loss of oxygen in the Bay's bottom waters, and undermine efforts to restore oysters due to worsening water quality. Such would be the future, if the trends of the latter decades of the 20th century hold to the year 2030.

The Purpose of Futures

While resource managers, decision makers, and the rest of us would, of course, love to have clear predictions of the future, the world has rarely proceeded quite as planned. Given the difficulty of prediction, especially with a system as variable as the Chesapeake Bay, what can we expect from Chesapeake Futures?

Chesapeake Futures is not meant to be predictive; rather it sets out a series of three possible scenarios based on choices we make now. To create these scenarios, the experts used Bay computer models, past and current, but they also brought personal experiences, observations, and opinions into play. Consequently, some of the reasoning in the report will track well with the computer models, but some will diverge. The purpose of Chesapeake Futures, then, is not to refine the current attempts to model the Bay, but instead to use what we know—in the broadest sense—to guide both our thinking and our management efforts as we journey forward through the first three decades of the 21st century.

Current Efforts

The Bay will fare better if we can fulfill several current commitments, as expressed in ambitious Bay agreements, including *Chesapeake 2000*. Total nitrogen loadings from all sources would decline by 45 million pounds, or about 15 percent of recent levels, by the year 2030. With these achievements, nitrogen loadings would remain slightly lower than the 1987 40-percent goal for reducing "controllable" sources. By meeting current objectives, total loadings of phosphorus would decline by some 4 million pounds or 21 percent of 2000 levels. Reductions in nutrient loadings under this scenario would be even greater, if not for a growing population and predicted land use trends.

Given the success of several current Bay programs, underwater grass beds should roughly double in area with consequent improvements in bottom habitats. On the other hand, shoreline erosion would increase and significant areas of tidal wetlands would be lost; with this erosion comes associated increases in light-blocking sediments.

The Bay's primary productivity would decline somewhat, but higher production by bottom-dwelling algae would cause some alteration of food chains, resulting in modest improvements in habitats and production of important Bay fisheries.

A Brighter Future

With the implementation of numerous alternative strategies and emerging technologies, the future of the Bay looks considerably different. Under a feasible alternatives strategy, the total loadings of nitrogen from all sources would drop by some 143 million pounds, or 47 percent of recent loadings, by 2030. Total phosphorus loadings would drop by 10 million pounds, or 53 percent. Reductions in nutrient and sediment loads, due to highly progressive land development practices, and cutting-edge agricultural and waste treatment methods, would lead to improved water quality in the Bay. The air, too, would be cleaner, with the potential to reduce both mobile and stationary sources of nitrogen oxides by some 70 percent—leading to less atmospheric deposition of nitrogen in the Bay and its watershed.

These changes would ultimately lead to improvements in Bay water quality, with resulting improvements in its food web. Fisheries habitat would recover, especially in the Bay's bottom waters, with positive impacts on bottom-dwelling organisms. These improvements, along with progressive fisheries management, would help sustain fish and shellfish stocks, and bolster the Bay's economic productivity, as well as its ecological health.

Land Use and Development

If recent trends continue. . .

- The area of developed land in the watershed will increase by more than 60 percent by 2030, resulting in the loss of more than two million acres of forests and agricultural land.
- Impervious surface area will increase by more than 25 percent in many sub-watersheds, further degrading the quality of streams throughout the central part of the Chesapeake watershed.
- Nitrogen loads to the Bay due to land development and population growth will increase by about 35 million pounds per year—only slightly offset by a loss of inputs from agricultural lands, estimated at some 5 million pounds of nitrogen per year. Phosphorus loads coming specifically from developed lands would increase by about 1.8 million pounds per year.
- Air quality will deteriorate as vehicle miles driven grow faster than the population, outstripping improvements in auto emissions technology.

If current objectives are met. . .

- Despite policies to preserve open space, new development will cause the loss of about 800,000 acres of forests and agricultural land by 2030.
- The amount of impervious surface will increase significantly, only slightly less than under Recent Trends.
- Though nitrogen loads to the Bay will decrease overall, contributions due to land development and population growth will increase by over 18 million pounds per year (slightly more than half the increase under the Recent Trends scenario).

- Annual phosphorus loads from developed lands will increase by less than 0.7 million pounds.
- Riparian buffer restoration goals will be met or exceeded, resulting in significant improvements in local water quality.
- Modest improvements in air quality will be achieved with tightened auto emissions standards; vehicle miles driven will continue to grow, but at a reduced pace.

If feasible alternatives are put in place . . .

- Creative growth management and strategic land preservation efforts will reduce the development of resource lands in the watershed to about 350,000 acres—about 17 percent of Recent Trends.
- The amount of impervious surface will increase only slightly—a reduction from Recent Trends.
- While overall nitrogen loads to the Bay will decrease, inputs from new development and population growth will increase by about 8 million pounds per year, roughly one-quarter of those projected under the Recent Trends scenario.
- Strategically preserved and restored riparian buffers will further ameliorate nonpoint-source inputs of nutrients resulting from development.
- New and expanded public transportation networks will stabilize or reduce the use of automobiles. Improved emission control technologies, increased fuel efficiency and alternative technologies (e.g., fuel cells) adopted to reduce greenhouse gas emissions will result in significantly improved air quality.
- The use of feasible programs and technologies could reduce nitrogen loading rates from urban areas—both impervious and pervious surfaces—from an estimated 22 pounds per acre given recent trends to an estimated 19 pounds per acre.

Forests

If recent trends continue . . .

- Despite several decades of increasing forest cover driven by reforestation, the amount of forest cover will level off quickly and then decline.
- Further wide-scale loss of forests will continue in or near metropolitan areas.
- The fragmenting of forests will continue throughout the basin, with fragmentation most acute near metropolitan areas and the Coastal Plain and Piedmont provinces.
- A drop-off in agriculture-to-forest conversion is possible, especially in the Ridge and Valley and Appalachian Plateau provinces, with fewer farms to go out of production.
- Riparian forest buffer restoration will produce positive effects locally, but regional gains will remain small as limited progress towards restoration goals is largely offset by losses elsewhere.

If current objectives are met . . .

- A decline in total forest cover within the Coastal Plain and Piedmont will continue, particularly in metropolitan suburbs, with increasing forest cover in other parts of the basin. A net gain in total forest of the Chesapeake Bay basin should result.
- Modest and localized decreases in forest fragmentation will occur, due to better planning of development.
- Gains in riparian buffer mileage will lead to significantly improved local water quality, but only modest decreases in nutrient and sediment inputs to the Bay.
- Despite the positive effects of efforts to preserve resource lands, the links among patches of forest will remain spotty and forest function will improve only slightly beyond the Recent Trends scenario.

If feasible alternatives are put in place . . .

- Forest cover will increase much more significantly as forest cover in the Coastal Plain and Piedmont is stabilized.
- Riparian buffers will increase somewhat, and there will be a decrease in forest fragmentation.
- Highly active management of private forestland and non-consumptive management of public forests lead to increased quality and quantity of forests throughout the watershed.

- Better product development and marketing lead to strengthened economic infrastructure for forest products.
- More sophisticated social attitudes and technical knowledge will aid in the development of a rich forestland base, with local and regional nutrient management planning, and potential long-term management of environmental impacts in the watershed.

Agriculture

If recent trends continue . . .

- Sprawling residential and commercial development will result in the loss of almost 700,000 acres of agricultural land.
- With less farmland available to go out of production, agriculture-to-forest conversion could decline, particularly in the Ridge and Valley and Appalachian Plateau provinces.
- Demand for undeveloped land will raise prices, fragment existing farmland, and alter the character of rural areas.
- Small farmers will find it difficult to make a living from traditional farming as global market trends and other economic forces erode their profits.
- Existing farms will experience a greater dependence on intensive agriculture.
- Technology and globalization will have some positive effects on agriculture.

If current objectives are met . . .

- Land preservation efforts of the *Chesapeake 2000* agreement will preserve open space and guide development patterns; however, 400,000 acres of agricultural land will still be converted to urban and suburban uses.
- Even if farmlands are preserved, agricultural industries will face economic difficulties and a dwindling number of people may be willing to farm for a living.
- The implementation of soil and water conservation plans on croplands and hay fields will reduce nitrogen loadings by 9 percent and phosphorus loadings by 21 percent.
- Nutrient management plans will be successfully applied to half of the tilled cropland and hay fields in the watershed.

If feasible alternatives are put in place . . .

- Land preservation efforts, in combination with programs that target the economic sustainability of farming, will preserve open space and viable rural communities. Fewer than 300,000 acres of agricultural land will be lost to new development.
- Technological advances and policies will resolve animal waste problems, improve efficiency, and provide financial planning and business management aid to farmers.
- Various economic and environmental policies along with behavioral changes could further ensure the existence and success of agriculture in the watershed.

Chesapeake Bay and its Fisheries

If recent trends continue…

- In addition to continued contributions from agricultural and legacy sediment, additional sediment will enter the Bay from rapid land development, bypassing of the Susquehanna dams, and erosion of the shoreline due to accelerated sea level rise. Coupled with the stimulation of plankton growth from increased nutrient loading, water clarity in much of the Bay will decrease.
- Significant areas of tidal wetlands—their landward migration restricted—will be lost to sea level rise.
- As average nitrogen loadings creep back toward 1985 levels due to population growth and development, excessive phytoplankton production will continue. Anoxia and severe hypoxia will be an annual occurrence, worse in high-discharge years.
- Loadings of toxic contaminants will decline slowly, but seafood consumption advisories will continue due to a legacy of contaminants.
- Submerged aquatic vegetation will contract, except in those tributaries remote from increased sources of sediment and nutrients.

If current objectives are met . . .

- More limited land development, improved stormwater management and riparian buffer restoration will hold the line for sediment inputs from the watershed, but sediments mobilized from shoreline erosion will increase.
- Water clarity in some regions of the Bay and its tidal tributaries will increase due to decreased nutrient loadings, but not in areas near rapidly eroding shorelines.
- Significant areas of tidal wetlands will ultimately succumb to sea level rise and restrictions to their landward migration.
- Average nitrogen loadings will decline, eventually resulting in demonstrable reductions of excessive phytoplankton growth and severe hypoxia, equivalent to levels of the mid-1970s. Except in the driest years, some anoxia will still occur.
- Loadings of contaminants will decline a bit more rapidly than under Recent Trends, but impairments due to legacy contamination will continue.
- Submerged aquatic vegetation will expand in selected tributaries, approximately doubling in extent through the Bay.
- Benthic microalgae will play a greater role in the Bay's biological productivity, while bacteria and small phytoplankton will contribute less. Production of fish relying on these bottom resources will increase as food chain efficiency increases and preferred habitats expand.
- The biological diversity and resiliency of the Bay ecosystem will increase, buffering the Bay from extreme events and reducing the frequency and severity of algal blooms.
- The socioeconomic value of the Bay's fisheries will increase modestly as the productive capacity of the Bay ecosystem increases and harvests are managed more sustainably.

If feasible alternatives are put in place…

Well-managed growth and development, substantial retrofitting of stormwater infrastructure, and removal of sediment behind Susquehanna dams will result in real reductions in sediment loads from rivers. Adaptive shoreline management strategies will help sustain tidal wetlands.

- Water clarity in most regions of the Bay will increase substantially due to decreased nutrient loadings.
- The total acreage of tidal wetlands will be maintained close to present levels by preventing barriers to their landward migration and through active management to enhance soil accretion in deteriorating marshes.
- Average nitrogen loadings will decline to nearly one-half of those experienced toward the end of the 20th century, approaching levels not seen since the 1950s. This decline will result in approximately proportional reductions in plankton productivity and substantial reductions in the extent of hypoxia, again back to levels typical of the 1950s. Significant anoxia will occur only during flood years.
- Practical applications of a zero-discharge ethic in industry, government, and society in general will lead to dramatically reduced loadings of many contaminants. Nevertheless, localized toxic effects will occur despite our best efforts to manage inputs of legacy contaminants and contaminated sediments, as well as our continuing reliance on herbicides in agriculture.
- Submerged aquatic vegetation beds will expand in extent some four- or five-fold.
- Primary production will decrease by one-third, but production of many fish and crabs will actually increase due to greater food efficiency.
- The Bay's useful production, diversity, and resilience will improve even more, approximating conditions characteristic of the 1950s.
- The living resources of the Chesapeake will provide more sustained and profitable benefits to society from the improved health of the Bay.

Endnotes

[1]Current Objectives include many of the concrete objectives in a series of Bay agreements, including *Chesapeake 2000*. This scenario is not, however, identical to those agreements, since much of their language is essentially goal oriented (such as "a toxics-free Bay") and not easily quantifiable for use in this exercise.

Imagining the Chesapeake

The kind of Bay our children inherit will depend on the choices we make at the dawn of this new century. Already, the projections are sobering. Over 300 people move into the Chesapeake watershed every day, with a projected population of some 19 million by the year 2030. More people will spread out from Norfolk, from Richmond, from Baltimore, from Harrisburg and Philadelphia.

The choices of the 20th century have proven complicated. Many citizens of the Bay region enjoy a standard of living unimagined by their forebears—a life filled with automobiles, refrigerators, CD players, and arguably, the best health care in the world. And yet progress has been uneven and has come at a price. Maryland, for example, has one of the highest cancer rates in the country. The Washington Metropolitan region consistently exceeds ozone standards many times each summer. Watermen throughout the region often seek alternative work, unable to make ends meet by working the Bay. Restaurants and picking houses that once relied on the Bay's blue crab now look elsewhere to meet the demands of a growing population.

The kind of Bay our children inherit will depend on the choices we make at the dawn of this new century. Already the projections are sobering.

Although, in the words of the ancient Greek historian Heraclitus, "nothing endures but change," changes now persist at an unsustainable pace—and many of the significant changes in the Chesapeake have resulted from human behaviors and human choices. As we ponder the Bay's future, we must necessarily examine the courses we might follow in the approaching years. What choices do we face for the coming decades? What implications do these choices have for the future Bay?

This report lays out three scenarios for possible Chesapeake futures. The first scenario assumes that we maintain, more-or-less, the status quo, and that current trends prevail. The second scenario assumes that we work hard to meet the objectives already set for ourselves, such as the cap of nutrient inputs to the Bay and the restoration of abundant underwater grasses and oyster bars. The third scenario explores the potential of feasible technologies and management strategies—and considerable political will—to envision what sorts of positive changes are within our reach.

Each scenario carries a promise and a price. In some cases, the cost hits our collective pocketbook. In

Tim McCabe, USDA NRCS

other cases, the cost diminishes the Bay's ecosystem—its spawning grounds, oyster rocks, or underwater grass beds. On land, the choices that underlie each scenario affect not only the amounts of runoff that reach the Bay's rivers and streams, but also the kinds of communities we will live in, the connections we will maintain—or lose—with the natural world around us, the quality of life we will enjoy, and perhaps even the attitudes and the values to which we will hold.

Courtesy of VDOT

Upon completion, this interchange, where routes 95, I-395, and I-495 join in Springfield, Virginia, will look like this enhanced photograph.

The State of the Bay

Our sense of the present shapes our perceptions of the future. While *Chesapeake Futures* focuses on the first three decades of the 21st century, a brief summary of our starting point, roughly timed to the year 2000,[1] provides a foundation on which to base likely scenarios. More explicit discussions for each topic area—development, agriculture, forest management, technological change, and the Bay itself—appear in chapters 5 to 9.

Since the Bay is admittedly in constant flux, any snapshot has its limitations. In the broadest terms, however, we can make the following observations about the Bay and its watershed as a whole at the time of this writing, our "present":

- Population continues to grow in the region, with an average of 334 new people moving into the Chesapeake watershed each day.[2]
- Between 1990 and 2000, the rate of land conversion in the watershed more than doubled over the previous decade. Development in many areas of the watershed, especially within commuting distance of large urban centers, is converting large tracts of farm and forest to residential subdivisions and shopping centers, with adverse effects on water quality.
- The Bay continues to receive large amounts of nutrients, especially nitrogen and phosphorus. These nutrient loads come from many sources, including agricultural lands, point sources (such as waste treatment plants), urban areas, and the atmosphere.
- The Bay also receives large quantities of sediment from agricultural lands, eroding shorelines, and urban/suburban areas.
- Hypoxic waters continue to plague portions of the Bay despite efforts to control the overabundance of nutrients that fuels oxygen consumption. In fact, these low-oxygen areas have apparently continued to expand over the past several decades.[3]
- Forests across the watershed as a whole have rebounded from their historical low in about 1900, but forests in key areas close to the Bay and its rivers have become increasingly fragmented.
- Only about 35 percent of the Bay's agricultural lands are currently under nutrient management for water quality protection.[4]
- Riparian buffer restoration efforts continue on a local level, but have encountered some resistance on agricultural property and other privately owned lands.
- Many waste treatment plants still do not use advanced nutrient removal technologies. The Chesapeake Bay Program predicts, however, that by 2005 almost 131 major municipal wastewater

treatment facilities will have biological nutrient removal treating about 63 percent of the wastewater flow in the region.[5]

- Crab stocks continue below the long-term average, according to independent surveys, including the baywide winter dredge survey.
- Oyster harvests continue at historically low levels and oyster populations cover only a fraction of their original range, despite the launching of new oyster reef restoration efforts.
- Striped bass numbers have rebounded since the five-year fishing moratorium ended in the late 1980s, although concerns have emerged about mycobacteriosis and other diseases along with the adequacy of forage species to support the larger population.
- Scientists and managers are analyzing and outlining new multi-species approaches to fisheries management, though current management techniques are primarily species-specific and often reactive rather than proactive, with little power-sharing among stakeholders.
- Recent fish consumption advisories have pointed to the continued presence of toxic contaminants in the Bay, although the advisories themselves have evolved based on changes in federally mandated thresholds for contaminants in food.

Can We Imagine?

Can we fast forward our minds to imagine the Chesapeake Bay and the vast area that surrounds it in the year 2030?

Do we envision a Bay with dwindling underwater grasses, a Bay with few crabs and fewer oysters?

Do we picture bayside restaurants on the shores of the Patuxent, the Potomac, the Choptank, or the James, where the menu offers seafood mostly from North Carolina, or Louisiana, or Asia?

Can we imagine what changes—both large and small—will come to pass in the Chesapeake watershed?

Will we see a landscape devoid of family farms—a landscape that in some areas stretches toward the horizon in an unbroken maze of subdivisions and shopping centers?

Can we imagine that by the year 2030, highways in the Baltimore-Washington corridor will likely carry an unprecedented number of cars and trucks?

When we peer into the future, do we picture a watershed where runoff from highways, homes, storm drains, and parking lots continues to flush toxic sediments into the waters of the Chesapeake Bay?

Or will our commitment to restore the Chesapeake, combined with ongoing technological advancements, allow us to imagine a different landscape, a different Bay?

Can we envision a landscape in which small towns dot the countryside, separated by forests and fields—a landscape where sustainable farming practices still make sense, ecologically, and economically?

Can we picture streams and rivers lined with native trees and plants carrying waters that run clean from upland woods and hamlets to the Bay?

Can we imagine a Bay where underwater grasses sway in filtered sunlight ten feet beneath the surface and host an a healthy diversity of Bay life?

And, can we imagine large but sustainable harvests of crabs, and fish, and oysters pulled from those clear waters?

Given the enormous demands on our energies and our financial resources, along with conflicting political agendas and differing visions for the future, can we imagine in the end a Chesapeake Bay that will sustain a variety and an abundance of life as we move into and through the 21st century? Can the Bay be returned, at least in part, to what it once was not so very long ago?

A Vision for the Bay

What Bay country will look like in the future depends on more than mathematical calculations. We must think about what wise stewardship will mean for the future. What do we want Bay country to be?

Stewardship: not taking more than our share. Clearly the Chesapeake of the future will be an impoverished place if we take from it more than nature can replace. This means that fisheries—both commercial and recreational—will need to be mindful of limits, of taking care. It means that boaters and others who use the Bay must be more aware of the impacts caused by their use of the estuary, more careful of their wakes, their exhaust, their noise, their speed, and their discharge of waste or chemical contaminants.

Sense of scale: the right things in the right place. When a giant discount store moves into a small community, it brings cheaper prices. But it can also drive out local businesses and change the community's character. We will need to be sensitive to an appropriate sense of scale. Wide roads, wide sidewalks, towering streetlights, huge stores—while these have become the hallmarks of many beltway communities, they are not necessarily appropriate for the small towns and villages that dot the Chesapeake watershed.

Sense of place: buildings and communities that belong. As Bay Country grows and changes, will we be able to preserve the features that define this region as a very special place? Will we remember enough of our heritage to protect the styles of architecture, the boat designs, the rural character of our Bayside towns? Will we be able to avoid the homogenization of the American landscape and maintain a real sense of place without succumbing to a superficial gentrification?

Matching form and function: making the useful beautiful. As we build retention ponds and plant riparian buffers, can we make them pleasing to the eye and inviting as habitat for birds and other species? Must retention ponds be ringed by chainlink fence? Must urban watercourses all be concrete? Can bridges, overpasses, retention walls, culverts, and streetlights be more attractive and integrated into the landscape? Must the future be one of billboards, utility poles, glaring streetlights, hard curbs, and gutters? As we slow the flow of polluted runoff, can we encourage grass swales and rain gardens that will add to our sense of nature and place?

Cultivating a new ethic: the enlightened citizen. Key laws, such as the Critical Area Act or the Chesapeake Bay Preservation Act, have helped control destructive development practices at the water's edge. But legislation cannot and should not guide all our behaviors and decisions. How can we instill a new ethic, so that the future Chesapeake retains the beauty and productivity that have made it famous? How can we teach our children to treasure the landscape, that their behavior ultimately determines the health of the Bay?

The "Recent Trends" scenario detailed throughout the report is based on these and other current conditions. Projections for this scenario are tied to the assumption that these recent trends will continue into the future, without additional progress in restoring the Bay ecosystem.

The "Current Objectives" scenario, on the other hand, is based on commitments by Bay-area jurisdictions in a series of Bay agreements, beginning with the first and very general agreement of 1983, to the more specific benchmarks set in 1987, to the ambitious *Chesapeake 2000* agreement. Virginia, Maryland and Pennsylvania, the District of Columbia, the Chesapeake Bay Commission and the U.S. Environmental Protection Agency, representing the federal government, are the signatories of these agreements. This report is not intended to critique these commitments; rather, it presents likely outcomes based on the best extrapolations at hand if the quantifiable objectives embedded in the commitments are met largely as stated.

Naturally, the Chesapeake Bay Program, which carries primary responsibility for fulfilling these commitments, has its own measures and metrics for success. Most notable among these are an extensive monitoring effort and intensive use of computer models. While cognizant of the watershed model, *Chesapeake Futures* incorporated a range of data and experience and did not rely solely on any one metric or model.[6]

Current objectives, as stated in the *Chesapeake 2000* agreement, are commendable, but with continued population growth and a range of problems confronting the Bay, the question arises of what the estuary and its watershed will look like in the future. What kind of water quality can we expect if we meet current commitments? Or if we do not? What if we adapt, during the next several decades, new technologies and approaches for the restoration of the Bay leading to a series of "Feasible Alternatives"? These fundamental questions have led to an effort which details three "what if" scenarios—aimed at the year 2030.

The Chesapeake Futures Project: What We Did and Why We Did It

Faced with questions about destructive land use patterns and the decline of water quality in the Chesapeake Bay, the Chesapeake Bay Program and its Scientific and Technical Advisory Committee (STAC) began to ask hard questions about the future. What information did we have that would guide better decision-making? What consequences could we expect if we did not act? The effort to answer these questions, dubbed *Chesapeake Futures*, provides a factual overview, from our turn-of-the-century vantage point, for those with an interest in the future and well-being of the Bay and its watershed. This multi-year effort has incorporated much work and research that have also found outlets in other reports and information documents, including the *Chesapeake 2000* agreement.

Chesapeake Futures is not intended as an advocacy document, nor is it meant to bolster a particular program or political position. Rather, it sets out three possible scenarios, based on the observations, analyses, experiences, and reasoned extrapolations of a wide-ranging team of experts from throughout the Bay region and beyond. These experts come primarily from the academic laboratories and departments of research universities in the Mid-Atlantic, but also from state agencies, privately funded research labs, and other experienced consultants and technical experts.

Sandy Rodgers, MD Sea Grant

Many of these experts have brought experience and knowledge from other regions of the country. Many share years of experience living and working on the shores of the Chesapeake Bay. All of them generously volunteered their time to help assemble this report.

This report focuses on three major areas: changes in the land, technologies, and the Chesapeake estuary itself. We have arranged the report as a progression, starting with the caveats and pitfalls plaguing predictions of the future, moving on to the Bay's history, continuing with its current condition given the framework of worldwide climatic change and sea level rise, and then taking steps into its possible futures. Naturally, even armed with a good understanding of the Chesapeake's past, the most current knowledge of its dynamics and present condition, and high-quality data on which to extrapolate, the Chesapeake's future still hinges on some unknowable factors. Given these limitations, we cover an array of possibilities ranging from projections based on recent trends to optimal yet feasible management options.


Tim McCabe. USDA NRCS

Operational farm on the outskirts of Richmond, Virginia. Cities and suburbs are encroaching on such farms throughout the Chesapeake Bay watershed, and many have succumbed to development pressure.

With the pace of technological and social change appearing to quicken with each passing year, predicting the region's character in 30 years seems a daunting exercise. We can, however, make reasonable trend projections in areas such as population growth, development methods, and agricultural practices to get a sense of the future's possibilities. Chapter 2, Risky Business, discusses the practices and pitfalls of predicting the future while suggesting the ways in which current information and data are useful for outlining three Chesapeake futures based on the choices we, as a society, ultimately make.

Applying the premise that the past holds the key to the future, Chesapeake Pasts takes a brief look back at the natural dynamics and cultural history that shaped the region. Understanding where we have come from should help us appreciate where we are going. The natural fluctuations that once dictated the structure of the Bay have given way, to a large degree, to the numerous and increasingly widespread anthropogenic factors that now play such a major role in every aspect of Bay dynamics. The chapter concludes with a comparison of the Chesapeakes of the past with the one of the present.

Changing Times paints a broad-brush picture of the ever-shifting Bay, its watershed, and its growing population. The backdrop upon which we paint the Bay and its three possible futures is, itself, ever-changing. Climate varies on many temporal and spatial scales—some of which affect the Bay directly while others have minor or indirect consequences. Sea level is rising in many places around the globe, including the Chesapeake. The effect of consistently rising sea levels is manifested through the erosion of shoreline, the disappearance of islands, greater landward incursion of stormwaters, and the influx of higher sediment loads. Other, less obvious effects, are also taking place. Finally, the chapter introduces the concept of population and its ultimate impact on the state of the Bay.

Development and Sprawl delves into the consequences of centuries of development along the Bay and within its watershed. Clearly, the way we continue to develop the land will have enormous consequences for both the health of the Bay watershed and the quality of life that Bay-area residents will enjoy, or alternatively, suffer through. In addition to development patterns that influence how we assemble our homes, businesses, and industries, large-scale uses of the land—such as forests and agriculture—determine exactly what the watershed looks like on a vast scale. After all, agriculture alone accounted for close to a third of land use in the watershed in 1990 in terms of actual area, and forestry accounted for 59 percent—a total of 92 percent of the watershed's 41 million acres of land. This pattern has, of course, been shifting with burgeoning development and the breakup of large parcels of farm and forest.

Chapter 6, Forests in Transition, deals with why forests make a difference, their environmental impact, and their economic benefits. Forests are the dominant land use in the Bay watershed, followed by agriculture and other open land. Yet, in many areas forests are disappearing at an alarming rate. In a watershed where more forest cover means better water quality, changes in forest cover are crucial.

Adapting Agriculture examines the current status of Chesapeake agriculture. As markets for both forest products and agricultural products become increasingly global, forces far beyond the boundaries of the Bay watershed are often setting cost and price structures. Without sound economics and financial incentives, forests and agriculture as we know them cannot continue to exist. Changes in these sectors will have significant consequences for land use in the Bay region.

New technologies carry not only the promise of solving specific problems but also of reshaping how we approach the future. Technological Solutions details some of the possibilities and feasible alternatives to current tools and methods. Clearly, it would have been difficult to predict in 1970 just how important computers would become in our daily lives only 30 years later. What new technical tools will we rely upon in the year 2030 and how might they influence the environmental character of the Bay?

The streams and rivers that feed the Chesapeake Bay—and the Bay itself—will reflect the way we use these new technological tools and the way we choose to live on and use the land. To picture the physical Chesapeake of the future, we must first understand its shifting hydrodynamics from both natural and anthropogenic changes. Likewise, researchers and others pondered potential changes in the Bay's chemical characteristics driven by physical and climatic factors but also by human behaviors in the watershed. On the receiving end of all of the changes in the land and shifts in development, agriculture, and forestry, lies the Bay itself and its remarkable food web. Integrating all this information, Chapter 9, Once and Future Bay, deals with future estuarine conditions by examining the array of components that make the Bay what it is: its physical characteristics, toxic contamination, trophic status, and finally the life in the Bay itself.

In each of chapters 6, 7, 8, and 9, we lay out the scenarios for each of the major topical areas for the three Chesapeake futures: Recent Trends; Current Objectives; and Feasible Alternatives. Necessarily, discussions in each of these chapters overlap or closely relate to those in the other chapters as all


Skip Brown

the individual fibers that make up the Chesapeake closely intertwine.

Chapter 10 closes the report with the choices that face us—choices that are far more than rhetorical. By summarizing the choices that the scenarios offer, readers can assess where and how financial resources and social programs should be focused—and the likely success of our efforts. Limited achievements to date underscore the possibilities of and the need for using a range of innovative and creative techniques to reach the fundamental goal of restoring the Bay's clarity and productivity.

As one researcher said, "The estuary bats last." Whatever impacts we have on the landscape and the many streams and rivers draining it will likely show up in the organisms that live in the Chesapeake Bay. The oysters, crabs, finfish, and other denizens of the Bay will send us signals about how the ecosystem itself is faring—the ecosystem on which all life, including *Homo sapiens*, depends. The haunting question is whether or not we are able to read the signs, and if we can, whether or not we have the wisdom and the will to act.

Endnotes

[1] For a summary of what is perceived to be the current condition of the Chesapeake Bay, see the Chesapeake Bay Program's State of the Bay report for any given year, available on the web at *www.chesapeakebay.net*. The Chesapeake Bay Foundation also offers an annual report card on the Bay at *www.savethebay.org*. Of course the Bay is a very complex system, and any simple characterization cannot capture either all available data or all the subtle nuances of an estuary in constant flux.

[2] Chesapeake Bay Program. 1997. *Beyond Sprawl: Land Management Techniques to Protect the Chesapeake Bay: A Handbook for Local Governments*. Annapolis, MD.

[3] Cf. Hagy, J.D. 2002. *Eutrophication, Hypoxia, and Trophic Transfer Efficiency in Chesapeake Bay*. Ph.D. Thesis, University of Maryland, College Park, MD. 446 pp. See also D.E. Smith, M. Leffler, and G. Mackiernan, (eds.). 1992. *Oxygen Dynamics in the Chesapeake Bay*. College Park, MD: Maryland Sea Grant, 234 pp.

[4] Chesapeake Bay Commission. 2001. *Annual Report 2001*. Annapolis, MD: Chesapeake Bay Commission, 31 pp.

[5] Delaware, New York, and West Virginia have signed memoranda of understandings and the Chesapeake Bay Program now includes these states (in addition to data from facilities in Maryland, Pennsylvania, Virginia, and Washington, D.C.) in its calculations.

[6] Chapter 9 contains comparisons of *Chesapeake Futures* scenarios with projections from the Phase 4.3 Chesapeake Bay Program model for tiers 1, 2, and 3.

Risky Business

Mary Hollinger, NOAA

Looking three decades down the road is indeed a risky business. Not only are our technical capabilities changing rapidly, but so are our policies, our plans, and our political and personal choices. The degree to which protecting the Chesapeake Bay will figure as a central issue in the year 2030 remains unknown, as do so many other factors.

Clearly, as the 20th century closed and the 21st century began, the Chesapeake Bay had become the focus of a rallying call for concern about a range of environmental issues and the impetus for many new and innovative programs to protect and restore the watershed. While initial efforts generally focused on direct inputs to the Bay and its rivers, including more rigorous enforcement of effluent controls under the federal Clean Water Act,[1] the emphasis has shifted over time to include general sources of nutrients and contaminants. Lying behind these inputs remains the difficult-to-address fact of ever-increasing population in the region.

Population numbers in the Bay watershed climbed from about 5 million in 1900 to approximately 8 million in 1950 and over 15 million in 2000. Based on projections, planners expect this number to rise to nearly 19 million by 2030 (Figure 2-1). The greatest concern, as will become clear in this report, is the manner in which the growing population will use the region's resources and impact its ecological systems—especially the Chesapeake Bay. Unquestionably, the issue of just how many people can live in the watershed without straining its carrying capacity will continue to challenge the best thinking of demographers, ecologists, and policymakers. In this report, the focus falls on likely scenarios of environmental impact based on current population projections. Some would suggest that we will actually have to limit the size of the population, but we leave that for another analysis—we merely address the implications of its growth.

If there is any ecosystem for which researchers and managers do have the opportunity to determine the balance between human impacts and ecological function, it may well be the Chesapeake Bay. Thanks to considerable support and effort, especially since the 1976 study of the Chesapeake launched by the EPA and the resultant multi-state and federal partnership known as the Chesapeake Bay Program (CBP) in 1983, scientists have accumulated large amounts of hard data. These data—physical, chemical, biological, and sociological—have driven models designed and constructed by both state planners and the Chesapeake Bay Program. The scientific and technical experts involved in the *Chesapeake Futures* project have taken advantage of these models in writing this report, although they have also drawn

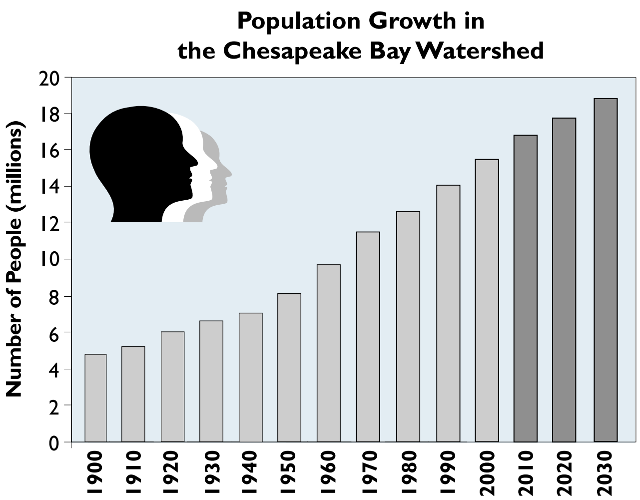


Figure 2-1. Since the beginning of the last century, population levels have shown a steady increase in the Bay watershed. Experts predict that numbers will continue to rise through the next three decades.

on other information, including the results of their own data gathering and research. Of particular use were the Bay Program models and data generated by the 2000 census. The population projections used in the U.S. National Assessment of the Consequences of Climate Variability and Change and its Mid-Atlantic Regional Assessment also proved quite useful.

Lying behind the *Chesapeake Futures* effort are other future-oriented reports, such as the study of growth and development known as the 2020 report.[2] That report, written in 1988 and also looking ahead approximately 30 years, depicts a series of visions prescribing an outline for how the Bay watershed *should* look by the time we reach the second decade of the 21st century. *Chesapeake Futures*, while mindful of such observations, is less prescriptive. Rather than a prediction of—or template for—a desirable future, *Chesapeake Futures* examines the evidence at hand and, using all the information and data now available, extrapolates to three different scenarios that describe three possible futures.

The *Futures* approach resembles very closely that of Allen Hammond in his study, *Which World?*, in which he offers three possible futures: Market World, Fortress World, and Transformed World.[3] In Hammond's first scenario, market forces largely run unchecked, creating considerable wealth for some, but abject poverty for others. This scenario presents not the worst of worlds, but far from the best. Of considerable concern is that widening divisions between the very wealthy and the very poor, the haves and have-nots, could well lead to the second scenario, he argues, in which wealthy nations and enclaves become like fortresses, walling out those less fortunate. This second scenario results in several frightening images of a world wracked by the worst kind of social tension, inequities, and violence. Hammond's third scenario, a transformed world, pictures a future in which progressive and intelligent policies have taken advantage of the positive aspects of market-driven economies but avoided the pitfalls of increasing concentrations of wealth. Clearly, this last scenario appears most desirable in Hammond's view, but by laying out all three scenarios he gives the reader an opportunity to consider alternatives all along the way. As Hammond points out, "Scenarios are not predictions or forecasts. Rather they suggest how the world might turn out."[4]

The Purview of Chesapeake Futures

Drawing on the data at hand, *Chesapeake Futures* presents three possible alternatives for the future. Unlike Hammond's *Which World?*, which focuses largely on economic and social issues, *Chesapeake Futures* has ecological concerns as its main focus—specifically the ecological functioning of the Chesapeake Bay and its watershed. Of course, economic, demographic, and other forces can and will impact environmental outcomes; therefore, such factors surface in several sections, including those dealing with development patterns, agriculture, and forestry. After four context-setting introductory chapters, including this one, each of chapters 5 through 9 provides a descriptive background of conditions and trends and offers three likely scenarios:

- ***Recent Trends*** - based on an extrapolation of the status quo.
- ***Current Objectives*** - based on fulfillment of current quantitative objectives.
- ***Feasible Alternatives*** - based on implementing programs to the reasonable limits of technology and political will.

Each chapter defines likely outcomes for each possible future in that particular area, such as growth and development, agriculture, forestry, and new technologies. Because each area impacts the others, the report has built-in redundancies. For example, a discussion of development patterns will include mention of the impact on forested lands; likewise, a discussion of forestry practices will include mention of changing land use patterns, including development. In some sense, all of these areas merge in the important penultimate chapter on future estuarine conditions (Once and Future Bay). Here a combination of driving forces—land use, agricultural patterns and practices, forest fragmentation, and the use of emerging technologies, as well as climatic and geological factors—all blend to shape the future of the Chesapeake Bay itself.

In composing the scenarios that describe the possible Chesapeakes of the future, we worked within the current guiding principles that shape our thinking about how the Bay works and responds to change. In all science, but particularly in speculative science, theoretical constructs are founded within what T.S. Kuhn coined "a paradigm," which is, in essence, a model of reality. More precisely, a paradigm is "a system of facts, theories, and philosophies that is widely accepted and becomes the framework for thinking about a scientific problem."[5] Paradigms shape the way we perceive reality and approach scientific challenges. In the Chesapeake and elsewhere, we make assumptions—both stated and unstated—based on the paradigms that ultimately mold our approach to environmental management.

Assumptions set boundaries on the problem at hand by circumscribing an area of consideration, so that a problem can be dealt with in a

Recent Trends

- Agricultural and Rural Zoning: *Generally permissive*
- Growth Centers: *Generally poorly supported*
- Transferable Development Rights (TDRs): *Negligible*
- Environmental & Resource Conservation Requirements: *Variable*
- Permitting Conventional Septic Systems: *Generally permissive*
- Easement Acquisition Programs (EAPs): *Generally ineffective*
- Infill/Redevelopment: *Negligible*
- Point- and Nonpoint-Source Controls: *As in 2000 progress run, Chesapeake Bay Watershed Model*
- Transportation: *Reactive, primarily to existing or anticipated traffic congestion*

Current Objectives

- Agricultural and Rural Zoning: *Moderately restrictive*
- Growth Centers: *Moderately supported*
- Transferable Development Rights (TDRs): *Marginal*
- Environmental & Resource Conservation Requirements: *Moderately progressive*
- Permitting Conventional Septic Systems: *Generally permissive*
- Easement Acquisition Programs (EAPs): *Moderately effective*
- Infill/Redevelopment: *Significant*
- Point- and Nonpoint-Source Controls: *As in continuing existing policies (Tier 1) run, Chesapeake Bay Watershed Model*
- Transportation: *Reactive, to both congestion and demand for mass transit*

Feasible Alternatives

- Agricultural and Rural Zoning: *Restrictive*
- Growth Centers: *Well-supported*
- Transferable Development Rights (TDRs): *Effective*
- Environmental & Resource Conservation Requirements: *Progressive*
- Permitting Conventional Septic Systems: *Restrictive*
- Easement Acquisition Programs (EAPs): *Significant*
- Infill/Redevelopment: *Significant*
- Point- and Nonpoint-Source Controls: *As in full implemenation of nutrient control efforts (Tier 3) run, Chesapeake Bay Watershed Model*
- Transportation: *Proactive, focused on enhancing communities and cities*

Table 2-1. General assumptions for land use scenarios. Explanations of tools and approaches listed here appear in Chapter 5.

scientifically rigorous manner given expected constraints. Such assumptions are necessary and even inevitable, but problems may arise when they are either unacknowledged or not recognized. Key in this process is being aware of, and then stating, the assumptions up front. In most sections, assumptions are discussed as part of each scenario. For example, Table 2-1 summarizes key assumptions used to develop scenarios for land use trends in the watershed.

The assumptions represent the spectrum of development patterns in the Bay basin, accomplished by measuring development in sample jurisdictions throughout the watershed during the last decade, and compiling descriptions of the land use, zoning, subdivision, and development plans and procedures under which they occurred. The assumptions for Recent Trends reflect the practices and associated patterns currently prevailing through most of the watershed. This scenario projects what would happen if these same techniques and practices were occurring everywhere. More progressive practices and development patterns currently employed by some jursidictions are reflected in the Current Objectives and Feasible Alternatives scenarios. The Current Objectives scenario projects the results if moderately progressive techniques used in some jurisdictions were used throughout the watershed. Similarly, Feasible Alternatives extrapolates the results of the most progressive techniques.

Assumptions about nutrient pollution control in the *Chesapeake Futures* scenarios are based on those used in the Chesapeake Bay Program's Watershed Model (Phase 4.3), specifically the 2000 Progress, continuing existing policies, and full implementation runs, respectively, for each of the three scenarios. *Chesapeake Futures*' development loading rates were derived directly from the Watershed Model (Phase 4) by model segment, with the exception of rates for nitrogen loads from septic systems; these assume that about 42 percent of the per capita nitrogen load entering septic drainfields reaches surface waters. Estimation of the changes in loadings from other sources was more generally made, however, by assuming percentage changes in the delivered loadings to the Bay as estimated by Watershed Model loadings for 2000. This approach allows the opportunity to compare potential future conditions using the same baseline (2000,) but with different analytical methods and assumptions concerning source changes—with *Chesapeake Futures* based on generalized scientific understanding and the Chesapeake Bay Program approaches founded on detailed engineering modeling.

Throughout the report, the scenarios appear at the conclusion of each section; any reader eager to "cut to the chase" can find the scenarios listed in the table of contents. Readers will glean a more complete understanding of the issues from reading entire chapters, however, which provide context, background, and explanation. For those interested in pursuing any particular subject further, references and endnotes point the way toward primary sources, synthesis documents, and other valuable resources.

Other Glimpses at the Future

Chesapeake Futures joins a wide-ranging collection of literature that considers the path of the future. Looking ahead can be simultaneously thrilling and disturbing—encompassing a range of possibilities from the great to the tragic. In fact, the whole notion of peering into the future poses an uncomfortable challenge for humankind, especially given the uncertainty of change. According to Eric Hoffer, "no one really likes the new. We are afraid of it."[6] In Hoffer's view, change—especially rapid, radical change—can sow seeds of discontent. "The revolutionary mood and temper," he says, "are generated by the irritations, difficulties, hungers and frustrations inherent in the realization of drastic change."[7]

Many analyses of the future have been frightening. Aldous Huxley's *Brave New World* (1932) and George Orwell's *1984* (1949) painted pictures of a human society shaped by dark, controlling forces with human choice and individual will crushed by rigid hierarchy. As Huxley said of Orwell's work, "In the context of 1948, *1984* seemed dreadfully convincing."[8] Of course, as with most visions, Orwell's imaginings were more instructive than predictive.

Alvin Toffler's *Future Shock* (1970) warned that the rapid pace of change upon us at the end of the 20th century would literally threaten our physical and psychological health. From his vantage point in 1970, he wrote, "In the three short decades between now and the twenty-first century, millions of ordinary, psychologically normal people will face an abrupt collision with the future."[9] According to Toffler, "the roaring current of change…[is] a current so powerful today that it overturns institutions, shifts our values and shrivels our roots."[10]

For Toffler, "The acceleration of time is, itself, an elemental force. This accelerative thrust has personal and psychological, as well as sociological, consequences."[11] His term, "future shock" denotes "the disease of change." It is "a real sickness from which increasingly large numbers already suffer."[12] And, as others have noted as well, Toffler sees that "the *rate* of change has implications quite apart from, and sometimes more important than, the *directions* of change."[13]

Some might argue that Toffler's book, written toward the end of the especially turbulent 1960s, may have overstated the case, or at least missed some of the more positive dimensions of what he called the post-industrial age. On the other hand, others might argue that recent violent clashes of culture may be symptomatic of frictions caused by differing rates of change and reflecting differing beliefs and philosophies. These violent clashes echo the scenarios depicted in *Which World?* in which differing rates of development lead to ever-expanding difficulties.

Interestingly, Toffler's *Future Shock* was written 30 years before the new millennium, while *Chesapeake Futures* looks another 30 years ahead, to 2030. Just how perceptive such future gazing will prove only history can judge, but clearly Toffler understood the perplexity of the challenge, quoting a Chinese proverb that advises: "To prophesy is extremely difficult—especially with respect to the future."[14] Toffler, in fact, warns against actual "prediction," while lamenting "the perishability of fact" in which facts change before one can even publish a study.[15]

There is agreement though that change is occurring at an increasingly rapid pace. Toffler and others could perceive this trend quite clearly as the new millennium approached. In Toffler's words, as the 20th century moves into the 21st century, "all history is catching up with us."[16] He points out, for example, that if there have been some 800 lifetimes (of about 62 years each) in the last 50,000 years, then while a full 650 of those lifetimes were spent in caves, most of the technological breakthroughs that now shape our daily lives were discovered within the last—the 800th—lifetime.[17]

Along with technological change has come population growth. In 1850, Toffler notes, "only four cities on the face of the earth had a population of 1,000,000 or more. By 1900 the number had increased to nineteen, but by 1960, there were 141…"[18] In 1970, when Tofflor was writing his book, the annual rate of worldwide population increase hovered just under 2.1 percent. As of 2000, that rate had declined to just over 1.2 percent per year; however, the worldwide population on which the percentage is based was much larger than in the 1970s, having reached 6 billion people by the end of the century.[19]

As population forecaster Paul Ehrlich has noted, birth rates have slowed somewhat since he and Toffler made their original predictions, but Ehrlich maintains that most demographers "think that growth will not end before the population has reached 10 billion or more."[20] Ten billion, he argues, is too many.

According to Ehrlich, "Global warming, acid rain, depletion of the ozone layer, vulnerability to epidemics, and exhaustion of soils and groundwater are all…related to population size."[21] Yet the topic of overpopulation remains a difficult one to discuss, and most groups, including the media, are reticent to address it head on. "One of the toughest things for a population biologist to reconcile," says Ehrlich, "is the contrast between his or her recognition that civilization is in imminent serious jeopardy and the modest level of concern that population issues generate among the public and even among elected officials."[22]

Ehrlich is well aware of the sensitivity of the subject. "To a degree, this failure to put the pieces together is due to a taboo against frank discussion of the population crisis in many quarters, a taboo generated partly by…groups who are afraid that dealing with population issues will produce socially damaging results."[23]

In *The Greening of America*, another book that appeared three decades before the new millennium, Charles Reich gave voice to rising concerns, especially among the young, over public policies that appeared to ignore the looming social and environmental costs of business as usual. "We think of ourselves as an incredibly rich country," Reich wrote, "but we are beginning to realize that we are also a desperately poor country—poor in most of the things that throughout the history of mankind have been cherished as riches."[24]

When Reich looked toward the future, he saw a "green revolution" coming. This change, he said, would depend on a new way of thinking. "It promises a higher reason, a more human community, and a new and liberated individual. Its ultimate creation will be a new and enduring wholeness and beauty—a renewed relationship of man to himself, to other men, to society, to nature, and to the land."[25]

From the perspective of three decades before the new millennium, Toffler and Reich represent somewhat different approaches to the future. For Toffler, rapid change, though bringing great promise, threatens to harm our health and our adaptive capacities if we remain unthinking and unprepared. For Reich, change is not only good, it is imperative. Proceeding down the familiar paths will not take us where we need to go. For Reich, the new generation (the generation now in power) needs to direct the country in innovative decision-making and new approaches. "At the heart of everything" he claims, "is what we shall call a change of consciousness."[26]

Chesapeake Futures must finally leave such larger questions about the character and impact of change to the sociologists and other students of the future. At the same time, however, there is no question that changes in an ecosystem—in this case, the Chesapeake Bay—will remain closely linked to cultural changes and choices made by citizens throughout the region about how they live and how they use the watershed's natural resources.

While gazing some 30 years into the future may be a risky business, past problems have made clear that not looking ahead can prove riskier still. One recalls, for example, the warnings of W.K. Brooks at the turn of the last century, when he foresaw the likely destruction of the Bay's oyster reefs and a squandering of our "birthright."[27] At times, looking ahead can help us avoid falling into the environmental traps we unfortunately have set for ourselves. For a common property resource, such as the irreplaceable Chesapeake Bay, we would do well to avoid as many of these traps as possible.

Endnotes

[1] A famous example is the lawsuit filed by the "downriver" counties along the Patuxent River against the State of Maryland and the U.S. Environmental Protection Agency. They demanded water quality controls on the "upriver" counties, which had been adding large amounts of sewage effluent to the river.

[2] For a brief summary of the 2020 Report, see the Chesapeake Bay Program. 1993. Cost of Providing Government Services to Alternative Residential Patterns. *www.smartgrowth.org/library/CoPGStARP.html*

[3] Hammond, A. 2000. *Which World? Scenarios for the 21st Century: Global Destinies, Regional Choices*. Washington, D.C.: Island Press, 306 pp.

[4] Ibid., p. 13.

[5] Brennan, R.P. 1992. *Dictionary of Scientific Literacy*, New York, NY: John Wiley & Sons, pp. 233–34.

[6] Hoffer, E. *1952. The Ordeal of Change*. New York, NY: Harper & Row, p. 3.

[7] Ibid., p. 5.

[8] Huxley, A. 1958. *Brave New World Revisited*. New York, NY: Harper & Row, p. 3.

[9] Toffler, A. 1970. *Future Shock*. New York, NY: Random House, p. 9.

[10] Ibid., p. 1.

[11] Ibid., pp. 1–2.

[12] Ibid., p. 2.

[13] Ibid., p. 3.

[14] Ibid., p. 4.

[15] Ibid., p. 4.

[16] Ibid., p. 16.

[17] Ibid., p. 13.

[18] Ibid., p. 21.

[19] 2000 U.S. Census. *www.census.gov*

[20] Ehrlich, P. and A. Ehrlich. 1990. *The Population Explosion.* New York, NY: Simon and Schuster, p. 16.

[21] Ibid., p. 17.

[22] Ibid., p. 13.

[23] Ibid., p. 21.

[24] Reich, C.A. 1970. *The Greening of America*. New York, NY: Random House, p. 1.

[25] Ibid., p. 2.

[26] Ibid., p. 3.

[27] Brooks, W.K. 1996. *The Oyster*. Baltimore, Maryland: The Johns Hopkins University Press. Original work published in 1891.

Chesapeake Pasts

Chesapeake Futures focuses on the hard choices that confront us as we move into the 21st century. Before peering three decades into the future and beyond, however, we would do well to cast a brief glance backward to the Chesapeake of the past. We do this for several reasons. First, as the saying goes, those who do not know history are doomed to repeat it. This warning carries special significance due to the way that science has been used—or not used—in past policymaking. Second, although natural forces such as rising sea level and climate change (regional and planetary) constantly shape the Chesapeake, humans have also affected the Bay biologically, chemically, and physically over many centuries.[1] We cannot easily envision the potential scope of such anthropogenic changes without some sense of what they have meant for the Bay over time. And third, by tracking the progress in Bay management—which is considerable—we can better position ourselves for making the best-informed management decisions for the future.

The Ideal and the Real

How the Chesapeake of the past appears to us will depend on when and where we look. One popular vision pictures a pre-Colonial shoreline swathed in dense forests, occasionally dotted with small Indian settlements, and its waters so thick with life that one could scoop fish with a frying pan.[2] Recent scholars have helped dispel the notion of an entirely untouched landscape. Well before Europeans arrived, native inhabitants used fire to clear underbrush for hunting, and worked the land for living space and agriculture—especially corn.[3]

As Mary K. Blair has observed, clinging to a vision of the early Chesapeake as an unspoiled Garden of Eden is irresponsible; it perpetuates an unattainable fantasy and creates an unrealistic baseline in both our perceptions and our restoration goals.[4] With this admonition against an Utopian ideal, we can generally characterize the estuary prior to European settlement.

Despite changes in long-term climate and other environmental variables (see Changing Times chapter), the Chesapeake had evolved into a remarkable ecosystem when John Smith encountered the height of the Algonquin culture in the early 1600s. What Smith didn't realize is that the Bay he found so hospitable had been created by the melting of huge glaciers. After reaching its maximum around 18,000 years ago, the Pleistocene ice sheet that covered the northern United States and Canada began to melt and retreat, raising worldwide ocean levels and steadily flooding the continental shelf. During the

Engraving by DeBray from John White

Down the Rolling Road: King Tobacco

Sandy Rodgers, MD Sea Grant

Smoked by indigenous peoples, the leafy plant we call tobacco quickly became integral to the economies of the southern English colonies and to the development of Chesapeake Bay country. Early settlers built plantations along the Bay's protected and easily navigated rivers, with the sea serving as the major highway to the rest of the world. Here colonists raised crops either brought from England or adapted from Native Americans. For cash, however, they needed a major export product. That product was tobacco.

Introduced to Sir Walter Raleigh by the Spanish in the late 1500s and promoted by colonist John Rolfe beginning in 1611, tobacco swiftly took root in the leafy soils surrounding the Bay. It also took hold in the markets of the Old World, hailed by many doctors as a cure-all, a *herba panacea*, or even a *herba santa*, something close to divine. Colonists flocked to the New World to grow "sot weed," the new cash crop, and bought up land along the major rivers.[8]

The farming system that resulted had a clear effect on the development of land surrounding the Bay. Historians have noted that more than 90 percent of known 17th-century Maryland sites are located on or near soils conducive to tobacco farming. Getting the tobacco to market usually meant rolling large barrels or hogsheads down a "rolling road" to a pier. It's not surprising, therefore, that 17th-century home sites in Virginia and Maryland were located at a median distance of about 600 feet from the modern shoreline.[9]

Although English authorities encouraged the development of towns, the colonists largely disseminated onto land-hungry farms—especially tobacco farms. "Tobacco culture . . . dictated dispersed settlement."[10] That far-flung settlement pattern, which required the clearing of huge amounts of land, not only to grow tobacco and corn, but to allow exhausted fields to lie fallow for as long as 20 years, set the tone for early land use in the region.

Tobacco brought wealth to the new colony and shaped a way of life in Bay country. It also left an environmental legacy of depleted soils and sediment flushed into Chesapeake waterways. Perhaps the ultimate irony is that tobacco, once hailed as a cure-all, has turned out to cause serious disease. Despite its dark legacy, tobacco will forever be entwined in the history of Chesapeake pasts.

last 10,000 years or so, the Susquehanna River valley flooded in earnest. The drowned valley developed into the estuary we recognize today, providing rich habitat for many marine and estuarine species.

We have known for some time that long-lived, slow-growing species such as sturgeon once flourished in the Bay. Recent estimates suggest that the early Bay, like other coastal waters, not only supported a wide range of species, but that these fish, oysters, and other sea life reached sizes much larger than the same species in modern times.[5] Also well documented are the massive oyster reefs that fringed the pre-Colonial Bay—tall enough to break the water's surface and create navigational hazards.[6] In these ways, the water body we see today is a diminished Bay, with the size and plentitude of many species significantly reduced. As one Bay expert has commented, "Never again would the modern Chesapeake Bay be as grand as that moment. It must have been a magnificent sight."[7]

Changes in the Land and Water

Although the Bay's pre-Colonial landscape was certainly not Eden, it was largely forested. Changes wrought by native inhabitants paled in comparison to the tree-clearing techniques of European settlers who not only grew food crops but also the major cash crop of the day—tobacco. Researchers who have studied the sediment record, most notably Grace Brush of Johns Hopkins University, have clearly documented changes in pollen types and sedimentation rates that signal the early clearing of the land near the Chesapeake Bay (Figure 3-1).

One obvious dividing line between the Chesapeake of the distant (pre-Colonial) past and the Chesapeake of the American historical past is this layer of sediment that marks the first major clearing of old-growth forests in the watershed. Increased sedimentation had specific and profound effects on the estuary, smothering oyster bars, silting in harbors, and changing the ecology of the benthos (bottom organisms) of the Bay. Chapter 9 discusses these changes along with prospects for the future, including shoreline erosion, the filling and dredging of channels, and the physical dynamics of the Bay.

In addition to sediment problems, growing settlement in the watershed led to another more pressing problem: the disposal of human wastes. The Chesapeake and its tributaries became receptacles for this waste, perhaps inadvertently at first, but also quite intentionally later. Court rulings made it clear that, despite damage to fisheries and oyster beds, receiving raw sewage was a legitimate function of the Bay. According to the Supreme Court of Appeals of Virginia in 1916, "The sea is the natural outlet for all the impurities flowing from the land . . ."[11] Two years later, it reaffirmed this view by citing the "ancient right of the riparian owners to drain the harmful refuse of the land into the sea, which is the sewer provided therefore by nature. . ."[12] Justice Oliver Wendell Holmes, in a 1919 opinion, demonstrated that the U.S. Supreme Court also agreed with the notion of the sea as natural sewer: "The ocean hitherto has been treated as open to the discharge of sewage from the cities upon its shores." [13]

The raw sewage that drained into the Bay caused serious health problems. During the late 19th century, several outbreaks of typhoid linked to tainted oysters caused great concern for human health and the seafood industry. Then, toward the end of 1924, a major typhoid outbreak in Chicago, New York, and Washington, D.C. resulted in 1,500 cases of the disease and 150 deaths. Most cases were traced to contaminated oysters.[14]

The Core of Time

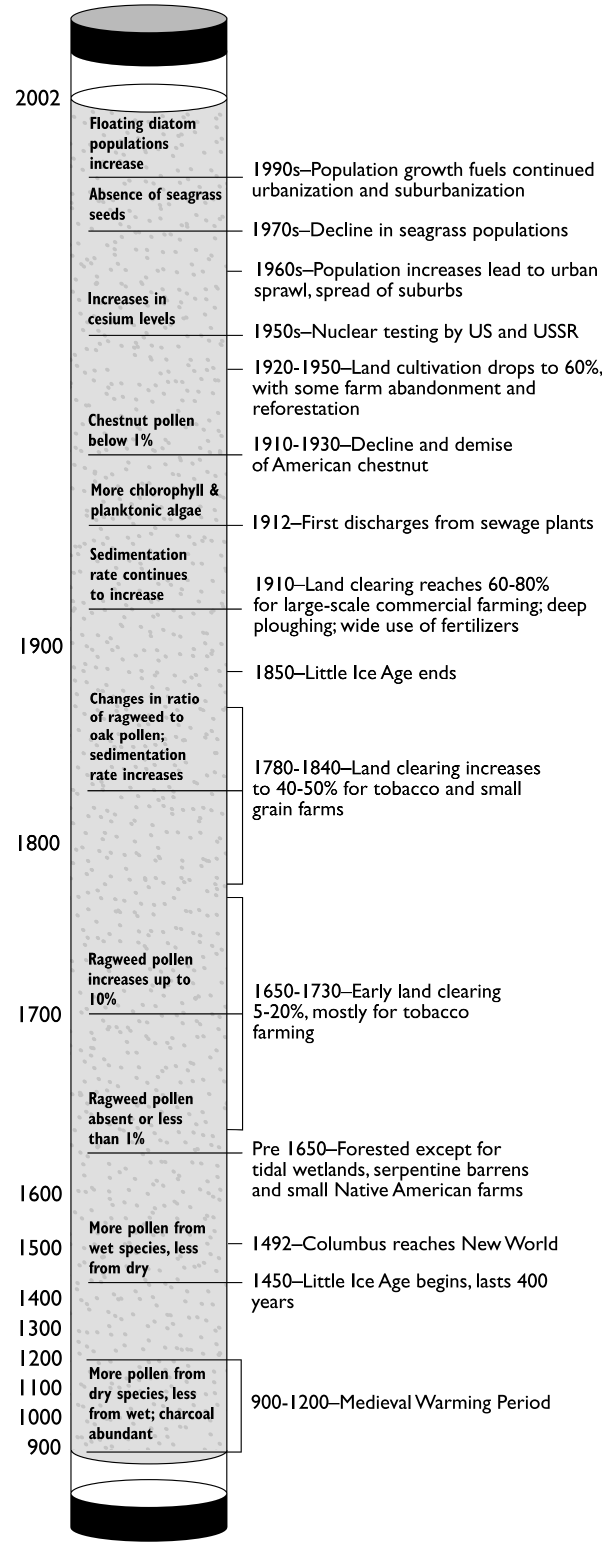


Figure 3-1. Grace Brush has mastered the art of reading the Bay's history through the pollen record. Shifts in pollen abundance indicate changes in the land around the Bay (courtesy of Maryland Sea Grant).

Detail of City Hall ruins after the Baltimore fire of 1904 (reprinted with permission from the Maryland Historical Society).

In many ways, modern waste treatment in the Chesapeake region owes much to the influence of the watermen and packers who depended on the seafood industry. While Virginia oystermen struggled with contrary court decisions, the political clout of Maryland's bayside districts, particularly on the Eastern Shore, made itself known when the time came for Baltimore to rethink its disposal of waste.

A prime opportunity came after the great Baltimore fire of 1904, which literally cleared the way for the sewer system that Baltimore sorely lacked. The obvious outfall for the new system was direct discharge into the Chesapeake Bay; in fact, the members of a Baltimore sewage commission made such a recommendation.[15] The city needed authorization to float bonds to raise the needed capital, however, and for this they required the approval of the Maryland General Assembly. The legislature gave its blessing, but under the guidance of shoreside delegates sensitive to the oyster industry, it stipulated no direct discharge into the Chesapeake Bay. This caveat led to Baltimore's pledge to carefully process the waste and to the building of the Back River sewage treatment plant from 1911 to 1912, regarded by many at the time as the most sophisticated such system in the world.

The early Chesapeake moved from a largely forested watershed, to an agrarian landscape cleared for farming tobacco and other crops, to a region dotted with growing urban centers. Most of these centers remained quite small—Colonial capitals such as 18th-century Williamsburg and Annapolis housed fewer than 2000 residents each.[16] Even Richmond, unincorporated until 1805, was only 8,000 strong by 1820. Unlike the others, Baltimore surged ahead, reaching a population of 62,000 within the first two decades of the nineteenth century.[17] In the southern Bay, Norfolk emerged as the most prominent port and became a principal destination for timber, particularly from the James River region.[18] Norfolk, Portsmouth, Hampton, and Newport News together soon formed a major population center, with rapid population growth following World War II.

The Rediscovery of the Chesapeake

Despite the growth of the urban centers, many stretches of Chesapeake country remained sparsely populated and, in a sense, "forgotten" by mainstream America as the country moved into the 20th century. Like today in some remote areas of the Eastern Shore or at the ends of long, low peninsulas in the southern Bay, the landscape remained dotted with small farms. In some instances, these lands became increasingly forested when farm fields turned fallow. The pace of life was slow. In these outlying areas, impacts on Bay water quality, except from sedimentation due to broken-soil plowing, were generally light.

During the early part of the 20th century, the remote peacefulness of long stretches of Bay countryside moved Swepson Earle to call for a rediscovery of the Chesapeake. In a preface to the 1923 edition of his classic tour of the Bay region entitled *The Chesapeake Bay Country*, he wrote, "I think it very desirable that the attention of present and future generations be called to the thousands of acres of fertile lands with picturesque building sites awaiting the coming of those who wish to find homes in this delightful part of our country."[19]

Summoning large numbers of people to build in Bay country these days has become the purview of real estate brokers, but if author Swepson Earle was calling in earnest for people to build by the Bay, his call was clearly heard. In the York River basin in Virginia, annual residential building permits issued jumped from 4,184 in 1990 to 4,981 in 2000—a rise of almost 20 percent within the decade.[20] Similarly, in a recent year in Maryland, developers and others submitted some 700 shoreline projects with nearly half of these in Anne Arundel County, the site of Annapolis as well as many navigable rivers and creeks.[21]

Differences In Chesapeakes Past and Present

With this brief description as background, we consider several specific factors that have changed significantly since the early days of the Chesapeake. Many of these will be taken up in considerable detail later in the report.

Demographics

Without question, a fundamental and considerable difference between the Chesapeake of the past and the Chesapeake of today is the change in population—not only the large increase in the number of people living in the watershed but also where and how they live. By tracking population growth in Maryland, beginning with the late 18th century, the magnitude of this change becomes apparent. In 1800, approximately half a million people lived in the Free State. By 1900, that number had reached about 1.5 million. By 1950, the population had climbed closer to 2.5 million, reaching over 5 million by the year 2000. The vast majority of this growth occurred during the 20th century—largely due to immigration from other parts of the country and the world.

Changing demographics have had distinct impacts on the Chesapeake Bay, but they have also affected political and cultural changes as well. The case of the 1904 Back River sewage treatment plant, for example, reminds us that the influence of the seafood industry—especially the oyster industry—in local politics was considerable in Bay country at that time. Even accounting for the plummeting value of oysters, it is unlikely that such an influence would be played out in quite the same way now, given the huge population shift (and therefore shift in representation) to the suburban counties of the western shore. With the population in the Chesapeake watershed expected to approach 19 million by the

Skip Brown

year 2030, demographics will clearly play a major role in distinguishing the Chesapeakes of the future from the Chesapeakes of the past.

Lifestyle

Although commenting on lifestyles in the region is beyond the scope of this report, the advent of countless new inventions and devices, as well as changes in tastes and opinions, have drastically altered the daily lives of those who live in Chesapeake country. These changes have not only meant great advances in convenience, health, safety, and transportation; they have also shifted the distribution of wealth and modified the way many experience life. People now crave bigger houses, new and larger cars, more convenience, "time-saving" gadgets, and greater amounts of leisure time. Bayside houses sell for a premium, more and more people buy boats to spend their free time cruising the Bay, seafood restaurants pack people in with all-you-can-eat blue crab specials. These demands are taking their toll on the Chesapeake. At the same time, citizens are more aware of the consequences of past unchecked exploitations.

Biological Changes

The Bay has seen considerable biological change over the last four centuries. Remnant oyster shells, early illustrations of fishing, and historical accounts all point to much greater numbers and much larger

This early 20th-century photograph gives a sense of the immense quantities of oysters once harvested from the Chesapeake Bay. Note the people standing on the mounds (courtesy of Hampton History Museum, James S. Darling Oyster Packers, Hampton, circa 1910).

individuals inhabiting the pre-Colonial Bay—large sturgeon, huge oyster reefs, and massive schools of fish (including shad, harvested by George Washington at Mount Vernon). In addition, the European colonization of the Bay brought several invasive species (not counting the colonists themselves). Purple loosestrife *(Lythrum salicaria*), native to Eurasia and apparently planted by early settlers, proliferated and now dominates many marshlands of the Bay.[22] Other species, such as the common reed *Phragmites* and the aquatic plants Eurasian watermilfoil and *Hydrilla* have at times grown aggressively in some rivers and tidal flats.[23] Other noxious animals, absent from the Chesapeake landscape prior to the 20th century, include nutria and mute swan. The former wreak havoc on tidal wetlands (on the Eastern Shore, for example); the latter consume large quantities of submerged aquatic plants, important food and habitat for native species.

Perhaps the most damaging invasive organism to hit the Bay, invisible to the unaided eye, is the Haplosporidian parasite popularly known as MSX. Accidentally introduced into the Delaware and Chesapeake bays during the 1950s, probably during failed attempts to culture the Japanese oyster, *Crassostrea gigas*,[24] MSX rapidly spread through the higher-salinity waters of Virginia and then up toward Maryland. A resurgence of MSX, triggered by drought and higher salinity levels during the mid-1980s, allowed further entrenchment of the disease well up the Chesapeake Bay. The combined attack of MSX and a second parasite, Dermo (*Perkinsus marinus*), has proven devastating to the oyster population both in terms of the Chesapeake oyster fishery and the keystone ecological role played by this reef-building mollusk.

Concerns have grown about the introduction of other exotic organisms, including microorganisms inadvertently carried by large ships in their massive ballast water tanks and dumped as ships clear the tanks to take on freight. The pumping of dirty water into the Bay by ships is not a new concern, however, and some of the earliest complaints about "pollution" centered on oily water flushed from ships' bilges. This particular complaint largely disappeared during the 1950s, after educational efforts by Bay pilots and time-consuming inspections in port—actual or threatened—moved the shipping industry to stop pumping out the oily waste once the ships entered the Bay.[25]

Municipal Wastes

Prior to the 20th century, the Bay region often saw little or no treatment of wastes, including human wastes, which often resulted in serious consequences, especially for public health. Even as late as 1955, Edgar L. Jones noted in a landmark article for the *Baltimore Sun* that many of Maryland's cities and towns failed to treat their wastes:

> Twenty-five Maryland cities and towns have public sewers but no treatment plants… Another thirty-two Maryland towns, of sufficient size to have significance from a public health standpoint, have no sewers at all… Still another sixteen Maryland cities and towns have sewers and treatment plants, but they are inadequate to meet the demands made upon them, so that some raw sewage either gets only partial treatment or bypasses the treatment plants altogether and flows directly into streams.[26]

Advances in waste treatment have greatly improved water quality by removing pathogens responsible for typhoid and other life-threatening diseases. Despite these advancements, Washington, D.C., with its aging sewers, still empties untreated waste into the Potomac River with every significant rainfall.[27]

Nutrients

Although waste treatment signified an important step in the improvement of water quality, the shear increase in population growth during the 20th century continued to tax many systems. Moreover, in addition to pathogens, municipal and other wastes added considerable quantities of nutrients—particularly nitrogen and phosphorus—to the Bay. During the 1970s, debates raged over whether nutrients posed a significant problem for the Chesapeake. Some resource managers argued that the Bay's flushing rates would prove adequate to handle the problem and doubted whether nutrients presented a real threat to the estuary.[28] Scientific evidence—much of it provided by a baywide study funded by the federal government in 1975 and overseen by the U.S. Environmental Protection Agency from 1976 to 1982—began to hold sway. Ultimately, the Chesapeake Bay agreements of 1983 and, more specifically, 1987 called for significant reductions in the flood of nutrients pouring into the Bay (by 40 percent, according to the 1987 Agreement).

In addition to municipal wastes, diffuse sources of nitrogen and phosphorus also began to contribute to the over-enrichment of the estuary. These harder-to-pinpoint sources included stormwater runoff from urban and suburban areas and seepage of septic tanks into groundwater feeding the Bay and tributaries. While farming had become an integral part of the Chesapeake landscape from the time of European colonization—and even prior, with Indian agriculture—the advent of affordable synthetic fertilizers after World War II meant a rapid increase in nitrogen and phosphorus applied to agricultural land in forms that washed more easily from the soil during rainstorms. The practice of importing animal feed to the watershed also created additional nutrient wastes.

The Chesapeake's past clearly includes increasing quantities of nutrients over time through the expanding use of fertilizers, not only on farm fields but also on lawns and gardens throughout the watershed. In addition to these nitrogen sources came ever-greater numbers of automobiles and trucks, each a mobile source of nitrogen oxides. Now, deposition from the atmosphere is thought to be responsible for 25 percent or more of the nitrogen entering the Bay.

Contaminants

Pollution is not new to the Bay; we have just become increasingly aware of its potential for wide-

An undated photo of women preparing tomatoes in a Maryland cannery. Such cannery operations resulted in early pollution to the Chesapeake Bay and its tributaries (Maryland State Archives - MSA SC 1477-6186).

spread harm to the estuary and its organisms. The types of pollutants have also changed over time. In addition to municipal waste problems, early Bay pollution also resulted from canning and packing plants. In the words of reporter Edgar Jones:

> Raw sewerage is not the whole problem, either. Into Maryland streams and Chesapeake Bay go the waste materials of big city and small-town production: acid mine waters, toxic chemicals, offal from meat and poultry packing houses, pulp and seed from canning companies, the washings from dairies, oil, grease, coal dust, pulp fibers, clay particles, and other foreign matter, to say nothing of the trash and garbage that householders toss into rivers and brooks.[29]

Much of the pollution described in Jones's 1955 diatribe had been around for decades—some even longer. A report from the Maryland Commissioners of Fisheries at the turn of the 20th century complained about the dumping of refuse, particularly singling out tomato canning establishments.[30] It was not until after World War II, however, that "toxic chemicals" from large industry became increasingly recognized as a major culprit threatening both the Bay and human health. Modern chemistry had created new products, including powerful organics such as DDT and PCBs, which proved extremely persistent and accumulated in tissue over time.

Studies by the U.S. Environmental Protection Agency identified the presence of heavy metals and other contaminants during the 1970s and 80s. The behavior of these contaminants remained uncertain, however, especially given the variation in water chemistry characteristics throughout the Bay. Differing salinities, sediment size, and sediment composition all affect the movement and chemical form of contaminants, making analyses more difficult. Additionally, the interaction among the contaminants and various organisms in the Bay remained difficult to track and characterize.[31]

Recent fish advisories have raised new concerns over the presence of chemical contaminants in seafood. In the Chesapeake's past, worries over shellfish contamination caused by human waste (now carefully controlled and monitored) posed the most pressing seafood concern. With the bacterial contamination problem largely cared for, apprehensions about chemicals in both fish and shellfish have taken center stage.

Changes in the Land

Colonial settlement initially followed the rivers. With the creation of roads and railroads, the settlements moved inland following these newly created conduits. Along with this development came the clearing of forests for agriculture. Later, particularly after World War II, individuals began converting farmland into housing developments and shopping centers.

A theoretical satellite image taken periodically over four centuries would show tree cover disappearing at a remarkable rate right up through the beginning of the 20th century, then gradually rebounding as some agricultural lands returned to forests and tree harvesting decreased. Towns and cities spread until they resembled large nerve cells, lit by countless streetlamps: Baltimore[32], Richmond, Norfolk, Washington, D.C. With time, these concentrations of people extended farther in less distinct patterns, as large segments of the population moved from the urban areas into the outlying regions. In some ways, this movement is a return to an earlier distribution pattern, when colonial farmers shunned towns to live on their own private estates—except now there are so many more of us.

Chapters 5 through 7 detail how development patterns, changes in forest cover, and shifts in farming practices are currently affecting the Chesapeake watershed and how they are likely to determine the ecological character of the future Chesapeake. Before moving to an analysis of these important trends, we take one last detour to examine how the Chesapeake Bay ecosystem itself may be transformed in the future. As we shall see, that ecological stage is a shifting one.

Endnotes

[1] Chapter 4 will detail large forces that continue to shape the Bay. Among these forces was a giant asteroid strike that may have helped direct the flow of rivers to the Bay mouth. Cf. C. Wylie Poag. 2000. *Chesapeake Invader*. Princeton, NJ: Princeton University Press.

[2] Many of our perceptions of an undeveloped Bay come from Captain John Smith and his *True Relation of Occurrences and Accidents in Virginia*, published in 1608.

[3] Cronin, W. 1983. *Changes in the Land: Indians, Colonists and the Ecology of New England*. New York, NY: Hill and Wang. Some scholars argue that it was corn (maize) agriculture that created a distinctive Indian culture in the Chesapeake region. See H. Rountree and T.E. Davidson. 1997. *Eastern Shore Indians of Virginia and Maryland.* Charlottesville: University Press of Virginia. See also J.R. Wennersten, 2001. *The Chesapeake: An Environmental Biography.* Baltimore: Maryland Historical Society, p. 8ff.

[4] Blair, M.K. 1981. Nature as Symbol. *Ethical Aspects of Chesapeake Bay Use*. Baltimore, MD: Citizens Program for the Chesapeake Bay. Blair writes that it is "unethical" to promote the notion of an Edenic Bay, and refers to James A. Mitchner's novel, *Chesapeake*, in this regard.

[5] Cf. Jackson, J.B.C. et al. 2001. Historical Overfishing and the Recent Collapse of Coastal Ecosystems. *Science* 293 (5530): 629.

[6] Captain John Smith, op. cit.

[7] Schubel, J.R. 1986. *The Life and Death of the Chesapeake Bay*. College Park, MD: Maryland Sea Grant College, p. 4.

[8] Smolek, M.A. 1984. "Soyle Light, Well-Watered and on the River": Settlement Patterning of Maryland's Frontier Plantations. Paper presented at the Third Hall of Records Conference on Maryland History, St. Mary's City, Maryland.

[9] Curtin, P.D., G.S. Brush, and G.W. Fisher, (eds.). 2001. *Discovering the Chesapeake: The History of an Ecosystem*. Baltimore, MD and London: The Johns Hopkins University Press.

[10] Walsh, L.S. 2001. Land Use, Settlement Patterns, and the Impact of European Agriculture, 1620–1820. In P.D. Curtin et al., (eds.). op. cit., p. 222.

[11] City of Hampton v. Watson. 1916. *Southeastern Reporter* 89: 81–2. See S.G. Davidson, J.G. Merwin, Jr., J. Capper, G. Power, F.R. Shivers, Jr. 1983, 1997. *Chesapeake Waters: Four Centuries of Controversy, Concern, and Legislation.* Second Edition. Centreville, MD: Tidewater Publishers, pp. 92–3.

[12] Darling v. City of Newport News, 249 U.S. Reports, 540–4 (1918). See Davidson, S.G., et al., op. cit., pp. 93–4.

[13] Holmes cited in S.G. Davidson et al., op. cit., p. 94.

[14] Davidson, S.G. et al., op. cit., p. 98.

[15] Davidson, S.G. et al., op. cit., p. 85. The 1897 Baltimore sewage commission held that there was "but little reason" not to take advantage of the Bay's "diluting effect" and to keep dumping sewage there.

[16] Davidson, S.G. et al., op. cit., p. 26.

[17] Davidson, S.G. et al., op. cit., p. 26.

[18] Curtin, P.D. et al. (eds.). op. cit., p. 157.

[19] Earle, S. 1923. *The Chesapeake Bay Country*. New York, NY: Weathervane Books, p. xiv.

[20] Mills, S. and B. Mills. 2001. *State of the York 2000*, The York Watershed Council, Walkerton, Virginia.

[21] Huslin, A. 2002. Looking Toward Washington Now: Census Confirms Arundel's Shift. *Washington Post*, May 30, page T3.

[22] The Kenilworth Aquatic Gardens in Prince Georges County, Maryland, for example, has mounted a program to eradicate purple loosestrife.

[23] *Exotics in the Chesapeake, Understanding Species Invasions*. Fact Sheet No. 3. 1999. College Park, MD: Maryland Sea Grant. The spread of Eurasian watermilfoil on the Susquehanna Flats was spectacular during the 1950s, growing from no plants in 1957 to 47 percent coverage by 1959. By 1960, coverage of this invasive species had reached 94 percent.

[24] Burreson, E.M., N.A. Stokes, and C.S. Friedman. 2000. Increased Virulence in an Introduced Pathogen: *Haplosporidium nelsoni* (MSX) in the Eastern Oyster *Crassostrea virginica*. *Journal of Aquatic Animal Health* 12: 1-8. Research by Eugene Burreson and colleagues at the Virginia Institute of Marine Science suggests a strong genetic link between MSX as it appears in the native Eastern oyster (*Crassostrea virginica*) and the Japanese oyster (*Crassostrea gigas*), which appears resistant and may serve as a carrier of the parasite.

[25] Cf. Curtin, P.D., op. cit., p. 124. This tactic appeared to work, and "oil disappeared from the list of primary pollution concerns."

[26] Jones, E.L. March 6, 1955. Maryland Pollution: Raw Sewerage, Industrial Waste, Acid Mine Water Poured into the Chesapeake Bay and Streams. *The Baltimore Sun*, p. A3.

[27] Cf. Leffler, M. 1999. Bringing the Anacostia Back. *Maryland Marine Notes* 17: 1–2.

[28] Greer, J. Spring 2002. Our Changing Vision of the Chesapeake. *Chesapeake Quarterly* 1 (1): 4.

[29] Jones, op. cit.

[30] Maryland Commissioners of Fisheries, quoted in Davidson, S.G. et al., op. cit., p. 105.

[31] Cf. Maryland Sea Grant and Virginia Sea Grant. 1997. Chemical Contamination in the Chesapeake Bay. College Park, MD and Charlottesville, VA. Also see Chesapeake Bay Program. 1999. Targeting Toxics: A Characterization Report. Annapolis, MD.

[32]To view an aerial reconstruction of Baltimore's growth over the past 200 years, go the the Science @ NASA website at *http://science.nasa.gov/headlines/y2002/11oct_sprawl.htm*

Changing Times

Bob Nichols, USDA NRCS

The Chesapeake Bay is a work in progress. As researcher and writer Jerry Schubel has pointed out, there have been many Chesapeake Bays—what we witness today is merely one of them. In the midst of this constant change, we depend on what we know not only of the present but of the past. We watch a few lone canvasbacks bobbing on the swells and imagine a flock of thousands. We find oyster shells scattered near the shore and picture huge reefs running along the Bay's shallow fringe mile after mile. When we try to imagine the Chesapeake Bay of the future we inevitably picture the past—and we long for it.

Perhaps the best-known manifestation of this longing for the past is the annual wade-in off Broomes Island in the lower Patuxent River undertaken by former Maryland state senator Bernie Fowler. Fowler remembers vividly how as a young man catching crabs he was able to wade in the water up to his chest and still look down and see his toes. Every June, accompanied by friends and politicians, he attempts to recreate this experience but comes up short. This event not only highlights the changes that have occurred but also tracks our efforts to reverse declines in water clarity.

The notion that the Bay can be returned to a previous, healthier state is clearly implicit both in the public mind and in the minds of the policymakers and environmental managers responsible for carrying out the public will. While even the most optimistic recognize the impossibility of recreating a Bay similar to the one that Captain Smith chronicled in the 17th century—a Bay then surrounded by some 100,000 people as opposed to more than 15 million today—many still believe that returning the Chesapeake to a condition similar to the one of the 1950s might just be achievable. Indeed, this belief was an inherent goal in the original multi-state Bay agreements of 1983 and 1987. Yet, this somewhat idyllic notion ignores countless changes in the world around us, changes that will continue to unfold far into the future.

Simply put, none of the Chesapeake Futures can be precisely like the Chesapeake Pasts. After all, the Bay is an estuary, a naturally dynamic environment that geologically speaking is young and ephemeral. Only a few thousand years old, the Bay is evolving and aging morphologically and ecologically, like all the world's estuaries. Beyond this, the world surrounding the Bay is shifting in ways that the regional community cannot fully control. Our climate, always variable and changing, may experience more rapid change as we move into the future. The human population residing near the Bay's margins and within its watershed will undoubtedly continue to grow and demographics will change. The regional economy will transform itself in ways that are difficult to predict as new technologies emerge and new adaptations take shape. All of these changes will influence the Chesapeake Bay and its watershed. These unforeseen changes will pose new challenges and new opportunities for those who live in Chesapeake Bay country, as they make choices about their own behaviors and commitments and as they seek ways to achieve Bay restoration goals set for the future. This chapter describes the changes that are likely to be seen in the new century and particularly during the next 30 years. It attempts to characterize the shifting playing field on which we have to weigh our options for choosing among achievable Chesapeake futures.

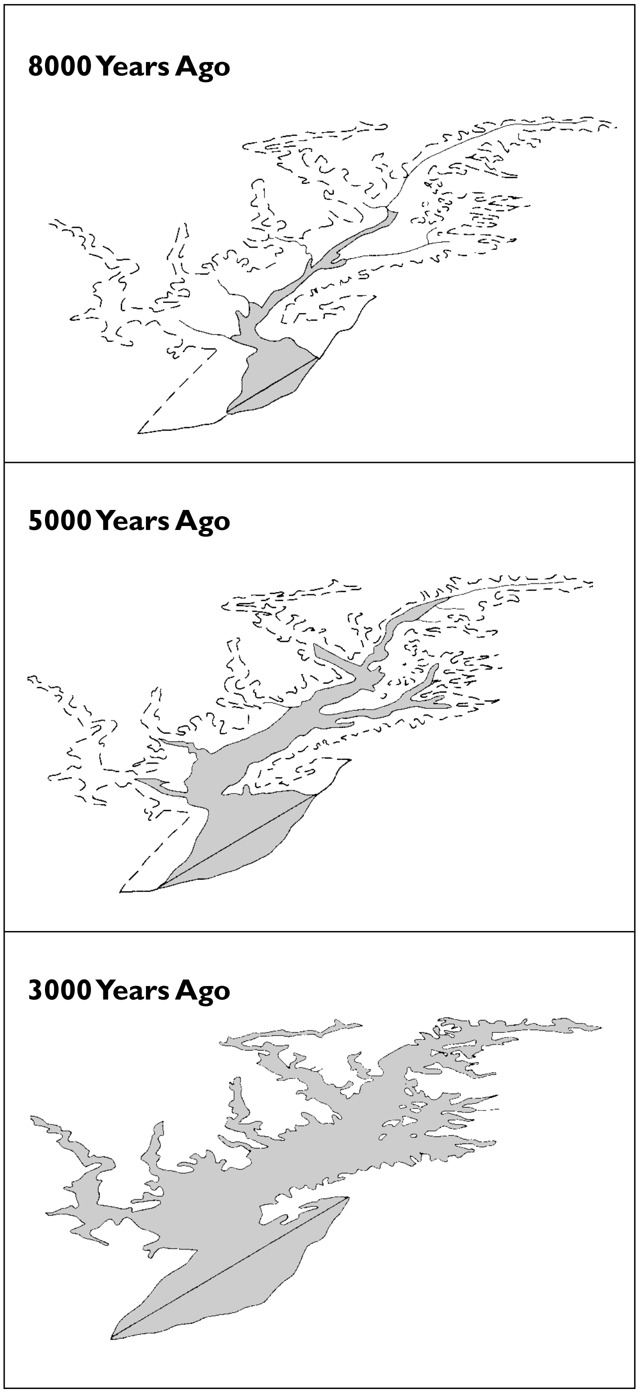


Figure 4-1. Post-Pleistocene map series of the rising Bay shoreline at 8,000, 5,000, and 3,000 years ago (adapted from S.P. Leatherman, 1995. Vanishing Lands: Sea Level, Society and the Chesapeake Bay).

The Aging Bay

Few fully appreciate that the Chesapeake Bay has not been around forever, or even as long as the human occupants of North America. The Bay is, in fact, a young feature, formed only after the last glacial period. When the glaciers reached their maximum some 18,000 years ago, they extended as far south as central Pennsylvania. At that time, the Atlantic coast was approximately 180 miles east of its current position near the edge of the present continental shelf. Sea level was more than 300 feet lower than today. Along the Atlantic coast, tributaries emptied directly into the sea and the small estuaries were essentially little more than river mouths. As the glaciers began to melt and retreat, the volume of the oceans increased. Sea level rose dramatically and the coast retreated westward, intercepting and flooding coastal river valleys. About 6,000 years ago, the rate of sea level rise slowed, leaving some semblance of the present Chesapeake Bay, which achieved its current shape only about 2,000 to 4,000 years ago[1] (Figure 4-1 and Figure 4-2).

Though coastal plain estuaries such as the Chesapeake are relatively young, they tend to age rapidly. This aging occurs principally as soil, formed from eroding rock in the watershed, begins to wash off the land into the estuary. Large estuaries are very effective sediment traps, capturing and sequestering—in bottom deposits and wetlands—much of the sediment moving down the rivers, sweeping in from the ocean with tides or storms, and eroding from the shorelines. Because estuaries exist at the interface between land and sea and because they are such effective sediment traps, their character and shape change rapidly. Their geomorphology evolves over mere hundreds of years even when sea level remains relatively stable.

In the case of the Chesapeake, aging has come even more quickly. Human activities have accelerated the rate of natural aging of the Bay by causing more sediment to wash off the land and into the estuary. Using carbon-14 dating of cores from bottom sediments, scientists have documented that the rate of filling of the deep channel of the upper Bay—after remaining relatively constant for more than 1,000 years—increased more than six-fold during the 18th and 19th centuries as forests were cleared for agriculture and fuel.[2] Even during the 20th century, sedimentation (infilling) rates were about three times greater than in pre-colonial times. Increased soil erosion caused the silting in of many of the Bay's tidal tributaries, including rivers such as the Anacostia and the Gunpowder, that once boasted colonial-era ports. The lower Bay has gradually experienced filling as well, but with mostly sandy sediment coming in from the Atlantic Ocean rather than from sediment eroded from the watershed. Approximately 3 billion metric tons of sediments from all sources were captured by the Bay over a 100-year period ending in the mid-1950s.[3] These sediments are eroded and redistributed by waves and currents, resulting in an ever-evolving Bay that is becoming shallower and has less-pronounced relief in its bottom topography.

Counteracting this shoaling of the Bay to some degree is the slow rise in sea level, not only from the increasing volume of the ocean but because much of the land surrounding the Bay is slowly sinking. This regional subsidence results largely from long-term rebounding of the Earth's crust north of the Bay region following the glacial retreat. While the glaciers did not extend as far south as the Chesapeake, they did cause a peripheral bulge, lifting the crust where the Bay is today. With the weight of the glaciers gone, the crust surrounding the Chesapeake began to subside (and is still dropping) similar to the other end of a seesaw. As a result, relative sea level around most of the Bay (measured relative to coastal lands) has risen at the rate of approximately 1.4 mm per year over the past few thousand years, but at a faster rate of about 3–4 mm per year during the 20th century.[4] A little more than 1 mm per year is due to this regional subsidence effect; the rest results from the rise of the ocean (about 2 mm per year) observed worldwide during the 20th century. Locally, relative sea level rise may be even greater as a consequence of groundwater withdrawals. For example, relative sea level rise at Cambridge, Maryland averaged nearly 9 mm per year between 1930 and 1993.

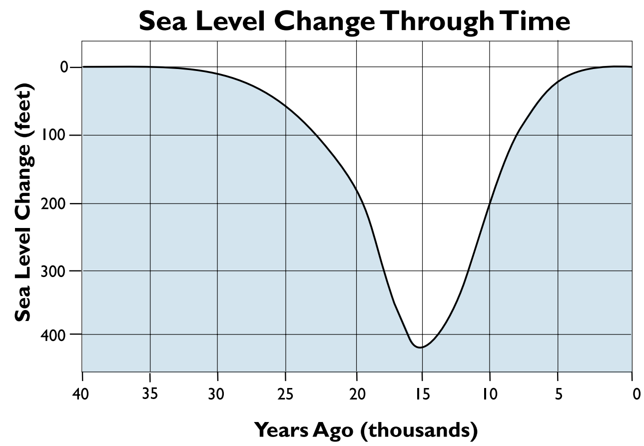


Figure 4-2. Sea level variations over the past 40,000 years with the advance and retreat of the continental glaciers. The lowest point on the graph represents the maximum of the last glacial period (adapted from Leatherman et al., 1995. Vanishing Lands: Sea Level, Society and the Chesapeake Bay).

While relative sea level rise makes the Bay slightly deeper, this effect is counteracted by the addition of sediments to the estuary through increased shoreline erosion—an inexorable result of sea level rise acting in consort with wind-driven waves. Even without an increase in the rate of sea level rise due to global warming (as discussed in the next section), rising Bay levels will cause further reductions in size and perhaps outright loss of remaining islands in the Bay over the next 30 years through inundation or increased wave erosion. Many islands in the Bay that were once inhabited, such as Sharps, Poplar, and James (Figure 4-3), have already been submerged or nearly so. Furthermore, other inhabited islands, necks, and low-lying lands around the Bay, particularly on the Eastern Shore and Tidewater Virginia, face increased inundation with retreating tidal wetlands and threatened waterfront communities.

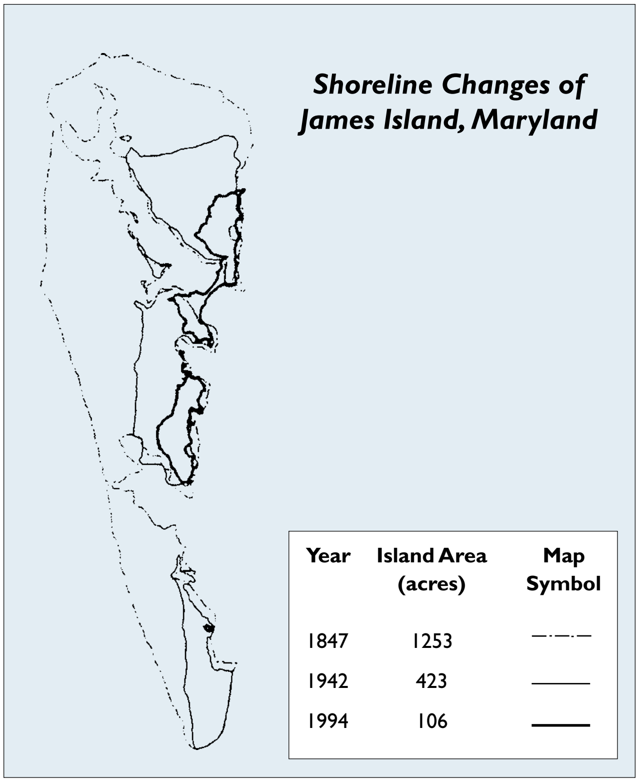


Figure 4-3. In the mid-1800s, James Island covered 976 acres. By 1994, rising sea level had claimed 884 acres, leaving a mere 92. The island once supported homes, schools, and a store. Now, none of these remain.

CLIMATE VARIABILITY

There is a growing appreciation, not only in the scientific community but also within the public at large, of the importance of weather events and climate change in coastal ecosystems such as the Chesapeake Bay. Extreme events, such as the floods caused by Tropical Storm Agnes in 1972 and the more recent 1996 floods, have sharpened this awareness (Figure 4-4). The importance of climatic cycles, such those related to the El Niño Southern Oscillation (ENSO), and the specter of long-term global climate change have also gained more broad-based recognition. While climatic variability and extreme events have always been important to the ecology of the Chesapeake Bay, ongoing studies of the chemical and microfossil record in Bay sediments suggest that recent degradation of this ecosystem from human activities has left it more susceptible to the impacts of extreme effects.[5] In other words, the Bay ecosystem has lost some of its resilience in the face of natural stresses. Floods now carry more nutrient and sediment than during pre-Colonial times, and periods of high river flow more easily cause widespread oxygen

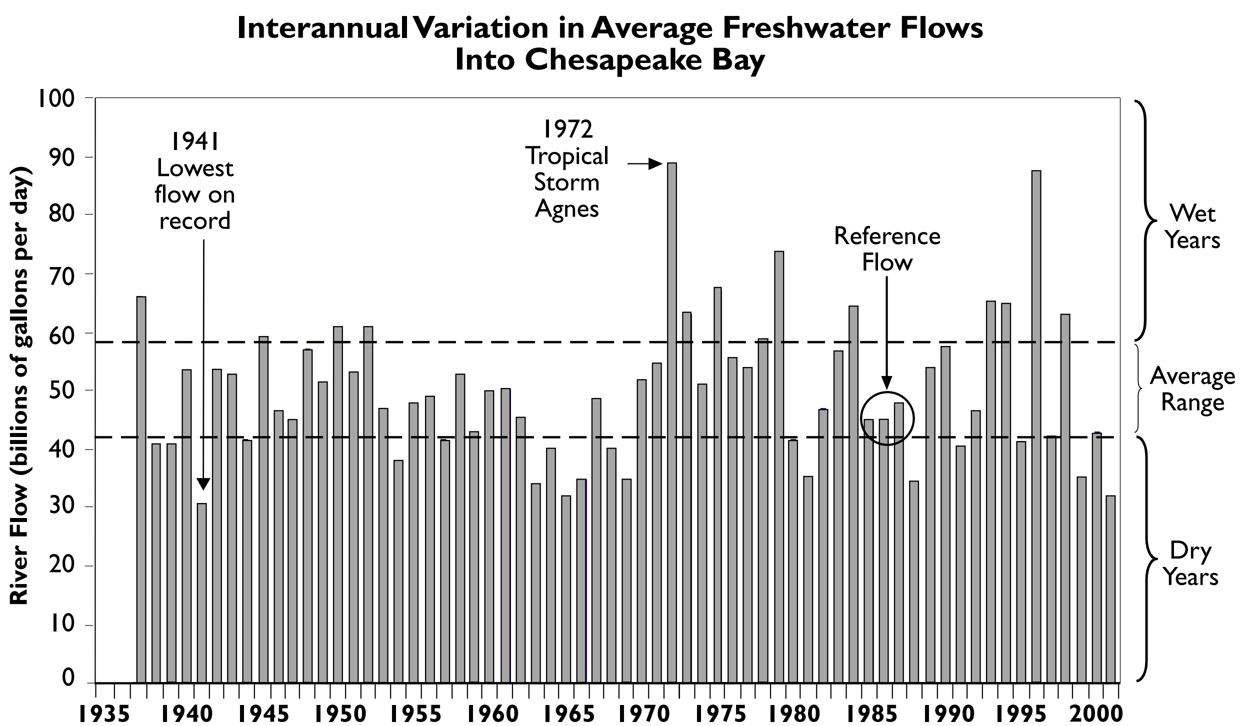


Figure 4-4. Plot of the average annual freshwater flows into the Bay from 1937 to 2001. Tropical Storm Agnes in 1972 caused the highest freshwater flow to the Bay; however, 1996 was also a particularly high-flow year.

Climate Cycles

Kent Mountford

Scientists have demonstrated that climate cycles, with frequencies ranging from a few years to a few decades, can affect many parts of the world. For example, research has shown that El Niño (the ENSO), a phenomenon of the tropical Pacific Ocean, affects temperature, rainfall, and storms not only along the Pacific coast but also over much of the United States. El Niño years tend to produce greater precipitation at least in the southern part of the Chesapeake Bay watershed, while La Niña years are drier.[6]

A more poorly understood climatic cycle in the Atlantic Ocean—the North Atlantic Oscillation (NAO)—might augur even greater consequences for the Chesapeake Bay. During the NAO, which has a cycle of a decade or more, the atmospheric pressure over the Atlantic Ocean shifts. This shift affects the pressure differential between the northern (boreal) and southern (subtropical) regions of the North Atlantic. When the pressure over Iceland is low and the pressure over the Azores is high, as has been the case for most of the 1980s and 1990s, strong westerly flows bring warmer conditions to northern Europe and wetter conditions along the U.S. East Coast.[7] When the reverse occurs, drier conditions are likely along the U.S. East Coast, as during most of the 1950s and 1960s, which were years of below-normal stream flow into the Chesapeake.

Growing evidence suggests that long-term climate cycles, such as the NAO and even planetary cycles, can affect water levels in the Atlantic Ocean and, consequently, the Chesapeake Bay. These cycles may result in varying rates of sea level rise over a decade or even over a few years—changes otherwise not predicted over the long term. For example, relative sea level appears to have been increasing at a faster rate than expected based on tide gauge records from the upper Bay, as much as 10 mm per year during the 1990s.[8] While such periods of more rapid sea level rise may be followed by a few years of little or no sea level rise, the damage in terms of eroded shorelines and submerged wetlands may have already been done. This variation also makes it difficult to distinguish any acceleration of sea level rise due to global warming, which is widely expected by the scientific community during the 21st century.

Since the atmosphere is a continuous medium, changes that take place in one region can affect "downstream" areas; these "teleconnections" can link the climates of different places. For example, climatologists are beginning to document an important teleconnection pattern between oceanographic conditions in the North Pacific Ocean and climatic patterns in the eastern United States. Recent satellite observations suggest that we may be seeing the beginning of a reversal in the Pacific Decadal Oscillation (PDO) that takes place every 20 to 40 years. Under a PDO warm phase, as witnessed during the 1980s and 1990s, the North Pacific is warmer off North America and cooler off Asia. If a PDO cool phase is actually beginning, this shift could portend two or more decades of colder, wetter winters along with a weakening of El Niño effects and a strengthening of La Niña effects, including more hurricanes.

IPCC Global Climate Change Predictions

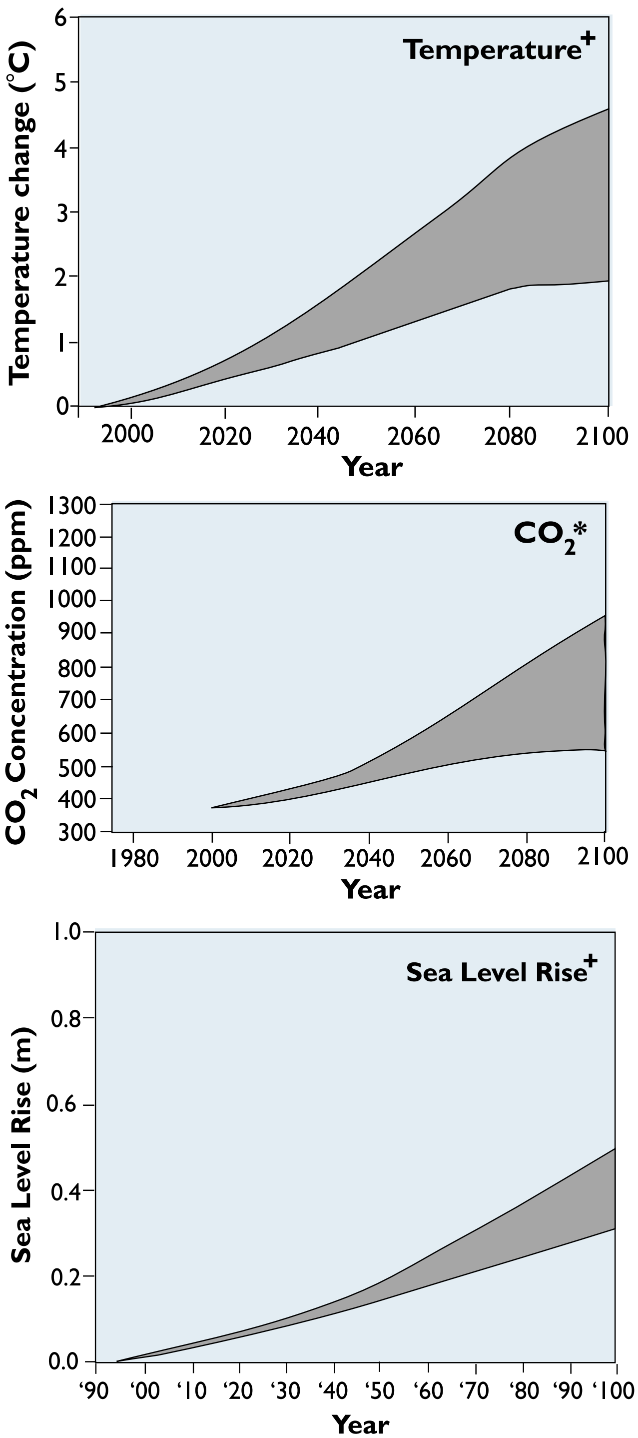


Figure 4-5. Predictions of global temperature, CO_2, and sea level rise to year 2100.
+ The region in dark shading shows the range of the average of model predictions for all 35 emission scenarios.
**** The region in dark shading shows the entire range of the six emission scenario groups.***

depletion, especially in the Bay's deeper waters. These larger-scale physical and chemical perturbations mean that organisms recover more slowly from otherwise natural flood events.

In addition to extreme storms such as Agnes and the 1996 blizzard—apparently the result of meteorological happenstance—we know that longer-term climate patterns or cycles also have a major influence on the Bay. For example, the 1960s were mostly dry, with much less runoff from the watershed. As a result of low river flow, salinity rose throughout much of the Bay and its tributaries, allowing more marine organisms, from sport fish to oyster parasites, to move farther up the estuary. At the same time, with the reduction of nutrients and sediment carried by runoff, Bay waters became relatively clear and oxygen concentrations rose. During this period, however, other changes continued to take place on the landscape. Their full importance did not become apparent until the drought years ended and precipitation and river flow returned to more normal levels. Of particular significance were both the rising use of chemical fertilizers and purchased feed along with the rapid increase of sprawling development in many parts of the watershed. When the drought ended in the early 1970s, the Bay got the shock of its life. After Agnes, hypoxia (severe depletion of bottom-water oxygen) spread through the Bay and water clarity declined. By 1978, when the first Baywide survey of underwater grasses took place, the area of vegetated Bay bottom had dropped precipitously.[9]

One certainty is that climate variability, as influenced by interactions of cycles such as those described previously (see Climate Cycles box), will continue to bring forth floods, droughts, warm periods, cool periods, and variations in sea level and storms—complicating and constraining the degree to which our society is able to shape our *Chesapeake Futures*. These large climatic shifts, often occurring on a global scale, will continue to surprise us and will no doubt occasionally set back our best efforts to restore the Bay ecosystem. If we are to have any chance at shaping the Chesapeake of the future, or even determining whether our actions are having an effect, we must understand the influences of dynamic shifts in climate on the Bay. We must learn to filter out the background noise in order to detect the signal—the response of the Bay to our best attempts at managing it.

Climate Change

In addition to changes in the Bay due to geological aging and varying climatic factors such as El Niño, there is the very real prospect that the Chesapeake region will witness a shift in climate during the 21st century due to an increase in greenhouse gases in the Earth's atmosphere. Concentrations of carbon dioxide in the atmosphere have increased by 35 percent since pre-industrial times. Given current trends in fossil fuel combustion, it will increase by approximately 30 percent more by the year 2030.[10] The degree to which we are able to reduce the combustion of fossil fuels in the Chesapeake Bay region alone will have no significant effect on this outcome. Furthermore, global efforts to limit emissions of CO_2 and other greenhouse gases, such as those called for by the Kyoto agreement, will make little difference in projected increases in CO_2 over the next 30 years. Climatic changes on a global scale are massive with a slow response time; for the next three decades, climatic and atmospheric shifts are already on a given trajectory. The following discussion, therefore, is not offered as an argument for or against controlling greenhouse gases, but rather as an explanation to help us understand and deal with changes that are likely to occur during the early part of the 21st century.

Many uncertainties remain regarding climatic change due to increasing greenhouse gases, particularly within a region such as the Chesapeake Bay watershed. Based on principles of physics, as well as our understanding of the history of the Earth, the most certain change is that the Earth's atmosphere will warm. Disagreements among scientists are not about whether this will be so, but concern how much, how fast, and where. As a result of overall warming, the volume of the ocean will almost certainly expand and sea level will rise faster than it has been rising, with or without the melting of glaciers and polar ice. Again, the scientific debates center on how much and how fast. A warmer atmosphere will also result in more evaporation and, necessarily, more precipitation. Location matters a great deal for precipitation, so it remains less certain whether precipitation will increase or decrease in a particular region. It is assumed, however, that warming will influence the weather-making heat engine of the Earth's fluids (the atmosphere and oceans), likely changing the frequency and intensity of storms and possibly even the course of ocean currents. Significant changes in ocean currents, such as the "conveyor-belt" circulation in the North Atlantic, is the least certain, but potentially the most dramatic consequence of climatic changes that could result from an increase in greenhouse gases.

Model Predictions of Climate Change

What, then, can science tell us about how the Chesapeake Bay environment may change as a result of climate change? The National Assessment of Climate Variability and Change has recently projected climate changes and their consequences for regions of the United States and for natural resource

Parameter	2030	2095	Reliability of prediction
Sea level rise (inches)	+4.3 to +12.2	+16.1 to +40.5	High
Temperature (°F)	+1.8 to +2.7	+4.9 to +9.5	High
Precipitation (%)	-1 to +8	+6 to +24	Medium
Runoff (%)	-2 to +6	-4 to +27	Low
Storminess (%, based on precipitation variances)	+18 to +36	+48 to +64	Low

Table 4-1. Pennsylvania State University projections for several indicators of climate change.

sectors such as agriculture, forests, water resources, and the coastal zone. A group of scientists from the Pennsylvania State University (PSU) conducted an in-depth assessment for the Mid-Atlantic region,[11] centered on the Chesapeake Bay watershed. Their study yielded the projections shown in Table 4-1 along with the reliability of each projection.

The PSU projections of sea level rise are based on high- and low-rate estimates (Figure 4-5) by the Intergovernmental Panel on Climate Change, with a local component of subsidence for the Mid-Atlantic region that is lower than that currently observed around the Chesapeake Bay. New climate models that take into account various population growth and emissions assumptions are being refined and will continue to provide additional information.[12] Practical projections can be based on recent observed trends in relative sea level around the Bay, assuming 1.4 mm/year for regional subsidence (i.e., the long-term rise before industrialization), and using the various model projections.

A conservative assumption is that relative sea level will continue to rise at the rate actually observed over the past 70 years, resulting in an increase of 10.5 cm (about 4 inches) by 2030 (Figure 4-6). Projecting that trend over the century yields an increase of 35 cm (over one foot) by 2100. It is highly likely, however, that the rate of sea level rise will accelerate over the next century as a result of global warming. A reasonable expectation is that relative sea level will rise by 14.5 cm (nearly 6 inches) by 2030; the increase could possibly reach twice that, however, if warming is more rapid or if significant melting of polar and glacial ice takes place. As we plan for a Chesapeake Future in 2030, we should appreciate that sea level rise is quite likely to accelerate even faster later in the century. A reasonable projection is that sea level will rise by 60-70 cm (at least 2 feet) by the year 2100. Based on the various models, this increase could be as little as 1.5 feet or up to 3.5 feet.

Increases in sea level of that magnitude will have several consequences for such a low-relief environment as the Chesapeake Bay and its margins. Quite likely, shoreline erosion will increase with more islands, lowlands, and coastal settlements inundated compared to the past century (Figure 4-7 and Table 4-2). This inundation will not only jeopardize traditional Tidewater fishing communities but will also worsen periodic flooding and drainage problems in shoreline urban areas ranging from Georgetown to Annapolis to Hampton Roads. Furthermore, the deterioration of intertidal marshes in areas of rapid relative sea level rise due to high local subsidence, such as those within the Blackwater National Wildlife Refuge, suggests that many of the Bay's intertidal wetlands will not be able to trap sediments and build soils rapidly enough to keep pace with increased sea level rise.[13] Telltale signs already indicate that tidal wetlands in many parts of the Bay are succumbing to such inundation.[14] Some of these wetlands may be able to migrate onto newly inundated fastlands. The topography of these lowlands and the actions taken by landowners to prevent this retreat, however, will likely mean that without more proactive management and restoration efforts, the area of tidal wetland habitat will shrink significantly.[15]

Additionally, a rise in relative sea level by up to a meter over the century will add considerably to the volume of the Bay, which currently averages only about 7 meters in depth. Counteracting this effect is the infilling of the Bay with sediments, including those dislodged by increased shoreline erosion. The

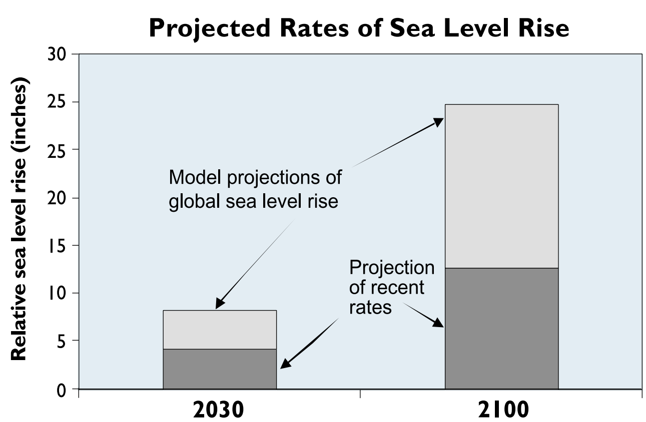


Figure 4-6. Projected sea level rise, given rates observed in the recent past (dark bars) and expected increases due to global warming (light bars). Together, these stacked bars show the projected mean for future sea level rise in the Chesapeake region.

Land Around the Chesapeake Bay Vulnerable to Sea Level Rise

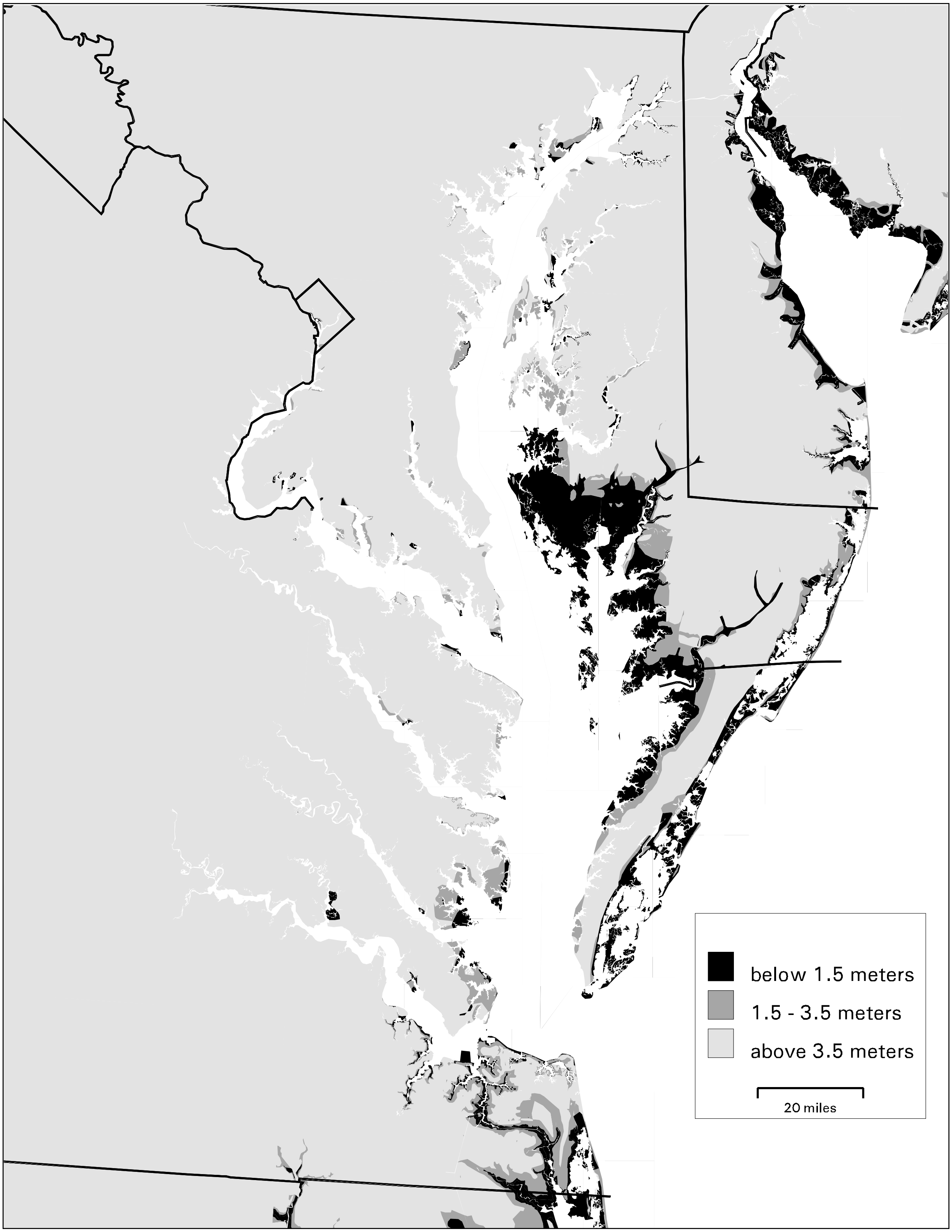


Figure 4-7. Elevations based on computer models, not actual surveys. Black regions show some areas that might flood at high tide if sea level rises 2 feet in the next century (including tidal variation and subsidence). Although the map illustrates elevations, it does not necessarily show the location of future shorelines.[16]

Island	Historic Acreage (Date)	Recent Acreage (Date)	% Lost	Comments
Poplar	1400 (1670)	125 (1990)	91	Abandoned in 1930†
Sharps	890 (1660)	0	100	Drowned in 1962
St. Clements	400 (1634)	40 (1990)	90	Abandoned in 1920s
Barren	700 (1664)	250 (1990)	64	Abandoned in 1916
Hoopers	3928 (1848)	3085 (1942)	21	Submerging
Bloodsworth	5683 (1849)	4700* (1973)	17	Submerging
Holland	217 (1668)	140* (1990)	35	Abandoned in 1922
Smith	11033 (1849)	7825 (1987)	29	Submerging

** Mostly marsh land*

†Poplar Island is now the site of significant reclamation efforts.

Table 4-2. Land area losses in the islands of the Chesapeake Bay through the historic past (adapted from S.P. Leatherman, 1995, Vanishing Lands: Sea Level, Society and the Chesapeake Bay).

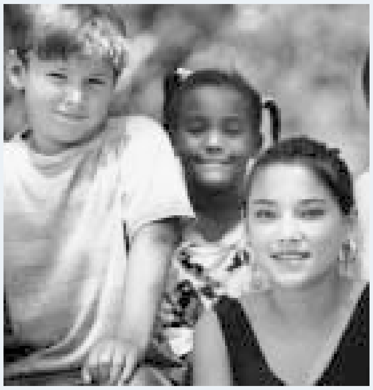
ultimate outcome of these countervailing trends will influence salinity distribution, circulation patterns, and the ecology of the future Bay. Rising sea level, combined with freshwater withdrawal, will also exacerbate the problem of saltwater intrusion, especially in relatively shallow wells. Farmers and others on the Eastern Shore are already experiencing this problem.

The range of projections of regional temperature increases (as projected by the PSU group) is based on two state-of-the-art global climate models used in the National Assessment, one developed by the Hadley Centre for Climate Prediction and Research in Great Britain and the other by the Canadian Centre for Climate Modeling and Analysis. Both models replicate the climate of the past century and then simulate future conditions based on similar assumptions for increases in greenhouse gases. These models produced quite dissimilar results beyond 2030, with the Canadian model predicting warmer and drier conditions in the later part of the century. Temperature increases will vary within the Mid-Atlantic region and will also vary seasonally, with greater predicted increases in winter than in summer.[17] While increases of 1.8° to 2.7°F by 2030 may seem small, they are equivalent to a shift southward of 100 miles or more. To put these changes in context, consider that the January temperatures in Washington, D.C. around 2030, as predicted by these two models as well as others, would be similar to January temperatures now characteristic of Hampton Roads, Virginia. By 2090, winters in Washington may be as mild as those of 20th-century Charleston, South Carolina or Atlanta, Georgia.

Although continued long, hot summers are expected, the more important changes for the Bay will likely be associated with warmer winters. Summer temperatures in the Bay will probably not be much higher, because evaporative cooling moderates rising water temperatures. Bay waters will likely warm earlier in the spring, however, and cool down later in the fall. Such changes will affect the Bay's seasonal physical, chemical, and biological cycles, influencing the duration of hypoxia, for example. Warmer winter temperatures will further reduce the frequency and extent of ice cover and will allow more temperate organisms to survive the Bay winter.

While specific predictions remain difficult, some cold-water species near the southern ends of their geographic range, such as the soft clam (*Mya arenaria)*, may become rare in the Bay. Alternately, warm-water species at the northern end of their range, such as the commercial brown shrimp *(Farfantepenaeus aztecus)*, may establish significant populations in the Bay. Also, warming of winter water temperatures could open the door to other

The Changing Face of America



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The region's human population will look different in 2030. Overall, Americans will be older. The Census Bureau predicts that the national median age will increase from 35.7 to 38.5 years. While this increase appears small, the changing age structure means that twice as many people over 65 years of age will live in the country compared to today. In addition to growing demands on Social Security and healthcare services—currently subjects of so much heated debate—this aging of the population has implications for many issues related to the Chesapeake Bay. These effects range from increased demand for recreation to changing dietary preferences to a growing potential cadre of retired volunteers.

As already apparent, the regional community will become increasingly more diverse. In the United States as a whole, the percentage of non-Hispanic white Americans is projected to decline from 72 percent to just over 60 percent between 2000 and 2030. While the percentage of African Americans should change only slightly, the percentage of Hispanic and Asian U.S. residents will grow from 15 to 25 percent. Between 1990 and 2000, according to the 2000 Census, percentages of Hispanics, Asians, and African Americans did increase in Maryland and Virginia. While the shifting appearance of communities in the Chesapeake region may be most apparent in some urban locations, smaller urban and suburban areas and even the agricultural areas of the Eastern Shore will show similar changes. Although social attitudes and behaviors are extremely difficult to predict, racial distinctions may become somewhat less meaningful due to intermarriage, racial mixing, and other factors as we move through the 21st century.[20] In any case, demographic changes may influence development patterns, consumption of goods and services, and policymaking. These changes may also shift the emphasis that the public will place on Chesapeake Bay restoration in light of competing priorities for education, health care, and other social programs.

warm-temperate invaders introduced by the discharge of ballast water by ships, through shellfish transfers, or by other means. In addition to shifts in estuarine species, temperature changes will also likely affect terrestrial species in the watershed. The PSU assessment predicts that the maple-beech-birch forests that characterize the northwestern part of the watershed will retreat, replaced by oak-hickory forests. Oak-pine forests will expand to cover much of the Coastal Plain.

The PSU estimates of changes in precipitation and runoff range widely. Regional variability and the complexity of processes influencing evapotranspiration and precipitation make the predictions of these changes less reliable than those for temperature and sea level rise. These estimates are based on the Hadley and Canadian Climate Centre models, and though the Canadian model predicts less precipitation than most other models, the Hadley model tends to agree with other models in predicting increased precipitation, especially during the winter.[18] Average annual precipitation has, in fact, increased by about 20 percent over the last century.[19] On the other hand, lower precipitation in the summer and increased evapotranspiration may force summer runoff to drop off from 20th-century norms. In addition to obvious effects on salinity distribution in the Bay and its tidal tributaries, such changing hydrography would affect our efforts to control nutrient and sediment runoff into the Bay. In fact, the combination of dry summers and wetter winters would probably result in an increased flux of nutrients into the Bay if all other factors controlling the sources remain constant. Larger winter and spring flows, coupled with warmer spring and summer surface water temperatures, would likely strengthen the density stratification of Bay waters, and thus cause more hypoxia.The PSU assessment also predicts a significant increase in storminess, albeit with low reliability. Such a change would mean more extreme rainfall events that result in stream flooding and the increased flow of sediments and nutrients to the Chesapeake.

We know that the average surface temperature of the earth has warmed by 1.1˚F since the late 1800s. This change, when considered with the cooling effects of sulfur dioxide pollution and solar influences, is consistent with model estimates of the greenhouse gas effect. Furthermore, both the scientific community and the public increasingly recognize that the occurrence of some of the warmest years on record during the 1990s probably heralds the human-induced global climate change that will affect our planet and humankind during the 21st century. To be realistic and successful, our efforts to shape the future of the Chesapeake must account for the significant changes likely to occur in the Bay within the next three decades, and beyond.

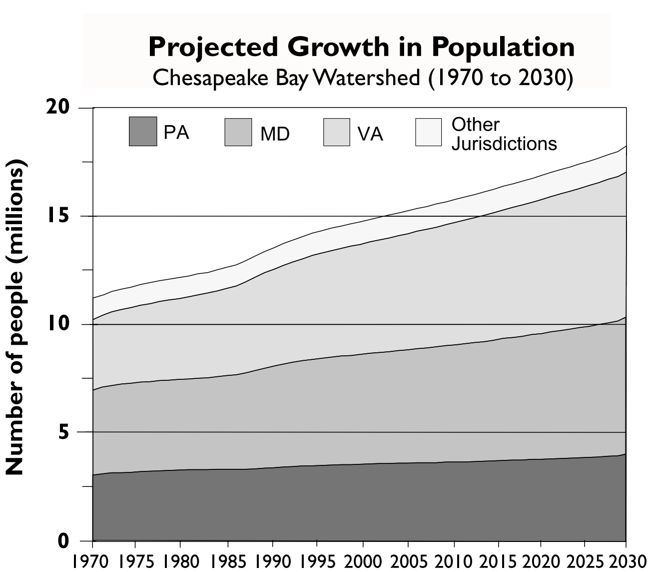


Figure 4-8. Population projections suggest that Bay-basin residents may approach 19 million by 2030. While the three major Bay states will see increased rates of population growth, Virginia is projected to have the greatest rate in the coming decades.

Human Population and the Economy

Unlike some European countries that are experiencing declining populations, the population of the United States is expected to continue growing during the early 21st century, due to its higher ratio of births to deaths and significant net immigration. The mid-range projection of the U.S. Census Bureau is that the U.S. population will reach 347 million by 2030, a 26 percent increase over 2000.[20] While the population of the Chesapeake Bay region is expected to grow at a slightly slower rate than for the nation as a whole, population shifts will vary within the region. For example, by 2030 Virginia's population should increase by a percentage equal to or greater than the national average, while the population of Pennsylvania should increase by less than 6 percent.

The population residing within the Chesapeake Bay watershed is projected to grow about 25 percent from approximately 15 million in 2000 to nearly 19 million in 2030. This jump is due not so much to intrinsically high birth rates or low death rates, but to continued net immigration into the region by foreign immigrants and through domestic relocation in response to economic opportunities and a perceived high quality of life. Chapter 5 considers the distribution of population growth within the watershed and its implications for the future of the Chesapeake Bay in detail. Generally, however, the fastest growing areas are close to the Bay and its tidal tributaries: the Baltimore-Washington metropolitan region, Richmond and Hampton Roads, and the suburbs and exurbs (a prosperous area of residences beyond the suburbs) surrounding these cities. Population growth in the hinterland will remain more modest.

These national, regional, and local population projections still contain obvious uncertainties. The Census Bureau's low-range estimate for the increase in the national population by 2030 is 7 percent; its high-range estimate is 46 percent. Significant population growth within the Chesapeake Bay region is a near certainty, however, barring severe economic problems or epidemics (Figure 4-8). Short of closing the door on the immigration of foreign nationals, no federal or state laws or regulations currently exist that could restrict population growth. Planning and zoning decisions will affect where people live within the region rather than how many people will live here. (Again, Chapter 5 provides additional detail on population and land use projections.)

Economic futures are probably more difficult to predict than environmental ones. Much of the Chesapeake Bay region experienced a booming economy during the 1990s, though a long-term cycle of expansion and recession continues. Discussions move from ways to eliminate the national budget deficit to discussions about a federal surplus and back to deficits again. During the end of the 20th century, the United States experienced what may have been its longest period of robust economic growth and nearly full employment, with inflation remaining at surprisingly low levels. A move toward recession, accompanied by the terrorist attacks of September 11, 2001, raises new concerns and uncertainties about the future. Will we have the economic wherewithal over the next 30 years to continue investing in the restoration of the Chesapeake? Will new economic forces present new risks for the Bay, or will they provide opportunities that allow us to deal with our current vexing problems?

Calvin Edgerton

While it is certainly prudent to consider scenarios under which employment may decline and income may flatten, most assessments suggest that the economic outlook for the Chesapeake region is good and will continue to be propelled by strong positions in technology and government services. Primary industries, including agriculture, mining, and materials manufacturing, have declined in their relative importance; this trend will likely continue due to production cost advantages enjoyed elsewhere in the new global economy. Information technology and biotechnology should become even more important to the evolving, knowledge-based economy.

Globalization of the economy is also increasing international maritime commerce in the United States and this commerce should continue to expand. Trends toward increased volume and larger carriers will present new challenges for maintaining and operating the Bay's channels and ports while improving environmental quality in the Bay. With the new world order, increased concern for national security emphasizes tactical deployment in addition to strategic defense. This focus on national security suggests that military activities in the region will remain an undiminished part of the Bay's future.

For the Bay, the ongoing shift to a service and information economy will continue the transition away from the economic reliance on factories and industrial plants—once the main threats to the Bay. Increasingly, roads and land development pose the biggest risks to the Bay's well-being.

Technology and Human Development

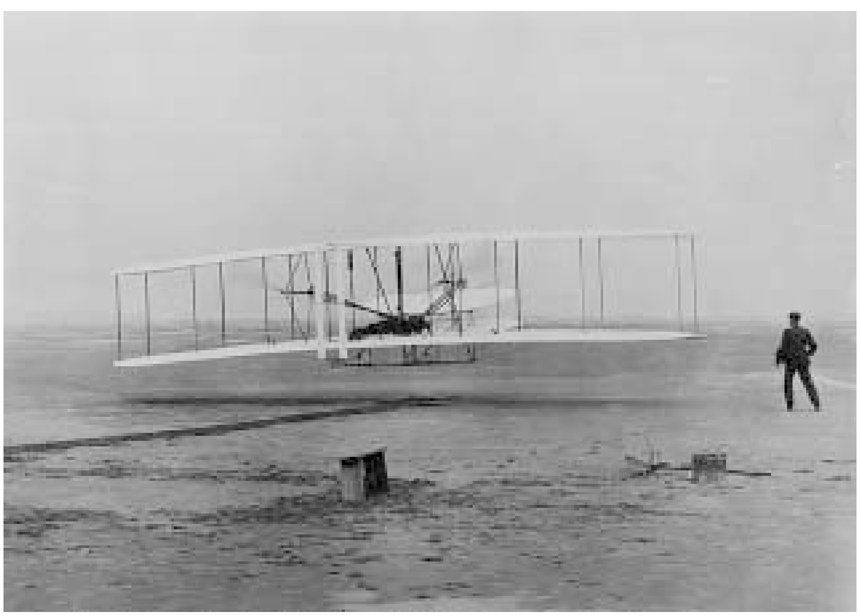
The ending of a century and the beginning of a millennium have produced much reflection on the extraordinary advances in science and technology, especially during the past 100 years. The remarkable technical revolutions of the 20th century have literally reshaped our understanding of the world around us—from subatomic particles to molecules and genes to the biosphere. New technologies have also clearly altered the way we live—from automobiles to pacemakers to the Internet. Although some pessimists may argue that we are at "the end of science,"[21] most futurists would argue that the pace of discovery and application of knowledge is likely to continue accelerating into the 21st century.[22]

As we shape our Chesapeake Future through 2030, we should be mindful that 30 years ago the scientific paradigm of Bay eutrophication that now drives so much of the restoration effort had not yet been clearly formulated. We had developed neither the scientific consensus nor the acceptance of policymakers. We now take for granted that elaborate, science-based models on supercomputers guide our actions in reducing eutrophication. What will the next 30 years hold in terms of practical advances and new explanations of the Bay's mysteries? Surely, we should not take a view of Bay science comparable to that adopted by Charles H. Duell, the director of the U.S. Patent Office, who recommended to President William McKinley in 1899 that the office be abolished because everything useful had already been invented.

What then can we anticipate as science's contribution in guiding us to a better Chesapeake Future? Near the top of the list must be the capability of grappling with the ecosystem's complexities by understanding the interrelationships among environments, actions, and resources in ways that allow more robust predictions of outcomes. Such new insights are becoming more likely thanks to technologies that permit the acquisition and analysis of vast amounts of data and allow development of computer models based on theoretical constructs but informed and corrected by real-world observations. Moreover, the application of existing and emerging technologies in such areas as agricultural production and waste minimization and treatment will shift "the limits of technology" in the forecast models used to assess future Bay conditions.

Chapter 8 covers in detail the opportunities that may be offered by advances of science and technology during the early 21st century. Here we simply point out that in addition to the shifting physical dynamics that will shape the Chesapeake Bay of the future—climate, sea level rise, sedimentation—social and technological changes, many likely unforeseen, will no doubt affect how we study the Bay, how we manage it, and how we use it. Among these changes will be the following:

- Information technologies will change where and how we work, shop, and interact. These changes will clearly have implications for development patterns and transportation systems that will, in turn, affect land use and runoff characteristics.
- Changes in energy technologies loom in the near future, including the potential transformation to a hydrogen technology. Such technologies have obvious implications for atmospheric emissions and, therefore, for deposition characteristics in the Chesapeake watershed.
- Biotechnology will no doubt continue to play an increasing role in agriculture and waste treatment with effects not yet known.
- Advances in environmental monitoring and monitoring technologies will provide better means for tracking the Bay's physical, chemical, and biological dynamics and how they are changing.
- Improvement in management technologies and approaches, such as adaptive management and co-



Courtesy of Smithsonian Institution

Now housed at the Smithsonian Institution's Air and Space Museum, the 1903 Wright Flyer was the first powered machine to achieve flight with a pilot aboard. Its inaugural flight came soon after Charles H. Duell, the director of the U.S. Patent Office, made his remarkable comments.

management regimes, have the potential to change the way in which we protect and guide the use of our natural resources.

Will those who live and work in the Chesapeake Bay region be able to couple a growing body of knowledge about this complex ecosystem with a mastery of technology and a broad awareness of the requirements for achieving some form of sustainability? The remainder of this report suggests where the challenges may lie as we confront the first three decades of the 21st century and the scenarios that may unfold—depending on what choices we make.

Endnotes

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[8] Kearney, M.S. and J. C. Stevenson. 1991. Island Land Loss and Marsh Vertical Accretion Rate Evidence for Historical Sea-level Changes in Chesapeake Bay. *Journal of Coastal Res*. 7 (2): 403–415.

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[11] Fisher, A., D. Alber, E. Barron, R. Bord, R. Crane, D. DeWalle, C.G. Knight, R. Naijar, E. Nizeyimana, R. O'Conner, A. Rose, J. Shortle, and B. Yarnel. 2000. *Preparing for a Changing Climate: The Potential Consequences of Climate Variability and Change: Mid Atlantic*. University Park, PA: Pennsylvania State University.

[12] Wigley, op. cit.

[13] Stevenson, J.C., J. Rooth, M.S. Kearney, and K. Sundberg. 2001. The Health and Long Term Stability of Natural and Restored Marshes in Chesapeake Bay. In M.P. Weinstein and D.A. Kreeger (eds.). *Concepts and Controversies in Tidal Marsh Ecology.* Dordecht, Netherlands: Kluwer Academic Press.

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[16] Titus, J.G. and C. Richman. 2001. Maps of Lands Vulnerable to Sea Level Rise: Modeled Elevations Along the U.S. Atlantic and Gulf Coasts. *Climate Research* 18: 205-228. This map is based on modeled elevations, not actual surveys or the precise data necessary to estimate elevations at specific locations. The map is a fair graphical representation of the total amount of land below the 1.5- and 3.5-meter contours, but the elevations indicated at particular locations may be wrong. Those interested in the elevations of specific locations should consult a topographic map. Although the map illustrates elevations, it does not necessarily show the location of future shorelines. Coastal protection efforts may prevent some low-lying areas from being flooded as sea level rises; and shoreline erosion and the accretion of sediment may cause the actual shoreline to differ from what one would expect based solely on the inundation of low land. This map illustrates the land within 1.5 and 3.5 meters of the National Geodetic Vertical Datum of 1929, a benchmark that was roughly mean sea level in the year 1929 but approximately 20 cm below today's sea level.

[17] Wigley, op. cit.

[18] Wigley, op. cit.

[19] Karl, T.R. and R.W. Knight. 1998. Secular Trends of Precipitation Amount, Frequency and Intensity in the United States. *Bulletin of the American Meteorological Society* 79: 231–241. The Mid-Atlantic Regional Assessment (MARA) puts this increase at 10 percent.

[20] U.S. Census Bureau report. 2000. *www.census.gov.* Historically, the blurring of racial distinctions has been more common, for example, in South and Central America, and Mexico.

[21] Horgan, J. 1996. *The End of Science: Facing the Limits of Knowledge in the Twilight of the Scientific Age.* Reading, MA: Addison Wesley.

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Development and Sprawl

Just as the history of land use in the watershed has had major effects on the Bay ecosystem, so too will changes in the landscape of the Chesapeake over the next 30 years determine the Bay's future. There are four key driving forces that will paint the landscape portraits of the 21st century: climate, urban and suburban development, agriculture and forestry, and land conservation. Before addressing changes in agriculture and forestry, we first examine the patterns and effects of development throughout the watershed. The spread of suburban development, in particular, has reshaped the landscape during the last half-century, increasing sediment loads to the Bay and its tributaries and flushing nutrients into the estuary.

Patterns of Growth

The coastal regions of the United States, including portions of the Chesapeake region, are experiencing some of the fastest population growth rates in the country.[1] An average of 334 new people move into the watershed each day.[2] According to the 1997 Natural Resources Inventory, 128,000 acres of "natural" land are converted to urban and suburban uses every year in the watershed.[3] Between 1990 and 2000, the rate of land conversion in the watershed more than doubled over the previous decade.

Of greater concern, however, is change in the *ways* people live. Many metropolitan areas throughout the United States have witnessed an exodus of tax-paying residents as people move out of the cities and into the suburbs. Baltimore, Washington, and Richmond have experienced population losses for decades as their surrounding, traditionally rural counties swell with new residents.[4] Out-migration from the urban core to the suburban fringe, conversion of natural lands into low-density, haphazard development, and burgeoning road and other transportation systems have led, in part, to the phenomenon known as sprawl.

The Sierra Club rated Washington, D.C. the third most sprawl-threatened large city in the U.S.[5] Over the past 16 years, the number of houses in this part of the country has increased more than *twice* the rate of population growth;[6] one-third of all development in the watershed has taken place since 1982.[7] Furthermore, the average size of new single-family houses grew from 1,500 square feet in 1970 to 2,265 square feet in 2000,[8] and the amount of land that each individual home consumes has increased by almost 60 percent. At the same time, the number of people per household has decreased.[9] Collectively, these facts signify that each person is occupying more space and consuming more resources.

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Sprawl Begets Sprawl

In recent decades, the modern version of the "American Dream" has caused some of the greatest impact on the Bay and its watershed. Acquiring an individual detached home on a private lot, away from the urban life, has become that dream. In the fifties and sixties, the pursuit of this goal resulted in suburban development on small to moderate lots, often in sewered areas expanding from metro cores. Now, the dream is increasingly fulfilled on agricultural and rural land subdivided into large lots on septic systems.

A prerequisite for the extensive sprawl in the Bay watershed is a large market of homebuyers who can afford residences in these areas. These homebuyers are generally employed in metropolitan areas, commuting to these jobs on a daily basis. As highways expand and design speeds rise to accommodate the resulting traffic, the "commuter-shed" (the areas from which people are commuting to metro employment centers) also enlarges and leads to a damaging cycle of self-perpetuating residential, commercial, and highway development.

The following factors lead to sprawl and its consequent problems:

- The desire to live near open space leads to conversion of rural lands and subsequent loss and degradation of existing open space. New development must then locate even farther away, or leapfrog, so that it can also be near receding open spaces.
- For different reasons, people are leaving many of America's cities. Often the poor are left behind—as has happened in Baltimore—which steadily lost population for five decades. Baltimore possesses 63 percent of Maryland's welfare caseload despite having only about 12 percent of its population.[10] As schools, infrastructure, and employment worsen, more people leave.[11]
- Older suburbs can experience deterioration similar to that of the urban core. These suburbs are often overlooked for newer suburbs closer to open space.[12]
- The search for better schools often leads to a population influx in districts with a reputation for quality education. Ironically, the increased number of students strains classroom space and resources, threatening the quality of that education.[13,14]
- Jobs are also moving out of cities. Communication technology enables some people to live farther away from work, bringing both positive and negative effects. Residential development can follow employment growth to the suburbs.[15] A study of the Washington, D.C. metropolitan area, for example, found that despite its infrastructure, the city itself has only one-quarter of the jobs in the region.[16] As jobs move to the suburbs, unemployment in urban areas increases for those who cannot afford the automobiles and other costs associated with commuting.[17]

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Several factors contribute to this type of development, with sprawl itself often exacerbating the undesirable trends and creating a vicious cycle (see "Sprawl Begets Sprawl" box). Factors often cited at the root of sprawl include: zoning policies; a lack of effective regional planning; government subsidy of roads, highways, and housing; competition among local governments for tax revenues; and residents' desire for a higher quality of life, including good schools and proximity to open space. Though towns promote growth for many reasons, they don't always specify what kind of growth is desirable and often fail to articulate a vision for their future.[18]

Consequences of Sprawling Development

New residential development around the Chesapeake Bay generally exhibits the familiar "checkerboard" pattern that has typified suburban development throughout the United States over the past forty years. Subdivisions look the way they do in part because they are governed by engineering and zoning restrictions for minimum road frontage, setbacks, and lot size. Importantly, typical suburban designs incorporate the "basic ingredients of many popular, stable neighborhoods with high property values."[19]

Developed land actually occupies a smaller percentage of watershed acreage than forests and agriculture. When development converts open natural land into impervious surfaces, however, it can create or worsen water quality problems. Urban and suburban lands contribute greater amounts of nutrient pollution on a pound-per-acre basis than any other land use other than broken soil agriculture.[20]

The uniform placement of houses in subdivisions frequently does not account for each parcel's ecological and physical characteristics. In fact, large land tracts are often stripped of all vegetation and regraded prior to construction. This practice changes a region's hydrology, disrupting natural waterflow patterns, greatly increasing sediment and nutrient loads into nearby streams, and eliminating any on-site benefits due to the original vegetation (e.g., shading, animal habitat, sediment retention).[21] Subsequently planted vegetation, such as young trees and lawns, may require years to provide equivalent ecological benefits. Often they never reach their former levels of benefit.

Where development impacts riparian forests, it often reduces the important ecological values and functions of these forests. Riparian forests—wooded areas along a river or stream bank—connect natural communities and foster the movement and exchange of plants, animals, nutrients, and energy.[22] Riparian forest vegetation moderates the light and temperature of streams and their associated corridors. Its complex of tree roots, woody debris, and other organic matter filters runoff and sequesters nutrients.[23,24,25] Streamside vegetation also stabilizes the channels, moderates water temperatures in the bordering streams, prevents erosion, and attenuates flooding. Widespread upland disturbance, which can increase sediment loads and flow rates, impairs the ability of riparian forests to protect water quality.[26] As population numbers swell, the quantity of nutrient-rich wastewater discharged to the watershed also rises. In areas served by municipal sewer facilities, increased population adds to the volume of wastewater requiring treatment.

Since new development increasingly takes place in rural areas, individual septic systems are frequently necessary to treat wastewater. Unfortunately, septic systems often discharge nutrients directly to groundwater, which may feed into surface waters and contribute significant quantities of nitrate to streams, rivers,[27] and groundwater. Failing septic systems can cause shellfish contamination and introduce unsafe levels of human pathogens to surface waters.[28]

Approximately 25 percent of the housing units in the watershed are served by septic systems, which contribute an estimated 33 million pounds of nitrogen per year to the watershed, mostly to groundwater. Almost one million pounds are loaded directly to the coastal zone of the Bay.[43] While advanced nitrogen-removing septic designs exist, they are not required in most cases.

Paving the Land

The increase in impervious surfaces associated with development—roads, rooftops, driveways, and parking lots—significantly affects the hydrology of the landscape[29] and, consequently, the Bay. Precipitation that formerly penetrated the soil and replenished the groundwater becomes concentrated. This concentration leads to increased volumes of stormwater runoff, higher peak flow rates, and in some areas, prolonged bankfull stream flow. Compared to pre-development conditions, these changes in hydrology result in severe direct and indirect impacts on surface water and groundwater quality:

- Increased and more severe flooding and erosion.
- Streambank erosion, channel instability, and loss of good aquatic and riparian habitat.[30]
- Lower baseflows from reduced rates of groundwater recharge.[31]
- Changes in the hydrologic and biological character of streams with impervious surfaces covering as little as 10 percent of a watershed.[32,33,34,35]
- Declines in macroinvertebrate and fish species diversity in streams experiencing upstream development.[36,37,38,39]
- Increased inflow of pollutants such as pesticides, fertilizers, animal wastes, sediments, nutrients, and heavy metals, as stormwater runoff sweeps contaminants into streams and eventually the Bay. As land conversion increases and activities change and intensify, the concentrations and types of contaminants also increase.[40]

Land Use	Percent Impervious Cover	Percent Runoff	Stream Habitat
Open Areas	0 - 10	10	Protected
Residential, Low Density	20 - 40	20 - 30	↑
Residential, Medium Density	35 - 45	30	↕
Residential, High Density	45 - 60	30 - 50	↓
Business District or Shopping Center	95 -100	55	Degraded

Table 5-1. Percentage impervious cover associated with various land uses.[41,42]

Typically, septic systems require that individual lots be spread out to provide adequate space for leach fields. Sewer systems, on the other hand, transport wastewater to a central location for treatment before releasing it to the aquatic environment, thus allowing for higher-density development. Most wastewater treatment plants use secondary treatment, which removes little of the nitrogen from the effluent. Since nitrogen has become a significant pollutant in the Chesapeake Bay, however, this region has become a leader in the application of advanced wastewater treatment—such as biological nutrient removal (BNR) and nutrient reduction technology (NRT)—for wastewater treatment. Currently, BNR technology treats about half of the wastewater discharges in the watershed during the warmer months of the year with more complete implementation anticipated (see Technological Solutions chapter).

New development entails more than residential construction. In addition to houses, the driveways, curbs, connecting streets, sidewalks, sewer systems, and septic tanks all become part of the development package. Local governments of sprawling municipalities experience increased costs of services such as water, sewer, roads, and school systems, because revenues from new growth often do not offset costs associated with greater demand for services.[44]

The movement of middle and upper class residents from the urban core to the rural fringe has implications for both the cities left behind and the newly inundated rural communities. Sprawling towns often experience a change in—or even loss of—community identity. On the other hand, towns often shun municipal sewer services and preserve large-lot zoning to maintain their rural character, often resulting in—"land-hungry septic tank sprawl."[45] Sprawl threatens the existence of farmland and creates conflict between newly settled suburbanites and the resident agricultural community. People who move to small towns for their picturesque, rural character suddenly find themselves complaining about the nuisances of the country: noise, odors, stray animals, pesticide spraying, farm vehicle traffic, and dirt roads. Such conflicts can result in new residents rejecting and remaking the very character that attracted them to a place.

Fighting Sprawl

Across the country, communities increasingly frustrated with sprawl are turning to new kinds of land use policies that allow towns to grow with less impact on the surrounding environment. The Chesapeake Bay region is considered, in many ways, a leader in this effort. With the *Chesapeake 2000* agreement, for example, the Bay states have committed to permanently preserve 20 percent of the watershed from development, reduce the rate of "harmful" sprawl by 30 percent, and restore 2010 miles of riparian buffer by the year 2010.

Virginia, Maryland, Pennsylvania, and Washington, D.C. have made considerable progress in achieving the *Chesapeake 2000* goal to "permanently preserve from development 20 percent of the land in the watershed by 2010." As of the turn of the millennium, almost 7 million acres in the watershed were preserved, with just over one million acres still in need of protection. Reaching this goal, however, will likely require new programs and innovative sources of funding.[46]

In 1999, Pennsylvania dedicated $65 million for establishment of its Growing Greener Program. This program focuses on preserving farmland and open space, restoring watersheds and abandoned mines, supplying new and upgraded water and sewer systems, and eliminating the maintenance backlog in state parks. At the same time, the state's nationally recognized Land Recycling Program develops vacant brownfields (abandoned industrial sites) into productive and safe job-producing sites. The program offers various incentives—from a streamlined review process to improved funding to liability protection—to encourage renewal of these sites.

In Maryland, the state's Smart Growth initiatives promote alternatives to sprawl, focusing on the location and design of new development. Underlying the Smart Growth concept is the notion that infill development, or redevelopment, on previously unused or underused land in existing centers can revitalize these communities and preserve surrounding natural land. "Filling-in" existing communities reduces the number of vehicle miles traveled, uses existing infrastructure, reduces the use of septic systems, and encourages remediation of contaminated "brownfields" sites.[47] Smart Growth programs direct state resources to support new construction in areas where infrastructure is planned or already in place. Local governments designate areas for growth as "Priority Funding Areas" which are eligible to receive state infrastructure funding, as well as economic development, housing, and other program monies. Master plans and land conservation programs can then target natural resource areas and historical landmarks for preservation.

"Harmful sprawl" is poorly planned expansion that destroys green space, exacerbates traffic, and inflicts costs on those in the community.[56] The key to reducing sprawl is more concentrated development, with much of the growth in designated growth areas. Such a strategy steers new housing toward centralized sewer systems, which effectively treat wastes and reduce nutrient loads to the watershed.

Importantly, this concentrated development requires far less land conversion per household than do various forms of sprawl, including traditional suburban and large-lot residential subdivisions in areas lacking infrastructure and services, such as sewer. The latter type typically results in residential lots ranging from about a quarter of an acre up to five or more acres. Well-designed, concentrated, desirable mixed-used neighborhoods can average ten or more dwellings per acre. Thus, concentrated development can accommodate a given population on much smaller amounts of land.

Concentrated development also centralizes the population along with the resources and services that help boost the quality of life. People travel short distances to jobs, school, shopping, and entertainment, resulting in fewer roads, less traffic, reduced auto emissions, and, if advanced waste water treatment is used, minimal pollution from human sewage.

In contrast, sprawling suburban and rural development separates people and their everyday destinations, requiring extensive roads, generating additional traffic, and resulting in more air pollution. The total amount of impervious cover grows to accommodate the roads and services demanded by a rising population. The impacts on

On the Road Again

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The migration of residents from urban areas means that people often live farther from where they work, shop, or go to school; suburbanites generally drive farther and spend a greater amount of time in their cars. While the nation's population increased by 35 percent between 1970 and 2000, the increase in the area of developed land was more than twice that. Meanwhile, the increase in the number of licensed drivers rose nearly twice as fast as the population, the number of vehicles almost three times, and the number of miles driven grew more than four times faster than the U.S. population. In the Chesapeake watershed, the population grew by 27 percent between 1970 and 1995, while the number of vehicle miles rose by 106 percent.[48] One study estimated that commuters in Washington D.C. spend the equivalent of 76 hours per year stuck in traffic jams.[49] This tremendous increase in the reliance on vehicles results in greater air pollution and contaminated runoff and requires new roads, more road repair, and additional money spent on car repair and gasoline. Increased traffic and narrow roads are oft-cited reasons for building new and bigger roads, but some studies have found that building these roads has little long-term impact on road congestion and can actually generate additional traffic.[50]

Automobile-related sources of pollution include motor oil, by-products from tire and road wear, soot, and exhaust. Studies of lake and reservoir sediments have revealed that increased concentrations of polycyclic aromatic hydrocarbons (PAHs) associated with combusted fossil fuels coincided with increased automobile use in the watersheds. Increased vehicle traffic in the watershed can adversely affect water quality, even if the actual growth occurs outside of the watershed.[51]

Vehicle emissions are responsible for 49 percent of the nitrogen oxides and 37 percent of volatile organic compounds released to the atmosphere.[52] There, they combine to form low-level ozone, a chemical that causes acute respiratory problems, aggravates asthma, and reduces lung function.[53,54] In 2002, from May 1 to September 11, Washington D.C. had 15 Ozone Action Day Forecasts (12 Code Red and 3 Code Orange), in which air quality reached unhealthy levels, especially for children and the elderly.[55] With issuance of a Code Red standard, people are advised to avoid strenuous activities outdoors.

land resources and watersheds—including habitat destruction, pollution, and stream impacts—are widely distributed. Areas of agriculture and rural natural resource populations that require large contiguous tracts of undisturbed land become rare or nonexistent. Streams become degraded by altered hydrology, prolonged bankfull flow, erosion, and pollution from runoff and septic systems.

Successful concentrated growth areas require a necessary counterpart: restrictions on the amount of development outside of growth areas. One objection to this practice is that it reduces land values: "If I can't develop as many houses on my property, it's not worth as much." Where significant development pressure for rural land exists, however, restrictive zoning is very effective when used in combination with programs to transfer or purchase development rights from the owners of the restricted land, and does not reduce land values.[57] Where little or no development pressure exists, such restrictions become irrelevant to land value; in these cases the value rests on the usefulness of the land for rural resource-based usages, such as farming.

One alternative form of residential subdivision—cluster or open-space zoning—has received considerable attention across the country, especially in rural areas (Figure 5-1). The intent of cluster zoning is to provide housing for the same number of people on the same total amount of land as does traditional suburban subdivision, but with less severe impacts on the rural land and associated resources. In this way, it can avoid landowner objections about the impacts of restrictive zoning on land values. The objectives of clustering are accomplished by concentrating houses on closely spaced, small lots, leaving key ecological, physical, and historical characteristics on each parcel undisturbed.[58] This undisturbed land in the resulting community is then preserved as natural area or open space, for use by all of the residents.

Despite the attention received by the concept, cluster zoning in its popular forms causes essentially all of the same impacts as suburban and rural sprawl when compared to concentrated development, although the impacts may be slightly less. Cluster subdivisions are most common in outlying or rural areas, separating people from their everyday destinations and resulting in many of the same demands and impacts as sprawl.

Cluster Subdivision

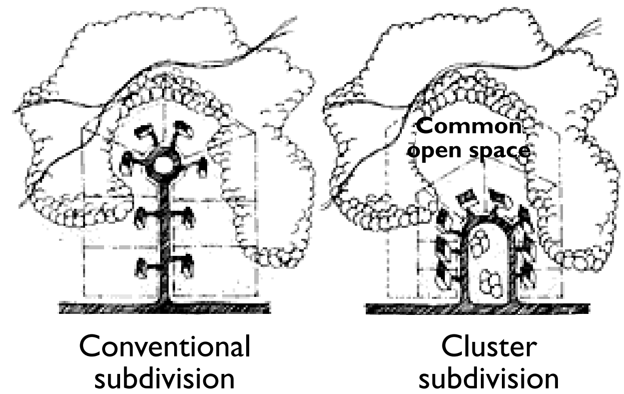


Figure 5-1. While cluster development reduces a subdivision's footprint, a given parcel of land developed outside planned growth areas and beyond the reach of current infrastructure does not solve many of the problems created by sprawl.

More importantly, clustering often doesn't succeed in providing a significant measure of protection to rural land and associated resources. To do so, the areas to be protected and preserved, as well as the appropriate extent of those areas, must be given first priority in the cluster development process. The appropriate number and location of clustered houses can then be determined on the remaining land.

Unfortunately, few cluster ordinances operate in this way. Rather, developers first locate the same number of houses and septic systems that would be possible without clustering, focusing on preservation objectives secondarily. This process results in the use of prime agricultural soils and proximity to desirable landscape features for houses, lawns, and septic drainfields—often compromising the use of the remaining land for agriculture. This situation is particularly true if the houses make up a residential neighborhood; residents don't like the nearby spread of manure, crop dusting or farm machinery noise. It also compromises the ability of the remaining land to support wildlife that requires continuity of habitat. Thus, one of the principal selling points of clustering—high lot yields—compromises its ability to deliver on environmental protection in a manner comparable to restrictive zoning, including ultimate impacts on the Bay. And, while cluster development may represent an improvement over more common suburban and rural residential subdivisions, in most cases its benefits for rural terrestrial resources, as well as the Bay, are likely marginal.

In some communities, custom "packet" systems hold promise as a means to process household wastes. At present, however, such alternative applications are rare. Progressive and innovative nonpoint source pollution control practices, such as low-impact development (LID) and alternative stormwater management techniques, can also lessen the impacts of development on water resources and the environment. For example, narrower streets, sidewalks on only one side of the road, and the use of pervious materials (e.g., gravel) for driveways limit the amount of impervious surface. The use of rain barrels, rain gardens, sunken medians, roof drain infiltrators, and other tools to catch or stall rainwater instead of funneling it into culverts can moderate the amount of water and sediment entering nearby streams. These approaches depend on participation from individual homeowners, as well as developers and planners. The strength of LID strategies is that they do not require huge government investment, but rather commonsense conservation measures by those living in the watershed. Just as farmers employ best management practices (BMPs), homeowners could also use appropriate BMPs that result in more native plants, less runoff of rainwater, and less area dedicated to lawns that require fertilizer, herbicides, pesticides, and mowing with gasoline-powered lawnmowers.[59]

Thus, while it may seem counterintuitive to advocate higher density development to protect land and water resources, it is, in fact, fundamental to successfully limit the impacts of continued growth and development on the Bay and its watershed. This situation would not exist if the overall population in the watershed was small, where most could live in houses scattered sparsely over extensive tracts of preserved forest and farm fields and travel only short distances to everyday destinations. Given the current population and its continuing rise, however, such a situation is simply not possible.

High-intensity developments, even when well planned, still cause environmental impacts to the Bay. Current and future population numbers, however, dictate that the alternative is some form of sprawling residential and commercial growth. The impacts of such an alternative on land and water resources, whatever the details, will be worse, for the reasons discussed previously. With an expected population increase of nearly 4 million residents by 2030, concentrated growth in areas served by well-planned infrastructure, and corresponding protection of large, extensive tracts

Tim McCabe, USDA NRCS

If sprawl continues unabated, expansive rural landscapes such as this one will become increasingly rare.

of rural resource lands, appears to be the only hope if we are to minimize the impacts of an increased population on the Bay and its watershed resources.

Accomplising such planned development would mean overcoming many obstacles in order to change the social behaviors that determine land use patterns. Since these behaviors are well-established, all parties involved—state and local governments, lending institutions, developers, and citizens—raise considerable resistance to the change. Cookie-cutter subdivisions are arguably easier and faster to build, finance, and manage than carefully designed infill development or redevelopment of existing communities.

These obstacles notwithstanding, positive change will require a shift in economic and social behavior toward development of these types. In addition to the environmental imperative, careful community designs that place residents close to the daily necessities and amenities that are part of a healthy lifestyle—jobs, shops, groceries, entertainment, open space, and recreation—also contribute to fiscal stability for businesses, government, and individuals, enhancing the region's quality of life.

Approaching issues in a coordinated fashion—whether on town, county, or regional scales—can achieve impacts with greater efficiency. Such coordinated strategies can include developing public transportation networks, restoring stream habitats that pass through multiple jurisdictions, designating urban growth boundaries, and purchasing land for conservation.[60] Effective growth management will require comprehensive regional approaches because techniques that only limit growth within a particular locale can drive development to other areas with no restrictions.[61]

Furthermore, focusing solely on growth management and land preservation does not address the social and economic problems of urban areas exacerbated by sprawl, such as the depopulation of urban centers and the exit of capital and community services.[62] Such problems demand different solutions, such as regional tax-base sharing and development of quality low-income housing.[63]

Finally, actions to slow and prevent sprawl will require not only modifications in policies and regulations, but also changes in what people view as desirable in where and how they live. These transformations can only occur through efforts of state and local governments and the development community, coupled with increasingly widespread public understanding of the issues and values at stake.

Unless developers are guided by motives other than amount and ease of profit, the incentives to invest in concentrated development must outweigh those in favor of more sprawl. In turn, the market for development products—potential businesses and residents—must insist on quality from the development community and from local government overseeing land use and development. The result will be successful, concentrated developments, such as mixed-use communities in and around existing neighborhoods, which gradually become an increasing force in the market. The main question is can such developments become the norm, and how soon? The answer will determine which Chesapeake future becomes reality.

In a survey by the Chesapeake Bay Program, those living in rapidly developing areas cited population growth as the leading cause of pollution.[64] Though the general public has expressed growing concern about this issue, the way in which citizens vote with their dollars will largely mold how development unfolds in the future. No matter how land use patterns take shape, balancing growth demands with concerns for environmental quality will prove crucial for the future health of the Chesapeake.

Scenario Assumptions

Projections for different land use patterns over this large watershed during the next thirty years could cover an entire spectrum of possibilities. In this exercise, consistent with the entire *Futures* project, we focus on three specific scenarios that present plausible alternatives for different levels of growth management throughout the watershed. They represent a quantitative analysis of the outcome of diverse management practices for one of the definitive changes in the watershed over the next century—the increase in the sheer number of people living on the land surrounding the Chesapeake.

Naturally, in a predictive exercise such as this one, we necessarily make many assumptions. Assumptions are inherent in the scientific process, but recognizing the import and limitations of the assumptions is critical. Chapter 2 contains a more complete discussion of the assumptions used and their role in the process.

Population Projections

Analyses by NPA Data Services, Inc.[65] for the National Assessment of the Potential Consequences of Climate Variability and Change[66] provided the population projections for all of the counties falling—either entirely or in part—within the Chesapeake Bay watershed. These are the same projections used in the Mid-Atlantic Regional Assessment,[67] which included the Chesapeake watershed.

The NPA projections include population by age class, households, employment by sector, and income by source for three growth scenarios. Only estimates of the total population by county under the middle growth (baseline) projection were used here. The NPA projections cover the entire region, use consistent methodology and assumptions, and extend to the year 2050. The projections for a specific county may vary from those developed by the states or local jurisdictions, but the NPA projection provides a reasonably sound basis for this generalized analysis, especially considering the highly speculative nature of 50-year projections.

Development Projections

How projected population growth (Figure 5-2) will translate land resources into residential, commercial, public facility, transportation and other forms of development is, of course, the key issue. The way in which local governments manage land use and growth will determine, in large part, the result. Predicting each local government's performance in this regard is beyond the scope of this general, basinwide analysis. Rather, current growth patterns and associated land use management practices were sampled in numerous jurisdictions throughout the watershed. We recognize that this synoptic approach may not be directly applicable for any given locale within the basin, but believe that it does provide a reasonable basis for comparing the consequences of the three *Futures* development scenarios for the watershed as a whole.

In a nutshell, the Recent Trends scenario projects recent land development patterns into the future as a function of population growth; the assumptions under the Current Objectives scenario reflect measured results of more progressive land use management approaches being implemented in some regions of the watershed; and the Feasible Alternatives scenario simulates even more advanced development management techniques, currently practiced by relatively few jurisdictions in the watershed.

These projections were accomplished by measuring growth patterns and rates of land use change associated with those land use practices prevailing in most jurisdictions and quantifying the rates of land use change on a per-new-household basis (Recent Trends). The same exercise was carried out for practices and patterns that represent typical Current Objectives for land use and growth management among the Bay states as well as for those practices and patterns representing the very best growth management techniques currently in use within the Chesapeake watershed (Feasible Alternatives).

The set of "multipliers and associated management practices" listed in Table 5-2 represents the results of these exercises. The multipliers quantify the rate at which each land use change occurred in the "average" rural or metropolitan locality (corresponding to the low- and high-rates for each parameter in Table 5-2) practicing land management approaches that correspond to the scenario definitions. These numbers were derived from studies by the Maryland Department of Planning in over 300 small watersheds, in

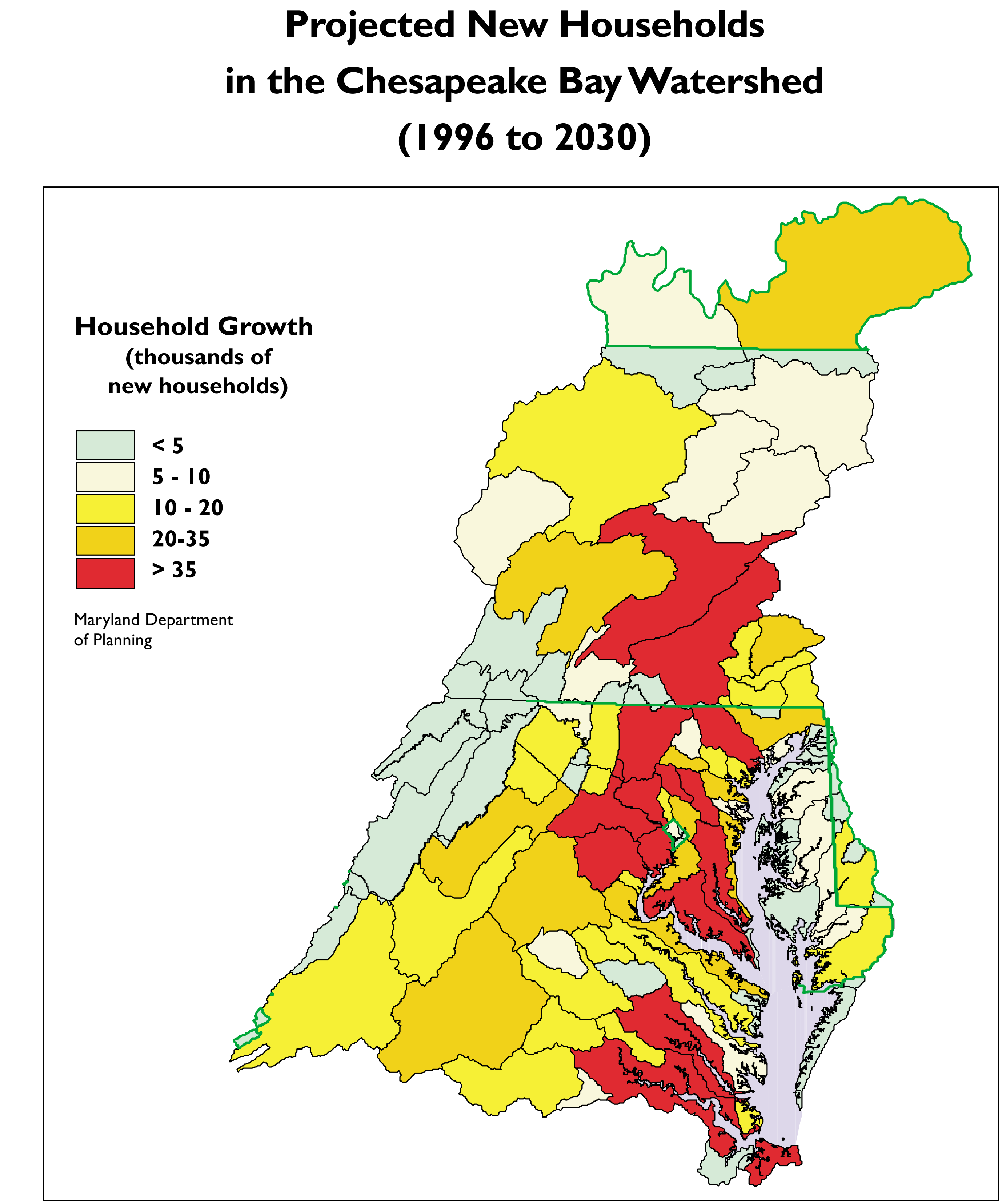


Figure 5-2. Recalling land use patterns of the Colonial period, new development will likely follow some of the Bay's larger tributaries—the James, the York, the Potomac, the Patapsco. But new development will also spread into the commuter-sheds of large cities, for example west of Richmond, Washington, Baltimore, and Philadelphia. How much land these homes consume will depend on land use planning, connections to current infrastructure, and the evolving demands and behaviors of new homebuyers.

	Recent Trends Scenario	Current Objectives Scenario	Feasible Alternatives Scenario
Percent new households on sewer	56 – 74%	74 - 82%	90 - 98%
Acres commercial/industrial land per new household	0.10	0.06 - 0.09	0.03 - 0.04
Acres infill/redevelopment per new household	0	0.06 - 0.12	0.07 - 0.15
Acres resource land lost per new household	1.03 – 1.55	0.42 - 0.91	0.14 - 0.24
Density of new residential development (units/acre)	0.6 – 1.1	1.1 - 2.4	2.9 - 5.9
Average lot size (acres) per new household	0.91 – 1.45	0.41 - 0.93	0.17 - 0.34
Acres impervious cover per new household	0.21 – 0.31	0.13 - 0.21	0.08 - 0.11
Forest conservation on development sites	Inconsistent	5% - 25%	10% - 50%
Riparian buffer conservation on development sites	Inconsistent	50 feet	100 feet
Open space conservation on development sites	Inconsistent	10% - 75%	10% - 75%
Conventional septic system permitting	Permissive	Permissive	Restrictive
Transferable Development Rights zones: acres preserved/acres lost	Negligible	1/20	4/1
Rural land acres preserved/acres lost	Negligible	1/3	1/2

Table 5-2. Multipliers and associated management practices for projected development patterns under the three Chesapeake Futures scenarios.

jurisdictions experiencing different development pressures and practicing a range of management approaches.[68] Although these multipliers vary among the watersheds and may differ in other jurisdictions, they provide an empirical basis for determining future projections.

Information about land use management practices and limited data on rates of land use change from jurisdictions in Pennsylvania and Virginia indicate that rates in these states are generally equal to or greater than the Recent Trends multipliers. Thus, the multipliers for Recent Trends probably result in conservative estimates of land use impacts on a watershed-wide scale. Table 2-1 enumerates the typical zoning, subdivision, and development plans, regulations, and procedures corresponding to each scenario. Under each scenario, land use changes were estimated by county, using the multipliers in Table 5-2 and the projected number of new households in the county. These estimates of change due to new households were then added to (or subtracted from) the corresponding statistic for each county for the year 1996. The results for each county are estimated total numbers for 2030 of new households on sewer and septic; acres of commercial/industrial land; acres of new development of various types; acres of impervious cover; and acres of resource land (both forest and agriculture) converted to new development.

Effects on Nutrient Loadings

The county population land development projections were allocated to the geographic segments of the Chesapeake Bay Watershed Model (which represent smaller watersheds, or segments thereof, within the Chesapeake watershed) proportionally. That is, if a county lies across three model segments, it was assumed for simplicity that the new land developed within the county would be distributed among the watershed segments in proportion to the relative amount of the county's land area that falls within that segment.

The effect of this land development on nutrient loadings to the tidal waters of the Chesapeake Bay was then estimated using in-stream loading rates of nitrogen and phosphorus that are functions of the amount of land developed.[69] Table 5-3 shows the median loading rates for nonpoint runoff, point sources, and septic system inputs for the three scenarios. In actuality, the rates applied ranged around these means depending on the location of the model segment within the watershed. The loading rates do not change considerably among scenarios, with the exception of point source nitrogen rates, which assume progressively more advanced waste treatment in each scenario (see Technological Solutions chapter).

For septic systems, this analysis assumed that 50 percent of the new septic systems under the Feasible Alternatives scenario would be of an advanced design that would allow greater nitrogen source control. On the other hand, in areas where the limited availability of public sewer is used as a way of controlling growth, widespread use of alternative septic systems might actually increase sprawling residential development if conventional systems are not a viable option due to soil conditions.

	Loading Rate (lbs/acre/yr)		
Scenario	**Recent Trend**	**Current Objectives**	**Feasible Alternatives**
Pervious Urban, N	9.6	9.5	8.7
Pervious Urban, P	0.40	0.37	0.34
Impervious Urban, N	11.0	11.0	9.1
Impervious Urban, P	0.94	0.92	0.88
Point Sources, N	5.1	4.0	2.1
Point Sources, P	0.35	0.33	0.12
Septic Systems, N	4.2	4.2	2.1 - 4.2

Table 5-3. Median in-stream loading rates used in the development scenarios.

Impacts on Resource Lands and Streams

Projections of new land development permit general estimates of the impacts on resource areas—forests and agricultural land. We estimated losses of agricultural versus forested land by allocating the total estimated resource land lost in a Watershed Model segment to these two categories in proportion to their relative size (aerial extent) in the base year. In this analysis, larger losses of resource lands also represent bigger losses of forest corridors, wetlands, riparian vegetation, and associated habitats.

Development projections include estimates of the increase in the amount of impervious cover (roads, sidewalks, driveways, building footprints, etc.) based on the multipliers in Table 5-3. Studies have shown that degradation of small streams (assessed by its ability to provide excellent habitat and maintain good water quality) can begin when more than 5 percent of the stream's watershed area becomes impervious (Figure 5-3). Low stream impacts occur when impervious cover reaches from 5 to 10 percent of a small watershed unit; significant impacts typically occur between 10 and 25 percent; and highly unstable conditions and severe impacts occur with over 25 percent of the watershed area impervious.[70] Hydrologically degraded streams are less effective at removing in-stream nutrients. Therefore, in addition to the estimated nutrient loading increases that result directly from land conversion under the three scenarios, greater stream degradation (as exemplified in Recent Trends) will result in additional nutrients reaching the Bay's tidal waters.

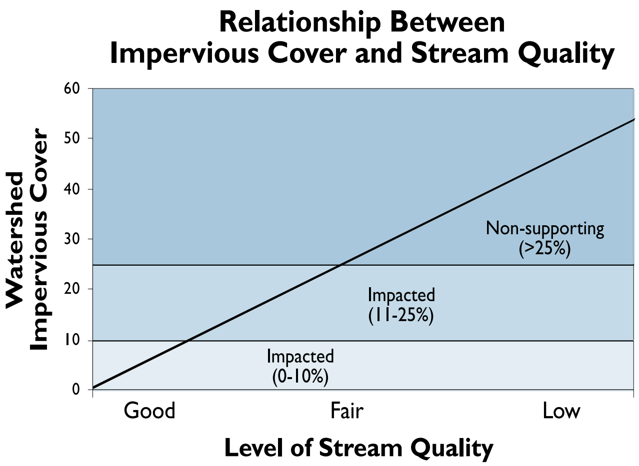


Figure 5-3. Effect of impervious lands on stream quality. Even small amounts of impervious cover can translate to declines in stream quality.

Percent impervious cover is a good indicator of stream quality and integrity in relatively small first- and second-order streams. Watershed Model segments are much larger; thus different streams within a segment (with, for example, 8 percent impervious cover overall) may be subject to vastly different impacts. For instance, the watershed of one small stream in the larger watershed may be 30 percent impervious while another may be 1 percent. Because interpretation of percent impervious cover is relatively meaningless at the scale of model segments, the change in impervious cover (absolute or percent increase) is primarily employed as an indicator of potential impacts to streams in each segement that would result from the new development estimated in each scenario.

Caveats

Chesapeake Futures growth and development scenarios do not presume to predict the future. Such predictions would require measurement of recent development trends and management practices for each jurisdiction in the watershed as well as modeling the effects of individually tailored management alternatives. This is well beyond the scope of *Chesapeake Futures*. Instead, the scenarios aspire to provide the best estimate of what is likely to happen if general recent trends in growth and development continue, and to characterize the potential benefits to the watershed if selected alternatives, with demonstrated ability to influence outcomes, are widely implemented.

The scenario projections in this chapter are based on an early version of Phase 4 of the Chesapeake Bay Watershed Model.[71] While the current version of the model (Phase 4.3) incorporates several improvements, the primary objective here is to compare the three scenarios in a relative way and, therefore, the results are little affected by these model improvements. The exercise examines whether the choices made to manage future population growth and development within the region, using a reasonable range of assumptions, will be consequential or trivial to the health of the Bay. It will also help determine the degree to which moving beyond current management objectives would lessen the impact of development on the Bay.

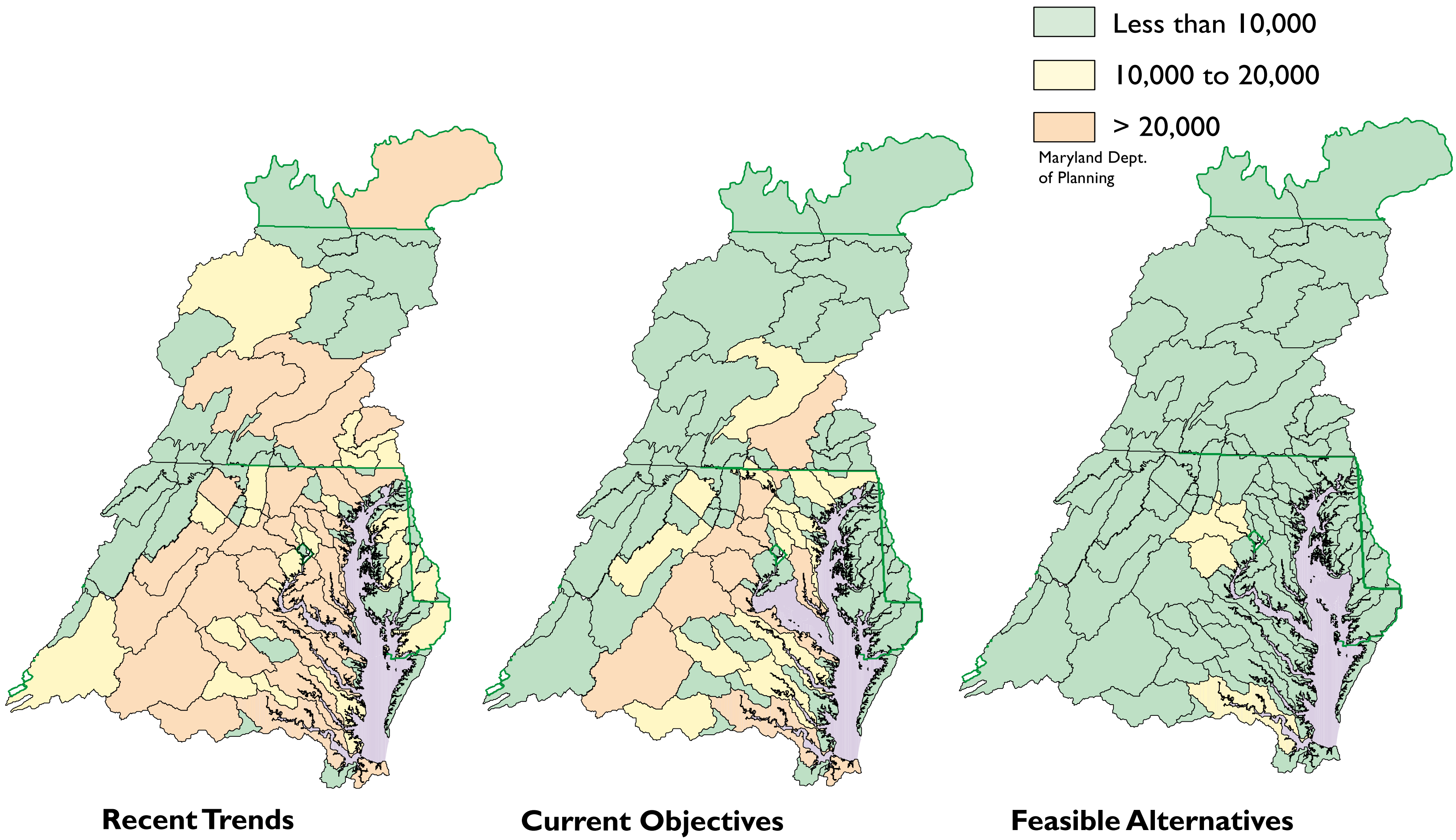
Scenario 1: Recent Trends

Primary Expectations:

- *The area of developed land in the watershed will increase by more than 60 percent by 2030, resulting in the loss of more than two million acres of forests and agricultural land (Figure 5-4 and Figure 5-5).*
- *Impervious land area will increase by more than 25 percent in many sub-watersheds, further degrading the quality of streams throughout the central part of the Chesapeake watershed.*
- *Recent progress in reducing sediment loads to the Bay is expected to reverse as soil disturbances from the high rate of land development (along with water-based factors) contribute new sources of sediment.*
- *Nitrogen loads to the Bay due specifically to land development and population growth will increase by about 35 million pounds per year (approximately 10 percent of current total nitrogen loadings from all sources) from increased nonpoint runoff, sewage discharges, and septic systems. Phosphorus loads will grow by about 1.8 million pounds per year (about 8 percent of current totals).*
- *Local positive impacts from riparian buffer and stream restoration efforts may occur; however, large-scale improvements will remain unrealized.*

Potential Loss of Resource Lands Under Three Scenarios (1996-2030)

Figure 5-4



- *Air quality will deteriorate as the vehicle miles driven continue to grow faster than the population, ultimately outstripping improvements in auto emission technology.*
- *Billions of dollars of transportation funds will be used to expand highways connecting sprawling residential communities with metropolitan job destinations, perpetuating the sprawl cycle.*
- *Local governments continue to realize very limited success in efforts to fulfill conflicting ambitions: encouraging growth versus preserving landscape, water, and environmental quality.*

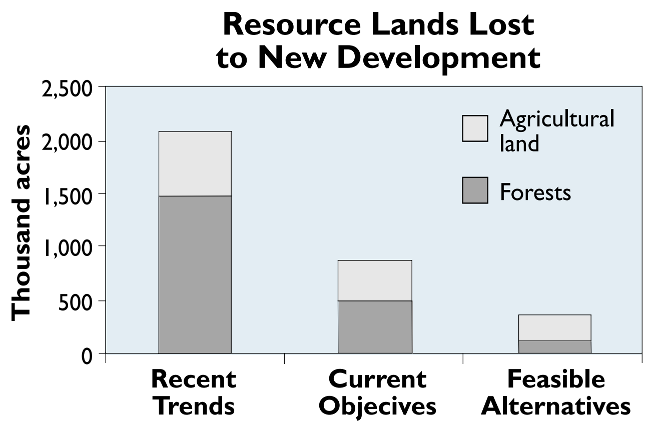
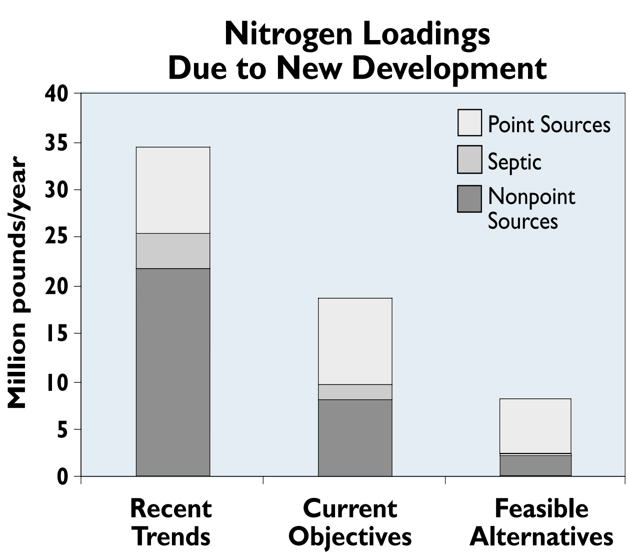


Figure 5-5 While forests will continue to be lost to new development over time, other factors, such as agricultural conversion, allow generation of new forests and may result in a small net gain in some areas.

If the trends of recent decades continue over the next three decades, the landscape of the Chesapeake Bay watershed will become increasingly dominated by various forms of sprawl: expanding rings of suburbs and low-density development in rural areas and ubiquitous strip commercial development along highways—first outside of and then between older communities. The rate of land development will greatly outpace the rate of population growth. Each new household will consume more than an acre of land based both on the housing construction and the development of support services (highways, schools, parking lots, and related services). Relatively little of the population growth will be accommodated by reconstruction or revitalization of existing developed areas in the cities and older suburbs. The majority of the new construction, therefore, will convert agricultural lands and forests to new development. This conversion will result in the loss of about 2 million acres of resource lands by 2030, about two-thirds of which are forests (Figure 5-5).

Much of this loss will occur in the regions experiencing the largest growth around the existing



Figures 5-6. Increases in nitrogen loadings from new development. The largest gains can be made by controlling nonpoint sources of nitrogen, such as stormwater runoff.

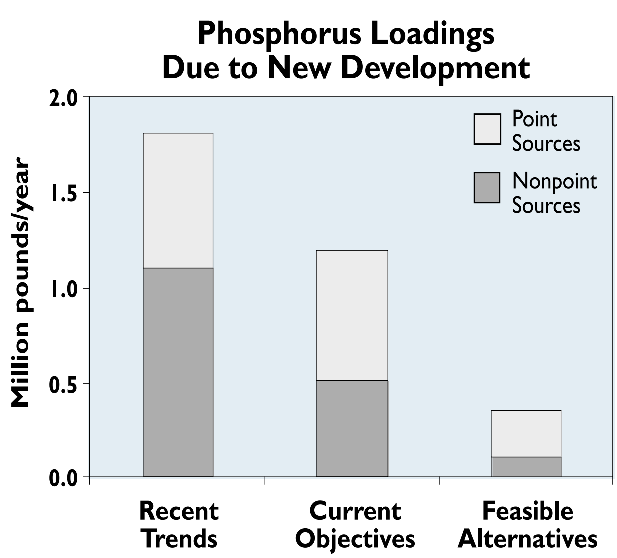


Figure 5-7. Increases in phosphorus loadings from new development. As with nitrogen, the largest gains in phosphorus control can be made through nonpoint source control.

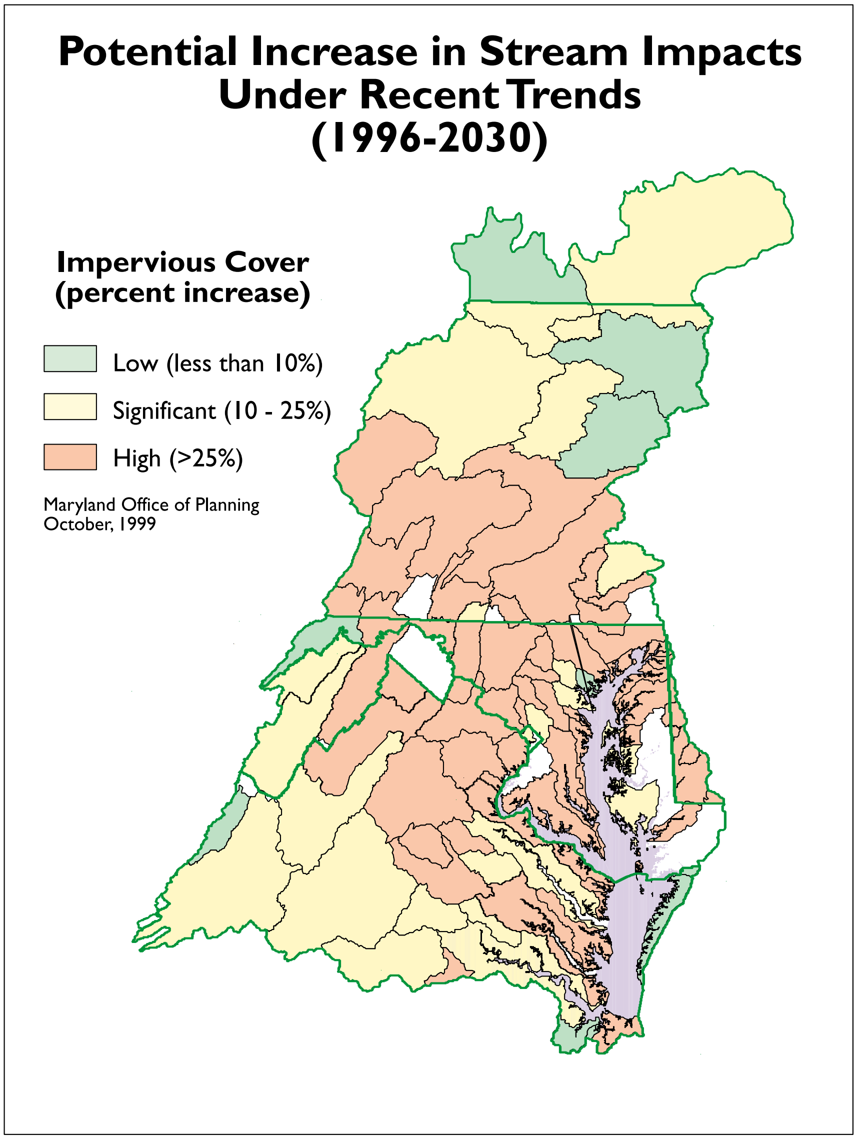


Figure 5-8. Great stretches of the Cheapeake Bay watershed will likely see more areas covered by impervious surfaces—roads, highways, driveways, rooftops, and parking lots. The areas most acutely affected (see map) will experience increases of 25 percent or more in impervious cover, if recent trends persist.

the tidal estuary due to new development. Under the Recent Trends scenario, 29 percent of the new housing units will be served by septic systems, which have less efficient nutrient removal capabilities than publicly owned treatment works. Throughout the watershed, new development will cause an increase of nearly 35 million pounds of nitrogen and 1.8 million pounds of phosphorus.

Both forests and riparian areas effectively filter nutrients, sediment, and contaminants. Despite localized achievements in preserving these important lands, however, net losses will continue, particularly in regions undergoing high development rates. Growth patterns predicted under this scenario will result in an increase in impervious cover over a large portion of the watershed (Figure 5-8). Impervious cover within the watershed will significantly change local streams, causing extremely high water flows during storms, followed by extremely low flows during dry periods due to diminished groundwater supplies. Such extremes result in eroded stream banks, loss of habitat, and degraded water quality.

metropolitan areas of Washington, D.C., Baltimore, Hampton Roads, and Richmond (Figure 5-2). These cities are close to the Bay and its tidal tributaries, but large resource land losses will also extend into western and southern Virginia and south-central Pennsylvania.

The combination of nonpoint runoff from developed land, ground- and surface-water pollution from septic systems, and discharges of treated sewage from wastewater treatment plants will result in widespread increases in loadings of nitrogen (Figure 5-6) and phosphorus (Figure 5-7) to

Additional dispersed development will force more vehicles on the road, bringing additional hours of driving time, more traffic congestion, and increased air pollution.[72] Projection of recent trends would result in a two- to three-fold increase in vehicle miles driven in the Washington, D.C. metropolitan area, creating enormous pressures for new road construction. Emissions of nitrogen oxides—precursors of ground-level ozone formation and significant sources of atmospheric deposition of nitrogen—will increase as the number of vehicle miles driven grows faster than the efficiency of emission controls currently in place. Between 20 and 35 percent of the total controllable nitrogen load coming in to the Chesapeake Bay is from atmospheric deposition.[73] Regionally, vehicles contribute approximately 35 percent of the sources of NOx.[74]

Similarly, new energy demands from population growth and development will outstrip the slow improvements in energy efficiency of recent decades, necessitating additional electricity generation. Existing regulations will, at most, stabilize nitrogen oxide emissions from stationary sources. Ozone levels will worsen in present non-attainment areas and air quality threats will spread with development.

In sum, if recent trends continue, localized improvements to air and water quality due to source controls will likely be reversed. New inputs of nitrogen and phosphorus to the estuary from development will offset much of the recent reduction in point-source inputs. Large amounts of resource land will be converted to urban and suburban uses, with consequent impacts on rural areas, agriculture, forests, and ecologically valuable lands, especially local streams and watersheds throughout many portions of the Chesapeake Bay basin.

Scenario 2: Current Objectives

Primary Expectations

- *Despite policies to preserve open space, new development will cause the loss of nearly 900,000 acres of forests and agricultural lands by 2030.*
- *Impervious surface will increase by 24 percent, only slightly less than that expected under Recent Trends.*
- *Efforts to restore 2,010 miles of riparian forest buffers and to significantly constrain development will produce substantially lower sediment loadings than under Recent Trends, but only modest reductions from present levels.*
- *Nitrogen loads to the Bay will grow by about 18 million pounds per year due to land development and population growth (slightly more than half the growth under the Recent Trends scenario). Phosphorus from developed lands will increase by less than 0.7 million pounds per year.*
- *Riparian buffer restoration goals will be met or exceeded, resulting in significant improvements in local water quality.*
- *Modest improvements in air quality will be achieved with tightened auto emissions standards; vehicles miles driven will continue to grow, but at a reduced pace.*

In this imagined future of the Chesapeake region, land use practices throughout the watershed would effectively incorporate current policies that lessen the impact of development. As a result, land use conversion falls by over 50 percent from that estimated under Recent Trends. New households would each consume between 0.5 and 1 acre of land, built on smaller, clustered lots near existing shopping and services. In addition, 13 percent of new development would occur on previously developed lands. Centralized wastewater treatment facilities would serve about 80 percent of the new housing units, allowing more effective removal of nutrient wastes.

Despite implementation of policies and practices to slow sprawl and preserve undeveloped land, commercial and residential development throughout the watershed will still consume over 800,000 acres of resource land (Figure 5-5). Many of the outlying regions will show significant reductions in land use conversion, although the urban areas and a north-south band through the center of the watershed will still exhibit considerable effect from development (Figure 5-4).

Increases in nitrogen loading due to new population growth and development will be almost one-half of that under the Recent Trends scenario (Figure 5-6), due to less nonpoint runoff from the smaller footprint of development and less reliance on septic systems. Nitrogen loadings from point sources will remain about the same as that under

Recent Trends, despite improvements in waste treatment efficiency, since treated waste volumes will rise as more households link into sewerage. Phosphorus loadings will show significant reductions due to reduced nonpoint source runoff compared to the Recent Trends scenario (Figures 5-7). Newly developed landscapes generally result in large phosphorus loadings associated with soil erosion.

Achieving the riparian forest restoration goals under Current Objectives will further ameliorate increased loadings associated with new development. Localized preservation of these forests, along with improvement of water quality, will result. The effectiveness of riparian buffer restoration in stemming nutrient pollution on the watershed scale, however, depends greatly on the geographic targeting of these efforts. The degree of preservation, restoration, and maintenance of riparian forest lands in areas of development is critical.

Although vehicle miles driven will continue to grow under the Current Objectives scenario, the rate of growth will decline considerably due to constrained sprawl and increased use of improved transit systems that reduce reliance on automobiles.[74] Public transportation will provide options for those who choose to moderate their automobile use. At the same time, worsening traffic congestion will make public transportation more attractive and vehicle miles traveled will begin to level off within 10 to 15 years.

In sum, new development—even within the constraints of current policy objectives—will result in a substantial loss of resource lands and significant additional nutrient loadings to the Chesapeake. It will place a significant burden on waste treatment technologies and controls of other nutrient sources, particularly those from agriculture and atmospheric deposition, to meet and sustain the nutrient reduction goals set forth in the 1987 Bay Agreement. Achieving the more ambitious goals for nutrient reduction under the *Chesapeake 2000* Agreement will remain a challenge under this restrained sprawl scenario.

Scenario 3: Feasible Alternatives

Primary Expectations:

- *Creative growth management and strategic land preservation efforts will reduce the development of resource lands to about 350,000 acres—less than 17 percent of Recent Trends.*
- *Impervious surface will increase by 15 percent, a smaller percentage than either of the other scenarios.*
- *Significant reductions in sediment loading from the watershed would result due to reforestation of large areas of the watershed, tightly constrained development of new lands, more effective control of sediment loss from construction sites, aggressive retrofitting and maintenance of stormwater management infrastructure in developed areas, and riparian zone restoration.*
- *Nitrogen loads to the Bay specifically from new development and population growth (about 8 million pounds/year) will be about one-quarter of those projected under the Recent Trends scenario. The net increase in phosphorus loads due to growth and new development will be about 1 percent of current total loadings.*
- *Strategically preserved and restored riparian buffers will further ameliorate nonpoint source inputs of nutrients due to development.*
- *New and expanded public transportation networks will stabilize or reduce the use of automobiles. Improved emission control technologies, increased fuel efficiency and alternative technologies (e.g., fuel cells) adopted to reduce greenhouse gas emissions all result in significantly improved air quality.*
- *Billions of dollars of transportation funds will be used to make it easy, pleasant, and efficient to move within and between communities, cities, and newer mixed-use developments, using public transportation and the pedestrian- and bicycle-friendly environments.*

The vision developed under the Feasible Alternatives scenario demonstrates that creative land management strategies can considerably decrease the propagation of developed lands, loss of forests and farms, and nutrient pollution throughout the Chesapeake Bay watershed. Houses clustered in small communities with significant tracts of land set aside as natural areas and open space result in each new household consuming less than one-quarter acre of forest or agricultural land.

In this scenario, sprawl will be contained with some 40 percent of all new development occurring on previously developed land, tapping into existing roadways, schools, shopping, and other services. Fewer than 400,000 acres of resource lands will be converted to development by 2030 (Figure 5-5). This loss is still considerable, but far less than the amounts predicted under the Recent Trends and Current Objectives scenarios. Some areas, such as the regions west of Washington, D.C. and surrounding the James River, will experience significant changes in land use due to development permitted under this scenario (Figure 5-4).

Sprawl will be constrained, reliance on automobiles reduced, and investment in public transportation expanded. Energy efficiency will also improve, eventually offsetting the growth in demand for power from the growing population. This development will allow the NOx emission controls established to achieve the goals of the Clean Air Act to overtake demand growth, resulting in air quality improvement and a reduction in the atmospheric deposition of nitrogen (see Technological Solutions).

Up to 98 percent of new development would be connected to centralized wastewater treatment facilities, dramatically reducing the quantity of nutrients from private septic systems. Advanced waste treatment technologies (see Technological Solutions chapter) will further reduce loadings of nitrogen and phosphorus to less than half those under the Current Objectives scenario. Zoning regulations will also preserve significant amounts of natural resource land, including 100-foot riparian buffers along stream banks throughout the basin.

Other point and nonpoint pollution control efforts will lower nutrient loading rates. Key among these will be "low-impact development" strategies (LIDs), including the use of rain barrels, rain gardens, sunken medians, roof drain infiltrators, green roofs, and other tools to catch, slow, or stall rainwater rather than funneling it into local culverts and streams. In this scenario, homeowners can choose to have more native plants, minimal rainwater runoff, and less lawn area requiring fertilizer, herbicides, pesticides, and mowing with gasoline-powered mowers.

In a future that takes advantage of feasible alternatives for wise land use, the increase in nutrient loads due to new development between today and 2030 will be relatively small. In conjunction with the effects of advanced technologies on load reductions, total loads from all development sources will be less in 2030 than they are today, despite the presence of an additional 3.8 million people in the watershed. Perhaps even more surprising, local watersheds and land resources throughout the basin would generally be in as good as, or in some cases, better condition than they were at the dawn of the 21st century.

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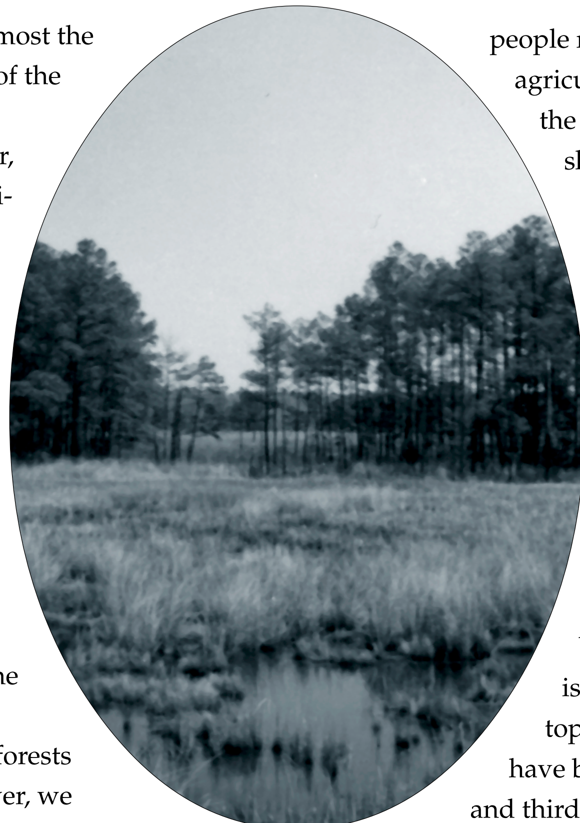
Forests in Transition

Forests once covered almost the entire vast watershed of the Chesapeake, but land clearing for agriculture, timber, and fuel changed that dramatically, especially in the 19th century. Currently, forests still account for the largest component of the 41-million-acre Chesapeake basin, covering 58 percent of the watershed—an estimated 24 million acres. Agricultural and other open land rank as the second most frequent type of land use, accounting for 33 percent of the land area, followed by urban lands at 9 percent.[1] Although forests remain the dominant land cover, we are currently losing up to 100 acres of forest per day,[2,3] mostly to development. The historical trends and spatial patterns of forests surrounding the Chesapeake clearly coincide with the dynamic interactions among agriculture, forestry, and population growth along with associated urban and suburban development.



While pre-colonial forests were not the pristine environments many assume, approximately 95 percent of the region was forested with only localized impacts arising from Native American agricultural and hunting practices and natural disturbances.[4] By the mid-1700s, however, 20 to 30 percent of the forest had been cleared for agriculture, with this percentage rising to 40 or 50 percent by the mid-1800s[5,6] (Figure 6-1). Forest loss followed settlement patterns as people moved out from the Bay. Less agricultural conversion occurred in the western portions of the watershed due to the generally steep topography of the Blue Ridge and Appalachian Plateau provinces; however, logging could occur throughout the Bay watershed due to the advent of technologies such as cabling systems and the narrow gauge railroad for transporting timber. Historical patterns of agriculture and forestry remain today because broken-soil agriculture is not feasible in most steep topographies and logged areas have been left to regenerate second- and third-growth forests. Following an historic low in 1900, forest cover has since increased to approximately 60 percent of the Bay basin due to less harvesting, old-field regrowth, reclamation efforts, and the establishment of state and national forests or parks.

Why Forests Matter

Forest cover in a watershed influences the quality of the water reaching an estuary; in general, the more forest cover the better the water quality. Given this presumption, the recent trend toward reforestation of the watershed as a whole can only be viewed as positive. Current forest cover is, however, neither uniformly distributed nor always concentrated in areas deemed most effective for water pollution

Skip Brown

Historical Trends in Forest Cover for the Chesapeake Bay Watershed

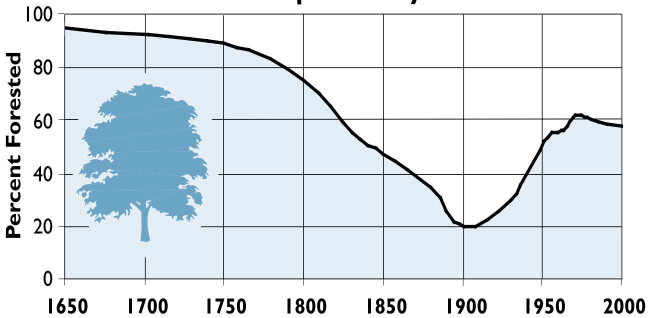


Figure 6-1. After bottoming out in the early 1900s, forest cover regained acreage throughout much of the last century. Recent decades show a slight decline.

control. Although the loss of forests in regions with fast-growing populations may be offset by gains in other parts of the watershed, this trade-off in acreage may not translate to equivalent ecological function or environmental service.[7]

The role of forests in the Chesapeake Bay watershed, as in any ecosystem, is multifaceted. Forests function as significant nutrient sinks, storing nutrients from soil, groundwater, and atmosphere,[8,9] thus reducing the quantity of nutrients that enters the Bay and its tributaries. Forests also trap sediment and reduce erosion rates along shorelines,[10,11] lessening sediment input to the water. Large stands of forest take up considerable amounts of atmospheric carbon which helps to mitigate climatic extremes regionally and slow global warming.[12,13] Forests form critical habitat for many types of terrestrial and avian wildlife. Humans rely directly on forests, harvesting them for wood products and using them for recreation and tourism, all of which provide economic viability.

Nutrient and Sediment Retention

Decades of study by the forest research and management communities have established two indisputable facts. First, forests retain nutrients and sediment much more effectively than virtually all other land uses in the watershed.[14] Although forest harvesting increases nutrient and sediment export, a regenerating forest quickly regains its retentive characteristics and can return to pre-disturbance levels within 3 to 5 years.[15] Forests function as critical filters for the streams and tributaries of the Chesapeake. This same filtering capacity also makes them invaluable in the production of potable water, especially for private wells and communities that rely on small to moderate-sized reservoirs with minimal treatment facilities.[16] Second, the distribution of forests within the watershed relative to the surrounding land type, water flow, proximity to tributaries, and other factors determines the utility of the forests in keeping nutrients and sediments from reaching rivers, streams, and ultimately the Chesapeake Bay. The integrity of riparian forests and the degree of forest fragmentation both influence the effectiveness of forests as sediment and nutrient filters.

Riparian Forests

Riparian forests provide critical water quality and habitat functions in stream and river corridors (Figure 6-2). Situated along the banks of rivers and streams feeding into the Chesapeake Bay, riparian forests reduce erosion from stream banks and trap sediment washing down from adjacent land. These forests also remove nutrients from groundwater before it enters the surface waters. Although research has shown that riparian buffers effectively filter nutrients and sediment, the buffer structure may need to be tailored to local land types.[17,18,19,20] Jurisdictions should focus on which species of plants are best suited to particular soil types and stream configurations in their efforts to protect and restore riparian buffers, ensuring that the vegetation will thrive.

State	Total Miles	Percent Buffered
Pennsylvania	80,967	64%
Virginia	61,147	58%
Maryland	31,046	53%
New York	14,612	53%
West Virginia	9,122	58%
Delaware	2,082	55%
Washington, D.C.	83	29%
TOTAL	199,057	59%

Table 6-1. Total shoreline and stream (both sides) miles by state in the Chesapeake Bay basin.

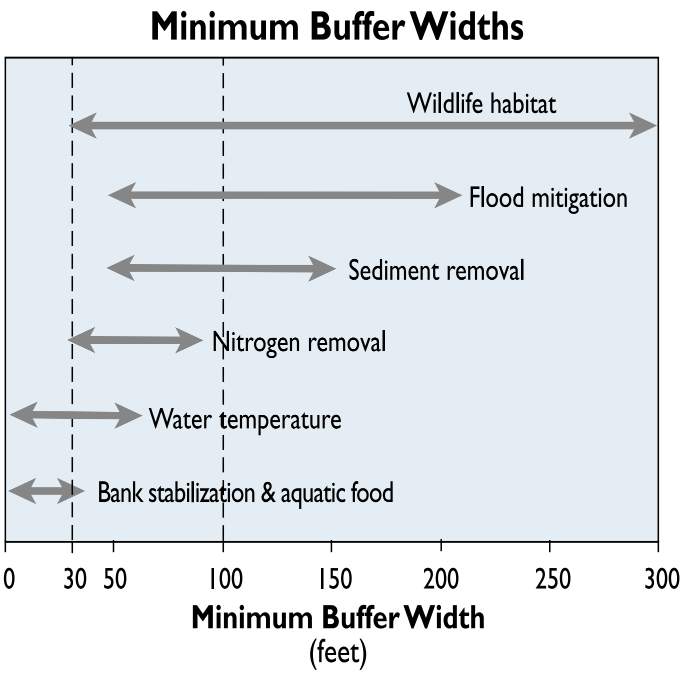


Figure 6-2. A riparian buffer's effectiveness depends on several factors, including types of vegetation, root depth, and soil composition. It also depends greatly on size—a 30-foot buffer helps shade a stream, but needs to be much larger to function as a significant wildlife habitat (from www.riparianbuffers.umd.edu).

The *Chesapeake 2000* agreement reaffirmed the earlier commitment to restore 2,010 miles of riparian buffers by 2010. By August, 2002, 2,283 miles of these buffers had been restored, eight years prior to the deadline. Despite this remarkable achievement, however, reforesting significant amounts of remaining stream banks and shorelines within the watershed (Table 6-1) remains a major challenge. A 1997 inventory of the watershed found only 59 percent of the Bay's stream and shoreline is forested within 100 feet on at least one side of the watercourse; over 45,000 miles (40 percent) of the Bay's riparian forest has been removed or severely degraded.[21]

Forest Fragments

Increasing rates of land clearing for urban and suburban development and the cutting of timber in the watershed have resulted in fragmentation of large contiguous areas of forest into smaller and smaller segments. An analysis of the southern portion of the Chesapeake watershed by American Forests revealed that dramatic changes in tree cover have occurred since 1970. Areas with high tree canopy cover declined from 55 to 38 percent between 1973 and 1997, with particularly severe losses in the Baltimore-Washington corridor.[22] Currently, areas closest to the Bay are losing forests the fastest; they also have the highest degree of fragmentation.[23]

This situation raises the important ecological question of whether scattered small fragments of forest (equal in total area to one larger forest region) are comparable in their ability to preserve watershed functions and good water quality. Researchers have learned that, in many ways, they are not. Consequently, this forest fragmentation is causing widespread concern that continued destruction and division of the forest land base may lead to further impairment of the forest ecosystem's ability to protect water flow and quality, provide healthy and diverse forest habitat, and remain a viable economic resource for recreation, timber, and other wood products and forest services.

Simply given the role of forests in nutrient and sediment transfer across multiple land use types, land use planning that considers forests is critical at larger spatial scales with a focus on the ecological aspect of each land use and its location relative to water flow. For example, could critical portions of the watershed, such as steep, crumbly slopes or highly erodible cliffs, be equally important to riparian zones for maintaining water quality? Can optimal arrangement of forest fragments within the watershed maximize benefits for both water quality and other

Courtesy of MD Cooperative Extension/ Wye Research and Education Center

Aerial photograph showing well-developed riparian buffers bordering a stream. Such vegetation helps to protect the waterway by minimizing the flow of nutrients and sediment into the water.

key natural resources? These essential questions remain unanswered. Addressing them is of utmost importance since: 1) restoration efforts must be efficient in their allocation of limited capital resources; 2) land use management in developing areas should reconcile concerns for both environmental quality and economics; and 3) conservation of many natural resources must be considered simultaneously to promote overall environmental integrity.

Forest Wildlife

Birds dwelling in the forest interior epitomize the dilemma for wildlife residing within multiple-use landscapes. Many of these avian species migrate annually between the tropics and North America and are highly dependent on forest interior habitat for nesting sites that provide protection from predators and nest parasites common along forest edges.[24,25,26,27] In the forests of the Chesapeake Bay region, these birds depend on the spring flush of forest insect larvae for food as they breed and raise young.

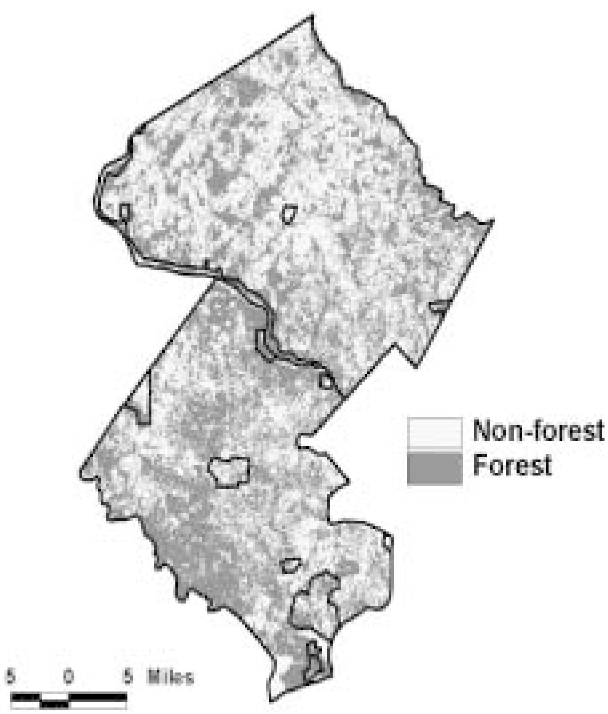


Figure 6-3. This aerial photo illustrates how fragmentation breaks an area into non-contiguous parcels of forest (courtesy of Mid-Atlantic Regional Earth Science Applications Center).

Several species of these forest-interior birds are declining in numbers.[28] This decline may have several contributing factors, including fragmentation of forests by road construction, harvesting, and urban and suburban development.

The decline of these high-profile migrants—magnets for recreational birders—is symptomatic of changes in the forest environment that influence many other species. For example, as forests shrink in size, horizontal light penetration into the forest[29] covers a greater proportion of the forest floor, increasing soil temperatures and decreasing soil moisture. These slight changes decrease habitat for native, forest-floor, herbaceous plants and amphibians that require moist conditions. Such changes also decrease the invertebrate populations that aid forest litter decomposition and provide a food source for forest interior birds;[30] spread the growth of weedy edge species throughout the forest; and alter ground cover for forest-floor-dwelling mammals and birds.

As forests become fragmented, forest patches support smaller populations of most non-mobile plant and animal species, resulting in greater likelihood of the elimination of species in each patch. Populations that survive in such a fragmented habitat will be forced to travel between forest patches, across other environments that are often inhospitable. Forest fragment distribution can cause serious disruptions within the ecosystem and is, therefore, a significant feature of multiple-use landscapes (Figure 6-3).

Forest Economics

Assessing the economic value of forests holistically is difficult. While timber sales and other statistics partially illustrate the worth of forests, estimating a value for aesthetic and mental health benefits remains more complex. But certainly, the economic benefits of the Chesapeake's forests are considerable.

Forests in the Chesapeake Bay Region Economy

The global market has a significant impact on forest products from the Chesapeake basin, providing opportunities for expanded markets, higher overall demand, increased use of less-used tree species, and lower price volatility. Nationwide, combined timber harvests for domestic use and export are expected to increase by more than 35 percent by 2040. Despite this demand, harvesting from national forests has declined to approximately one-third of its production volume in 1987. Private forests are expected to compensate with a 47 percent increase over 1991 levels, with the majority of the increase in non-industrial private forests. The south, including portions of the Chesapeake basin, is expected to produce more than one-half of the future forest harvest.[31] The economic outlook for national and global marketing of wood products from the Bay region, therefore, is quite good. One challenge, however, will be increasing the amount of value-added product to generate additional income from harvested trees.

Because of the robust demand for products, forests provide a significant source of employment and income for the region. The mid-Atlantic forest industry produces 244,100 jobs and $4.5 billion in real wages per year, accounting for 2 percent of the employment in the region.[32] In addition, non-wood and specialty forest products provide extensive cottage industries and contribute to local economies.

While placing dollar values on the environmental and social benefits of forests is difficult, such values are at least as important as, and likely surpass, wood

Social Trends Affecting Forests and Their Ownership

With a population of 15 million people and counting and over 64,000 square miles of land area, the average population density in 1995 for the Chesapeake basin was 234 people per square mile. By 2030, the region's population should reach almost 19 million people. As previous sections pointed out, the demographics of this population are changing. Like the United States as a whole, people in the Bay region are moving to the suburbs and, to a lesser extent, into the central cities. The population is also aging. The percentage of people 65 or older will double by 2030 and people are living longer. Retirement age is declining and people are healthier and more active. Jointly, these trends suggest a growing demand for the recreational assets of natural lands[33] with implications for demands on public and private forests as well as for forest ownership and management.

The number of private forest landowners has increased over the last twenty years; individuals now hold about 94 percent of the privately owned forest acres in the watershed.[34] More than 90 percent of the private landowners, however, individually control fewer than 100 acres of forestland. This shift from a few landowners with large holdings to many landowners with smaller holdings is known as parcelization. Parcelization differs from fragmentation, although the two are related. As the number of landowners increases, attitudes and objectives become increasingly diverse. Some landowners may convert their forests to other uses which, in turn, leads to forest fragmentation.[35]

Landowner death, property and inheritance taxes, second homes, and uncertainty about regulation all contribute to parcelization. Such changing ownership demographics and patterns will prove significant, since the behavior of landowners largely affects what happens to private forestlands. In addition, the transition from one to many new landowners makes imparting information about management or good stewardship more difficult.[36] Public programs dealing with such issues will need to shift their focus to become more available and more relevant to a busier, wealthier population with differing values and opinions about what they want from forests. Securing working forests requires practical and sustainable strategies for small parcels. Ultimately, only careful planning at the local level may slow the parcelization process.[37,38]

products. As noted previously, forests prevent pollution and protect against flooding. They increase property values and provide places for learning, restoration, and tranquility. Forests remind us of the eternal processes of regeneration.[39] None of these forest roles are readily quantifiable, yet each is clearly valued by forest owners and much of the general public. These values are reflected in increasing recreational demand, which shapes forest management on both public and private land. In fact, non-consumptive use of forests and wildlife is expected to grow faster than the nation's population, as the interests and demographics of Americans change.[40] Consequently, many citizens aspire to preserve forests so that future generations have the opportunity to make choices about the use, management, and protection of these forests.

Forests in a Changing Environment

The environmental benefits of forests must be viewed in the context of environmental change. Interestingly, forests lie at the heart of the three greatest environmental change debates of the latter 20th and early 21st centuries: acid deposition, atmospheric carbon concentration, and land use. Each of these issues has received extensive attention with scientists viewing forest cover as either a primary impacted resource or an integral part of the solution, or both. Despite this attention, specific impacts and concrete solutions remain elusive.

Kent Mountford

The amount of forest cover varies across the Chesapeake watershed based on ownership, transportation networks, urban and suburban development, topography, and the economic value of forest products. This combination of factors has resulted in some general patterns: more forest cover farther from the Bay; clusters of forest on state and federal forest or park lands; and unmanaged forest fragmentation at all spatial scales.

Clearly, not all forest environmental benefits have been lost due to fragmentation—even small, well-placed stands of trees in urban areas can reduce stormwater runoff, lower street temperatures, provide shade that lowers energy use, and filter particulate material from the air. Across the Chesapeake Bay region as a whole, however, the extent of environmental services has become disjointed, locally extirpated, or reduced in magnitude. Examples include decreased forest acreage for carbon and nutrient sequestration, reduced riparian buffers for maintaining high water quality, lost wildlife habitat, increased dominance of non-native and invasive species, and perhaps reduced opportunities for native vegetation to respond to other environmental changes such as climate shifts. In addition, acidic deposition, atmospheric carbon, and land use patterns have interrelated effects that require long-term planning to prepare for changing environmental variables. In general, rethinking the redistribution of forests and the general reduction in forest services demands a tradeoff with the non-environmental services provided by urban and suburban environments and food products from agricultural lands.

Forests as Nutrient Sinks

Will the forests of the Chesapeake Bay watershed continue to absorb nitrogen deposited from the atmosphere? Atmospheric deposition of nitrogen and sulfur—from coal-fired power plants and other sources of burned fossil fuel—increases the input of these compounds to forest ecosystems, which can influence and interact with the normal forest nitrogen cycle. Conventional theories of terrestrial ecosystems as nitrogen-limited systems suggest that actively growing vegetation, soil biota, or decaying litter serve as sinks for anthropogenic atmospheric nitrogen. Under this reasoning, forests take up whatever additional nitrogen anthropogenic activities introduce to the atmosphere.

In much of the Chesapeake Bay watershed, however, forests are subjected to such high levels of atmospheric nitrogen deposition[41] that nitrogen saturation may be occurring.[42,43] If this influx of nitrogen is not ameliorated by emission controls and other technologies, scientists and managers must question the continued ability of forests to serve as nitrogen sinks and reevaluate the influence of forest management on forest nitrogen storage and export. For example, how do projected emissions and resultant deposition rates compare with forest retention capacities? How do forest disturbances and fragmentation affect the ability of forests to retain nitrogen? Does disturbance of a nitrogen-saturated forest result in greater pulses of nitrogen release? What is the cumulative impact of forest management activities and other disturbances on the Chesapeake Bay basin? These questions need answers.

Forests and Global Warming

Because of their standing biomass and spatial extent, forests constitute a large carbon sink; conversely, deforestation contributes significantly to atmospheric carbon and global warming. While in any final analysis, deforestation constitutes only one factor in global warming, managing forests to sequester carbon plays a major role in solving global warming problems. For long-term planning, the concept of regional carbon balance should be maintained as a backdrop within which local forest management decisions are ultimately made. Regional impacts of climate change on forests should be considered now, because the lengthy life cycles of trees dictates long-term planning to accommodate change and ameliorate potential threats.

The potential for climate change creates additional uncertainty. The Chesapeake Bay region will likely experience higher average annual temperatures and increased winter precipitation.[44] The timing and extent of potential impacts remain very difficult to predict, especially at regional and smaller scales, but over the next 30 years impacts may include:[45,46,47]

- slower forest growth due to water stress during the growing season (higher evapotranspiration);
- increased forest productivity due to the fertilization effect of atmospheric carbon dioxide;
- changes in the severity, frequency, and extent of natural disturbances such as fire;
- lower nitrogen uptake due to decreased forest growth rates;
- altered carbon/nutrient ratios;
- altered decomposition rates of forest litter;
- altered nutritional value of tree tissues for herbivores; and
- gradual changes in forest species composition from shifting climate regimes and competition among tree species (northward expansion of oak-hickory communities, for example).

Despite our inability to make specific predictions, climate changes will clearly alter forest conditions and could well decrease the environmental benefits we now enjoy from forests.

Scenario 1: Recent Trends

Primary Expectations:

- *Despite several decades of increasing forest cover driven by reforestation, the amount of forest cover will level off quickly and then decline.*
- *Further wide-scale loss of forests will take place in or near metropolitan areas.*
- *Continued forest fragmentation will occcur throughout the basin, most acutely near metropolitan areas and the Coastal Plain and Piedmont provinces.*
- *Possible drop-off in agriculture-to-forest conversion, especially in the Ridge and Valley and Appalachian Plateau provinces, as fewer farms will exist to go out of production/business.*
- *Riparian forest buffer restoration will produce positive effects on a local level, but regional gains will remain small as limited progress towards restoration goals are largely offset by losses elsewhere.*

Assuming that recent trends are the best predictor under prevailing conditions, timberland ownership and use, as they influence forest cover, were reconstructed from 1955 to the present using U.S. Forest Service data.[48,49,50,51,52] Projections from the present through 2030 were then based on this trend, along with personal communication and professional judgment from forestry professionals.[53] "Timberland" carries a specific definition for the Forest Service: forestland that is producing or is capable of producing crops of industrial wood and that is not withdrawn from timber utilization by statute or administrative regulation. Acres qualifying as timberland are capable of producing more than 20 cubic feet per acre per year of industrial wood in natural stands. Given this definition, results show increasing forest cover in the Chesapeake Bay states over recent decades, with the increase apparently driven largely by greater acreage of private timberland. Clearly agricultural economics since 1950 have led to a large decline (>50 percent to date) in farmer-owned timberland. This decline was offset by a large increase in forest owned by other private citizens along with a relatively modest increase in public timberland. Although forest industry timberland also increased over much of the time period, this ownership category entered a phase of decline in the late 1980s that offset the gains of previous decades. Much of this industry timberland is not being lost, but is shifting to owners who do not engage in direct use of wood products.

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This shift in private ownership primarily reflects two mechanisms: transfer of forest ownership as farmers retired or otherwise discontinued operation; and reversion of cropland to forest with retired or former farmers retaining ownership. Although the data do not separate these mechanisms, the latter category may well have a greater likelihood of further "parcelization" and fragmentation when the owner dies. Given the aging population and declining number of farmers, this decrease in forestland parcel size will likely continue through the next decade. In addition, the likelihood of cropland or grassland reversion to forest will depend on geography and the attractiveness of alternative uses, with rural upland areas showing greater gains in forests and farmland near metropolitan areas (especially on the Coastal Plain and Piedmont) having a greater chance of suburban development.

What are the characteristics of these new, private landowners? In general, the "new" forest landowner is younger, better educated, and earns more than the average owner of a decade ago. The percentage of retired owners increased significantly between 1978 and 1994 (rising from 22 to 31 percent) whereas blue-collar (26 to 16 percent) and white-collar (43 to 32 percent) owners declined. These "baby-boomer" owners are retiring sooner and living longer; many have a strong environmental ethic. Such demographics suggest two possibilities: new owners may not be inclined to harvest because they don't need the income and value forests as part of their residences or as personal green space; or these new owners may be inclined to harvest liberally for additional immediate income and because they lack detailed understanding of forest growth and health. In either case, this profile of the new forestland owner suggests individuals that should be readily approachable concerning professional advice on forest management and economics.

Current trends in forest ownership are likely to continue through 2030. Total timberland in the

Chesapeake Bay states should peak around 2010 and then hold relatively level. Public ownership will continue to increase slightly, perhaps aided by transfers from forest industry holdings; these holdings may themselves decline somewhat or hold relatively steady. Farmer-owned timberland will continue to decline while other private ownership increased at a similar rate. Since changes in private ownership status dominate these trends, farmland reversion to forest will continue to increase total timberland in the Chesapeake Bay states until about 2010. Ultimately, however, many larger farms may be divided and sold in smaller parcels, with inevitable low-intensity development and loss of forest cover. This development pressure may depress total timberland slightly from 2010 to 2030.

The distribution of owner class size (the number of acres held by an owner) has shifted between 1978 and 1994. Although the number of owners holding fewer than 10 acres decreased, the number of acres in that class jumped dramatically as owners acquired larger lots in that size class. The number of medium-sized tracts (10-49 acres) has doubled over the 16-year period; the 50-99 acres size class has also increased. Conversely, large classes (100-499, 500-999, and 1000+ acres) have all declined. These numbers indicate that small lots have grown larger. The largest forest tracts, however, have been divided into smaller ones, presenting additional management challenges. Traditional information and outreach methods may become less effective, reducing the likelihood of landowners developing management plans and carrying out stewardship activities on their land.

Despite the move towards parcelization—exemplified by the more than 80 percent of forest landholders owning tracts of 49 acres or less—about 70 percent of the region's total forest acreage lies in tracts over 50 acres. In terms of the percentage of total acres, most of these large plots range from 100 to 499 acres (28 percent), followed by very large lots of 1000 acres or more (23 percent). Middle-range plots of 50 to 99 acres represent 17 percent, with plots of 500 to 999 acres accounting for only 5 percent. That is, while most forest owners have fairly small plots, the large swaths of forest (50 acres or greater) are owned by only a few—less than a quarter of all forest owners. Clearly the management and physical location of both small and large private land parcels are critical in the value of remaining forestlands for providing environmental benefits and the protection of Chesapeake Bay resources.

Although forest cover increased during the 20th century, the water quality of the Bay actually worsened, since many other factors are also important in maintaining water quality. Nonetheless, what happens to the forests remains important to the Bay's future. The magnitude of forest cover change within the Chesapeake watershed is likely to be small over the next 30 to 40 years. In a simplistic way, this prediction bodes well for water quality, wildlife habitat, and other environmental services within the Bay basin. Total land cover alone, however, can be a misleading indicator of the ability of forests to provide desirable environmental services.

Relatively small changes in the spatial distribution of forest cover can have potentially large impacts. Ongoing programs of riparian restoration exemplify efforts that impact local water quality positively through nutrient runoff abatement and amelioration of stream water temperature by the buffers. These buffers also have some cumulative positive impact downstream. They cannot, however, offset a lack of buffers in upstream areas. Because of this issue of scale and distribution, current efforts to restore riparian forest buffers and stabilize stream banks are not sufficiently extensive to improve water quality notably on a regional scale.

Given the human demographics and economic conditions of the Bay basin, forest fragmentation will continue even as programs to restore riparian buffers proceed. Current development patterns suggest that this fragmentation will continue at a much faster pace in the Piedmont and Coastal Plain provinces. Significantly, fragmentation in these regions close to the Bay's tidal waters and tributaries will likely have a proportionately greater impact than similar fragmentation farther away, since forests reduce nutrient loading and sediment transport and help prevent much of the nutrient and sediment load from reaching Bay waters.[54]

Current efforts to control power plant and automobile emissions, when fully implemented, may significantly decrease the atmospheric deposition of nitrogen. Because of cumulative effects and residual deposition, however, the threat of forest nitrogen saturation will not be eliminated. In fact, evidence suggests that the effects of forest acidification may persist for long periods even after inputs of nitrogen and sulfur have declined.[55]

While the steps required to reduce greenhouse gas emissions are hotly debated, it is now clear that the Earth is warming and is likely to continue warming at a more rapid rate during the 21st century.[56,57] The gradual warming predicted over the next 50 years may well affect tree-growth rates, but is unlikely to decimate forests. Individual tree species will more likely feel the effects, with resultant impacts on forest communities and ecosystems. It is unlikely that climate change will drastically alter the overall environmental services provided by regional forests; more likely are gradual changes in forest community organization driven by new environmental conditions. This shift will result in relative abundance changes for many plant and animal species, altering the ecological composition of forests. These changes will be widespread and include increased potential for exotic species invasion, altered abundances of game animals, and necessary reevaluation of favored tree species in the forest industry.[58]

Scenario 2: Current Objectives

Primary Expectations:

- *Continued decline in total forest within the Coastal Plain and Piedmont, particularly in metropolitan suburbs, with increasing forest cover in other parts of the basin. A net gain in total forest of the Chesapeake Bay basin should result.*
- *Modest and localized decreases in forest fragmentation due to growth planning initiatives.*
- *Gains in riparian buffer mileage leading to significantly improved local water quality but modest decreases in nutrient and sediment inputs to the Chesapeake Bay.*

Summary data from the land use change simulation for this scenario indicate a potential gain of over 900,000 acres of forestland within the Chesapeake basin. While the exact magnitude of this increase might be questioned, the management techniques simulated clearly indicate additional forest cover. The spatial distribution of this increase is notably skewed, with continued net loss of forest near metropolitan areas and near the Bay. At the spatial resolution of this simulation, it is impossible to predict sub-county distribution of forestland. Many specific impacts on environmental services provided by these forests, therefore, remain difficult to predict. In general, however, forests ameliorate local stream temperatures, reduce airborne pollutants, and provide visual beauty. Continued loss of forest in urban and suburban areas decreases the potential for such benefits. Conversely, such environmental services should generally increase in areas showing gains in forest cover.

Specific effects of urban forests on stream water quality remain less predictable, because positive impacts are intimately associated with topography and water-flow paths. This scenario assumes, however, that ongoing management efforts (such as those in the Tributary Strategies) will direct significant reforestation and forest conservation efforts toward streamsides and other areas likely to prevent erosion and abate nutrient runoff into local surface waters. These efforts, along with implementation of conservation policies for other land uses, should contribute significantly to local improvements in water temperature and water chemistry.

On a basin-wide scale, this scenario simulation indicates an increase in the amount of total nitrogen and phosphorus to the Chesapeake Bay coming from forests. This rise stems solely from increased forest area and the application within the model of constant rates for nutrient loading from forestland. This low loading rate (approximately 2.3 lb/ac/yr) contrasts sharply with higher loadings for most other land uses. Although forests are not 100 percent nutrient retentive, they do constitute a positive tradeoff for other land uses.

In the context of changing environmental conditions, the constant nutrient loading rate for forests deserves review. If atmospheric nitrogen input is not checked, forest nitrogen loading rates could increase as forest ecosystems become more "nitrogen-saturated." Saturation, however, would likely be limited to high-deposition areas with soils of low-buffering capacity. Likewise, alteration of climatic conditions by greenhouse gases could modify forest plant-soil relationships and influence forest nitrogen retention. Constant loading rates assume that forest stands are static, but clearly forests are subjected to many different disturbances that alter their nutrient- and sediment-holding capacity. Quantitative assessments for the cumulative impact of small or chronic local forest disturbances on regional nutrient and sediment export to the Chesapeake Bay are lacking, even though such disturbances temporarily increase forestland loading rates. Such changing and interacting environmental conditions must be considered when assessing potential improvements in environmental quality and services.

Given current programs and objectives, this scenario should bring modest but positive changes in fragmentation patterns. With the current density of forests, along with predicted forest increases under this scenario, fragmentation declines will likely be greatest in the Appalachian Plateau and Ridge and Valley provinces. In contrast, projected forest declines in the Piedmont and Coastal Plain, combined with already low forest cover, hold little promise for alleviating forest fragmentation in these regions. Even though programs to develop riparian buffers, stem development sprawl, and protect resource lands at the suburban fringe may strategically plant and preserve some forests, the connectivity of small forest patches will likely increase marginally with similarly small increases in environmental services.

Full implementation of current policies and regulations represent positive attitudes and constructive steps in sustaining forest environmental services within the Chesapeake Bay basin. Nonetheless, in the face of expected population increases and development pressures, these policies and regulations take only a timid step toward conservation or redevelopment of forests and the services they provide. In sum, they represent only a modest improvement in forest condition and environmental services compared to the Recent Trends scenario.

Scenario 3: Feasible Alternatives

Primary Expectations Based on Land-Use Simulations:

- *Greater increase in forest cover that includes some stabilization of cover within the Bay basin's Coastal Plain and Piedmont.*
- *Marginal further increase in riparian buffers and decrease in fragmentation.*

Further Expectations if Alternatives (see following list) are Implemented:

- *Increased quality and quantity of forests through highly active management of private forestland and non-consumptive management of public forests.*
- *Strong recognition of the environmental and economic importance of private forestland, especially heightened recognition of these values by private forest owners.*
- *Strengthened economic infrastructure for forest products, including marketing and product development, especially value-added products.*
- *Development of a forestland base and social attitudes conducive to immediate short-term assistance in local and regional nutrient management and potential long-term management of environmental change impacts.*

Simulation of land use change based on population trends indicates possible, large-scale reorganization in forest cover for the Bay basin. The simulated progressive efforts in environmental management of Feasible Alternatives yielded increased forest coverage within the Chesapeake basin compared to the Current Objectives scenario. This increase over full implementation is marginal, however; the conclusions from Current Objectives largely hold for the Feasible Alternatives scenario as well. In addition to the slight increase, the distribution of forest signals greater retention of forests within areas of the basin most subject to suburbanization, as well as in the

Piedmont and Ridge and Valley provinces. This positive result would improve forest environmental services in these areas. The true value of gains in forest cover (especially if modest) will come from the local distribution of forests as much as from their total extent.

Regional land use modeling does not necessarily account for some techniques that help basin forests provide maximum environmental benefits. Such techniques or actions ensure that "quality" forests are created and maintained rather than emphasizing "quantity" or total coverage solely. Alternatives, though not exhaustive, include:

- *Mandatory development of buffers for nutrient control and as effective corridors between larger upland forest patches*

  Restoring and maintaining riparian buffers for nutrient management, wildlife and fisheries management, and surface and groundwater protection present clear advantages.

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- *Promotion of "multiple-use forest tree species"*

  The forest industry has always been innovative in finding uses for wood fiber. Wood fiber, however, is not the only potential product from trees. A strong incentive for the development of streamside buffers is planting tree species that offer the promise of new economic benefits to the landowner. The science and practice of buffer development could include the economics and marketing of different tree products, such as fruits and nuts.

- *Reforestation of marginal agricultural land*

  "Reforestation" implies an active management role. That role should include two components: the active recruitment of landowners to reforest land that is erodible or nonproductive; and promotion of aesthetic and economically productive tree species. Many federal and state programs already promote the retirement of marginal farmland. These programs could receive greater levels of support and emphasis. In return, however, reforestation should be carried out to promote forests with economic potential, low occurrence of exotics, high aesthetic value, and high wildlife habitat value.

- *Expanded control of exotic species*

  Encouragement of forest retention and economic potential requires attention to forest health and quality. Greater consideration, therefore, must be given to means of controlling multiple invasive exotic species that are often unmarketable (e.g., Tree of Heaven), inhibit forest regeneration (e.g., *multiflora* rose), preempt forest resources (e.g., privet), or damage forest health (e.g., insect pests). Resource managers must also consider the detrimental effects of some native species, such as white-tailed deer, that can damage forests.

- *Further development of specialty markets for tree species*

  Economic development of specialty markets can provide incentives for even small landowners to plant and maintain forests. While forest plantations may not provide all the environmental services of "real" forest ecosystems, proper plantation management can stabilize soil, retain nutrients, and provide significant income. Sometimes these specialty markets might include exotic species such as the Princess-Tree *(Paulownia tomentosa)*; when grown in controlled plantations, this tree becomes a useful species rather than a noxious exotic.

- *Direct enforcement of forestry BMPs*

  The economic gain of growing forests usually derives from some level of tree harvesting. Disturbance due to harvesting clearly results in pollution, even if short-term, of surface waters. Stringent enforcement of established forestry BMPs throughout the Bay basin would reduce such impacts.

- *Easements for forestland*

  Forests are a valued resource for environmental, economic, and aesthetic reasons. Private organizations and public programs that preserve forests in perpetuity could be encouraged and coordinated to "design" easements that alleviate forest fragmentation, maintain stream buffers, and promote other forest environmental services.

- *Encouraging private forest management to meet demand for wood products*

  This effort could include a public subsidy to offset increased timbering costs on smaller forest parcels and also a greater dependence on plantation-grown trees (versus natural forests). It would also provide an economic incentive to properly maintain private forestland (the greatest portion of existing forest within the Bay basin) and to develop new private forestland. Encouraging growth and management of widely distributed private forest would also extend forest environmental services to a much broader portion of the Bay basin than possible through public forest.

- *Decreased harvesting of public forests*

  In conjunction with increased private forest management, parcels of larger, contiguous public forest could be managed as economic focal points for burgeoning recreational demands (including hunting and fishing) or as source areas for wildlife populations.

Two themes bind this list of actions. First, people care about the environment. The values and concerns of current private forestland owners should make them receptive to education efforts and environmental management of their land. Second, people are concerned about personal economics. Blending the conservation of forestland for environmental goals with the potential for increased income should present a winning proposition for private landowners in the coming decades. These themes extend also to public forestland, where the greatest environmental and economic gains over the long run will lie not in consumptive uses but in management for ecosystem health, recreational demands, and the restorative role of forests in our often-tedious modern lives.

Endnotes

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Adapting Agriculture

Agriculture has been and will remain a very important land use and economic force within the Chesapeake watershed. As a percentage of the region's gross domestic product (GDP), however, agriculture's contribution has declined steadily over the past decades, with its current contribution estimated at about 13 percent of GDP. In Maryland, for example, 36,000 farmers operated in the state in 1950. By the year 2000, that number had fallen to 12,000—a 66 percent decline.[1] Much of the food consumed by Chesapeake Bay watershed citizens is grown outside of the region and even within some states, agricultural sales are becoming more localized. In Maryland, five counties accounted for almost half the state's agricultural sales in 1997, down from seven counties in 1950.[2] On the other hand, some newer agricultural activities, such as greenhouses and nurseries, are geographically more widespread than in the past.

Of course, the importance of agriculture to the Bay region extends far beyond its direct economic value. About 25 percent of the land area of the Chesapeake watershed is currently used for agriculture, including grain and vegetable crops, grass and hay, livestock, and orchards. This land provides important open space for those living in the watershed. Agricultural areas also provide many important environmental services, particularly where farmers use environmentally sound practices.

Current Status of Chesapeake Agriculture[3]

Compared to other parts of the United States, agriculture in the Chesapeake region is characterized by smaller farms and a wider range of products. The average Chesapeake-area farm is about 180 acres, compared with more than 500 acres for the rest of the United States,[4] though this varies widely from state to state. On the other hand, poultry and hog operations in the Mid-Atlantic tend to be quite large as measured by the number of livestock per farm and quite intensive as measured by the number of livestock per acre. Crops, rather than livestock, account for three-quarters of total farm sales in the Mid-Atlantic region. Other important products from the Chesapeake watershed include dairy, mushrooms and other vegetables, nursery products, chickens, eggs, apples, peaches and other tree fruits.

Crop production in the Mid-Atlantic region is primarily rain-fed rather than irrigated, because most years yield sufficient rainfall. Less than 3 percent of crop acreage in the Mid-Atlantic is irrigated, compared with about 13 percent in the rest of the United States.[5] As discussed in Chapter 4, however, climate changes may boost the need for irrigation during the

Bob Nichols, USDA NRCS

growing season as increasing evapotranspiration lowers soil moisture.[6] The amount of evapotranspiration increase may be counterbalanced by the model prediction of increased precipitation.

An examination of major land resource areas (MLRAs) provides a snapshot of agriculture in the Mid-Atlantic region (Figure 7-1). These areas exhibit common patterns of soil, climate, water resources, and land uses.[7] Similar to the Bay watershed as a whole, about one-quarter of the total land area in the Mid-Atlantic is in agricultural use, predominantly for hay and pasture. The proportion of agricultural land varies among MLRAs, from over 50 percent in the Mid-Atlantic Coastal Plain to a mere 10 percent in the Eastern Allegheny Plateau and Mountains.

Agriculture accounts for about 4 percent of the total labor force in the Mid-Atlantic region (including both full- and part-time farmers). Yet agriculture's importance extends well beyond its role as a source of income and employment. Both within and outside the region, many value agricultural areas for their rural amenities. Fishing, boating, hunting, sightseeing, and other recreational activities remain important in rural areas. Agricultural lands also provide important habitat for certain wildlife species. Public programs that protect farmland from development and preserve agricultural landscapes in all six states within the Chesapeake region reflect these valuable features.[8] Regional programs include zoning for agricultural protection, differential property assessment, and conservation easements.

Agriculture can also have negative environmental impacts, including water pollution from nutrients, eroded soils, and pesticides. Of 2,105 watersheds (defined at the eight-digit hydrologic unit code level) in the 48 contiguous states, watersheds in southern New York, northern and southeastern Pennsylvania, western Maryland, and western Virginia rank in the top 10 percent in terms of manure nitrogen runoff, manure nitrogen leaching, manure nitrogen loadings from confined livestock and poultry, and soil loss due to water erosion. Watersheds in southeastern Pennsylvania and along the southern Virginia coast also rank in the top 10 percent for nitrogen loadings from commercial fertilizer applications.[9]

Socioeconomic Trends and Implications

Trends in costs and prices at regional, national, and international scales will influence the future of agriculture in the Chesapeake watershed. Key trends include markets for agricultural commodities and inputs, emerging technologies, and public policy. Prices for most commodities currently produced in the Chesapeake region are being set based on competition from other areas of the country and world, where production costs are usually lower than in the Chesapeake. The small scale of agricultural production in this region relative to total U.S. and global production means it will be difficult—if not impossible—for Chesapeake Bay states to affect these trends except through the influence of public polices.

Commodity Markets

Two key factors drive market behavior: real prices (inflation-adjusted) of tradable agricultural commodities (exports from and imports to the Chesapeake region); and demands for non-traded agricultural commodities entirely produced and consumed within the region.

Major tradable commodities currently produced in this region include dairy products, beef, pork, poultry, eggs, corn, wheat and other grains, soybeans, tobacco, greenhouse products, apples, and peaches. These commodities account for the vast majority of current farm income. Although the Chesapeake region remains a nationally important producer of many of these commodities, it accounts only for a small percentage of total U.S. production, including milk and poultry. On a global scale, the region contributes an even smaller fraction of production and trade. Changes in both supply and demand for these commodities in the region are unlikely, therefore, to significantly affect overall prices.

The most important non-tradable commodity in this region is hay. Other agricultural goods—considered non-tradable because shipping remains uneconomical and little or no interregional or international trade occurs at present—include some seasonal fresh fruits and vegetables. Future demands for non-tradable commodities are likely to depend on

Major Land Use Areas

Chesapeake Bay Watershed

MLRA, Name

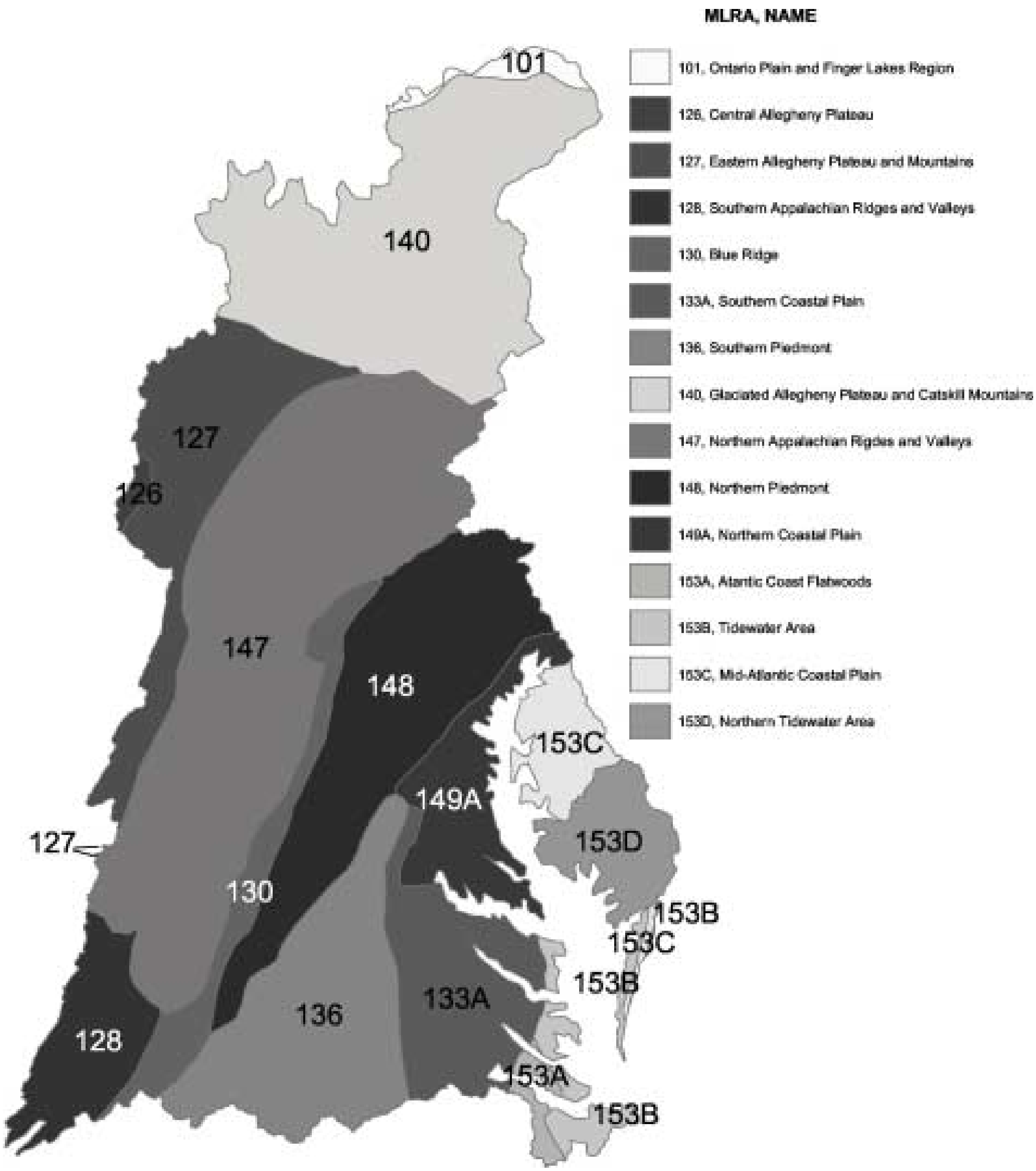


Figure 7-1. Major land use areas are determined by the land use, elevation and topography, climate, water, soil, and potential natural vegetation of a land area. The Chesapeake watershed comprises many land use areas with differing characteristics. For example, the Northern Piedmont (148) is characterized by farmland, although 35 percent is urban or is urbanizing rapidly. The gently sloping Mid-Atlantic Coastal Plain (153C) is about 45 percent woodland and 45 percent cropland, with less than 5 percent pasture and less than 5 percent urban.

regional population growth, per capita income growth, and trends in the prices of substitutes.

Projections for agriculture at the international scale by several global policy futurists suggest that real prices for major agricultural commodities such as wheat, corn, other grains, soybeans, dairy products, beef, pork, chicken, and eggs are all likely to decline in the coming decade, perhaps significantly. These projections are based on the assumption that productivity growth in world agriculture is likely to outstrip additional food demand caused by population growth and increase in per capita income. If true, these projections would be consistent with observed trends in global agricultural prices since the end of World War II. Generally speaking, real prices of agricultural commodities today are about one-quarter those of 1950. Changing the market's status quo may be difficult as long as food is abundant, cheap, and relatively safe.

Other global policy futurists, however, are more pessimistic about the potential for productivity growth in world agriculture to outstrip growth in global food demand. They suggest that the real prices of agricultural commodities could rise somewhat over the next few decades. Because the Chesapeake region is a marginal producer of several agricultural commodities, price projections become quite important. Many other regions and countries can produce grains, dairy products, poultry, and other commodities at lower prices than can farms in this region and still remain profitable, since fewer alternative uses compete for their agricultural land.

Future population growth in the Chesapeake region will likely result in additional conversion of farmland and forestland to residential and commercial uses.[10] Similar to the trend of the last 30 to 40 years, increases in per capita income and shifts in lifestyle choices could result in larger homes and lot sizes, with land development continuing at a rapid pace.

At the same time, demand may grow in the Bay region for fresh fruits and vegetables, particularly organically grown produce. These items are relatively non-tradable due to shipping costs and regional production may satisfy much of the regional demand. Even with fragmentation of large farming areas, farmers can still grow fruits and vegetables on smaller parcels, even if other agricultural commodities are not feasible. Access to processing markets, however, may prove difficult for small farmers.

Input Markets

Key factors in determining the value of (i.e., the markets for) agricultural inputs are: real prices of capital, labor, and purchased materials—including seed, processed livestock feed, fertilizers, pesticides, and energy—as well as competing demands within the region for non-traded inputs, principally land. Over the next 30 years, capital and labor will tend to be highly mobile between agriculture and other sectors of the economy in the Mid-Atlantic region as well as between this area and other U.S. regions and the world. Because purchased materials also tend to be highly mobile, real prices for agricultural capital, labor, and purchased materials will all be set essentially by forces well beyond the region.

Bob Nichols, USDA NRCS

In the not-too-distant past, much more of the land in the Chesapeake region resembled this small farm in Lancaster County, Pennsylvania.

An upward national trend in real wages and salaries will likely continue, resulting in rising costs of farm labor and in farmers and prospective farmers seeking better earnings outside agriculture. Historically, this trend has resulted in fewer farms, fewer farmers, and larger farm sizes.[11]

Technology Drivers

The Bay region is too small economically to affect national and global rates of technological change significantly especially since most technologies are developed for national or global markets. New technologies that increase productivity are, therefore, unlikely to produce a competitive advantage for agriculture in this area, though some regional advances could have local effects. For example, pelletized poultry waste sold as a lawn fertilizer or other high-end uses could help solve the poultry waste problem while creating a value-added product.

Other technological trends remain somewhat unpredictable, although two known technologies may have significant implications for Chesapeake agriculture: precision agriculture and biotechnology. Such technologies allow farmers to better understand the physical environment in which they operate and enable them to better adapt to changes in climatic conditions. These technologies may also significantly reduce the use of pesticides and fertilizers, while lowering the nutrient content of livestock waste. These trends will affect agriculture overall and Chesapeake Bay farmers will have to keep up with them to remain competitive. (For a more complete discussion on possible technological advances that affect pollution control, see Technological Solutions.)

Public Policies and Institutions

Public institutions can create policies to encourage certain types of agriculture and agricultural practices, including economic development, investment, and marketing strategies. Among traditional methods of affecting agricultural economics and production, as well as environmental impacts and land preservation, are:

- agricultural price and income-support policies;
- environmental policies concerning agricultural producers;
- agricultural land preservation policies;
- land set-aside policies; and
- land use regulations and institutions.

In the United States, the federal government almost exclusively controls agricultural price and income support policies. Because the contribution of Chesapeake-region agriculture is a small fraction of the total U.S. agricultural economy, institutions in the watershed are unlikely to influence, in any significant way, the structure of federal price and income support policies or institutions. Beyond this, a slow but inexorable movement appears underway toward liberalizing global trade, further reducing the influence of local agriculture on large-scale trends.

If this trend toward globalization continues, the dismantling of traditional agricultural price and income-support policies will accompany it. Replacing those conventional supports will be a movement toward direct payments to farmers tied to something other than current production, such as environmental or land preservation efforts. Agricultural trade liberalization should have modest effects on the prices of most agricultural commodities, with a major exception in dairy products. Since dairy markets in most countries, including the United States, are currently protected from imports, any liberalization of trade in this area could significantly reduce the price of dairy products. This liberalization could, therefore, significantly affect dairy farming, an important component of the agricultural economy of the region. Dairy production would likely shift to other regions and other countries with comparative price advantages. Of course, other agricultural sectors, from grain to animal production, could be affected by a simlar dynamic.

Policy changes, particularly at the federal level, could affect farming behavior if, for example, conventional commodity-based subsidies were replaced by “green payments” for ecologically desirable practices. Such environmental services could include planting buffer areas on farmland or providing carbon sequestration by allowing vegetation to grow in wet or otherwise marginal areas (through the Conservation Reserve Program, for example).

Federal, state, and local governments all have some authority or influence over land use, including agriculture. Local governments in the Chesapeake Bay basin, including counties, exert substantial influence over land use through zoning, property taxes, and other policies. Most state governments in the Bay watershed have policies to foster the preservation of agricultural land, especially programs to purchase development rights on prime farmland.[12] At the federal level, land retirement and set-aside policies have long been part of agricultural price and income support programs. The limiting factor in such programs is often the availability of funds, particularly public funds. Table 7-1 shows the status of agricultural land protection programs in several Chesapeake states. Increasingly, agricultural land preservation is being pursued for a broad array of social reasons (see "Why Save Agriculture?" box).

States have traditionally controlled environmental policies toward agriculture, with the notable exception of pesticide regulation. Recently, however, EPA has required states to implement regulations for nutrient management at concentrated animal feeding operations (CAFOs).[13] In addition, states have responsibilities under the Federal Clean Water Act to reduce nonpoint-source pollution (including agricultural sources) to alleviate water quality impairment.

Environmental policies toward agriculture in the Chesapeake region remain somewhat uncertain. If growth occurs in large-scale, highly intensive livestock poultry farms, state and federal environmental regulation of these farms is likely to increase. Prospects for regulatory changes affecting less intensive livestock operations or crop farms seem less clear. With increasing suburban growth and development, conflicts between agriculture and suburban residents are likely to multiply—with the increased likelihood of additional regulation.[14]

Scenario Assumptions

Even assuming that prices of major agricultural commodities rise somewhat in coming decades, it is difficult to envision agriculture in the Chesapeake region any more economically important than today. The region does not have a comparative advantage in most agricultural commodities; other regions and countries will likely be better poised to take advantage of rising commodity prices. At the same time, competing demands for land within the region will most likely still cause the loss of agricultural land, even with higher commodity prices.

All three scenarios assume that the trend of generally declining agricultural profitability will continue in the Chesapeake region. This downward trend in production will be accelerated by a growing demand for urban land uses to accommodate the expanding population, particularly near the Chesapeake Bay and existing major urban areas (Figure 7-2). A decrease of land in agriculture and a decrease in the agricultural labor force will

Program	Maryland	Virginia	Pennsylvania
Environmental Quality Incentives Program (2000)	$1.7 million 307 contracts	$2.2 million 172 contracts	$2.5 million 189 contracts
Conservation Reserve Program (1987-2002)	3,456 contracts 44,676 acres	2,479 contracts 49,051 acres	2,929 contracts 83,180 acres
Conservation Reserve Enhancement Program (1998-2002)	2,309 contracts 27,017 acres	604 contracts 5,414 acres	789 contracts 17,606 acres
Wetlands Reserve Program (2001)	28 contracts 1,844 acres	27 contracts 1,040 acres	172 contracts 3,440 acres
Forestry Incentives Program (2000)	83 contracts $123,365	344 contracts $600,000	46 contracts $43,000

Table 7-1. Status of agricultural land protection programs in Chesapeake Bay states. (Source: USDA, NRCS, and FSA)

Why Save Agriculture?


Tim McCabe, USDA NRCS

Why save farms? With an economy that is increasingly technology- and information-based, especially in the densely populated eastern United States, why worry about farming? According to some experts, in addition to food, here's what we stand to lose:

Connections with the land Ecologists, philosophers, and others have pointed out that our modern way of life tends to cut us off from the landscape. Automobiles carry us over asphalt, while shopping centers and office parks give us places to shop and work that have become disconnected from the land. Housing subdivisions, highly developed and highly structured, may likewise separate us from the landscape. As ecologists such as E.O. Wilson and Stephen Kellert have argued, a direct connection with nature brings many benefits, whether physical, emotional, or spiritual. Some argue that these connections must go beyond passive enjoyment to actual engagement with nature. "Working landscapes," such as farms, provide ample opportunity for that kind of interaction.

Definable communities In our agrarian past, the family, the workplace, and the local town were all interconnected through a series of shared needs and purposes. Farming families depended on each other and on local businesses—feed and seed stores, equipment dealers, grain elevators—for survival. Now families, businesses and workplaces are often widely disconnected, with commuters frequently driving many miles (and hours) between work and home. While not everyone could or should work on a farm, the loss of remaining farmland robs the population at large of cultural diversity and identifiable communities associated with rural landscapes.

Open space and habitat With development of agricultural lands, the landscape loses large amounts of edge habitat important to many birds—the Eastern bluebird, for example—and other species. Development brings predictable increases in impervious surfaces, such as roads and rooftops, which lead to accelerated runoff, stream erosion and channelization, and less recharge to aquifers. Once land is developed, it rarely reverts, while agricultural land can more easily return to forest or wetland.

Scenic landscapes How can we measure the effect on the human spirit of pleasant farm fields stretching off into the horizon? Or, conversely, of endless billboards, streetlights, and parking lots? Human beings, many have argued, have powerful evolutionary attachments to particular landscapes, to certain aspects of a green world. A world devoid of open spaces, green spaces, and farmland would appear impoverished in the minds of many, lacking visual and spatial diversity. With increasingly homogenized landscapes composed of the same large chain stores in the same kinds of shopping centers, and often arranged in the same ways, such landscape diversity will likely assume even more importance in the coming decades.

accompany the decline in agricultural production. Agricultural production, as a percentage of the region's total economic output, will also decline.

Although agriculture will continue to wane over the next few decades for the Chesapeake region as a whole, it will not die. In parts of the watershed where land is under less pressure for urban development and land prices remain relatively low, agriculture will remain a viable and important part of the local, if not regional, economy. Remaining agriculture will fall into two major categories: larger farms and more intensive animal agriculture for traditional commodities, and specialized niche agriculture. Farmers who remain in agriculture will enjoy higher living standards than do farmers in the region today since the farms that remain will be significantly larger, both in acreage and livestock numbers. Of course, larger farms may cause problems. For example, farmers working large tracts of land may not be able to provide adequate stewardship for the maintenance of soil quality, buffer areas, and other factors—though conservation payments and other programs should help. Under specialized agriculture, the production of organically grown fruits and vegetables, horticulture, and other specialty products will likely expand.

Discrete sectors and different areas will respond to shifts in price, cost, and climate quite differently. For example, the low price structures that plague grain producers on the Delmarva Peninsula will be a plus for grain consumers such as dairy and poultry farms. Likewise, policy shifts may affect varying agricultural sectors in different ways. In Maryland, for instance, the Water Quality Improvement Act of 1998 will have a greater impact on poultry and dairy operations than on crop farms.[15]

The three scenarios below reflect differing assumptions about the amount of agricultural land converted to urban use, as well as differing assumptions regarding the use of technologies and best management practices (BMPs) that affect nutrient export from farms. The scenarios do not directly incorporate assumptions about trends and policies influencing the conversion of agricultural land. We assume, however, that the major factors shaping agricultural land conversion are urban and suburban development and abandonment of marginal agricultural lands in remote parts of the watershed (see Forests in Transition chapter).

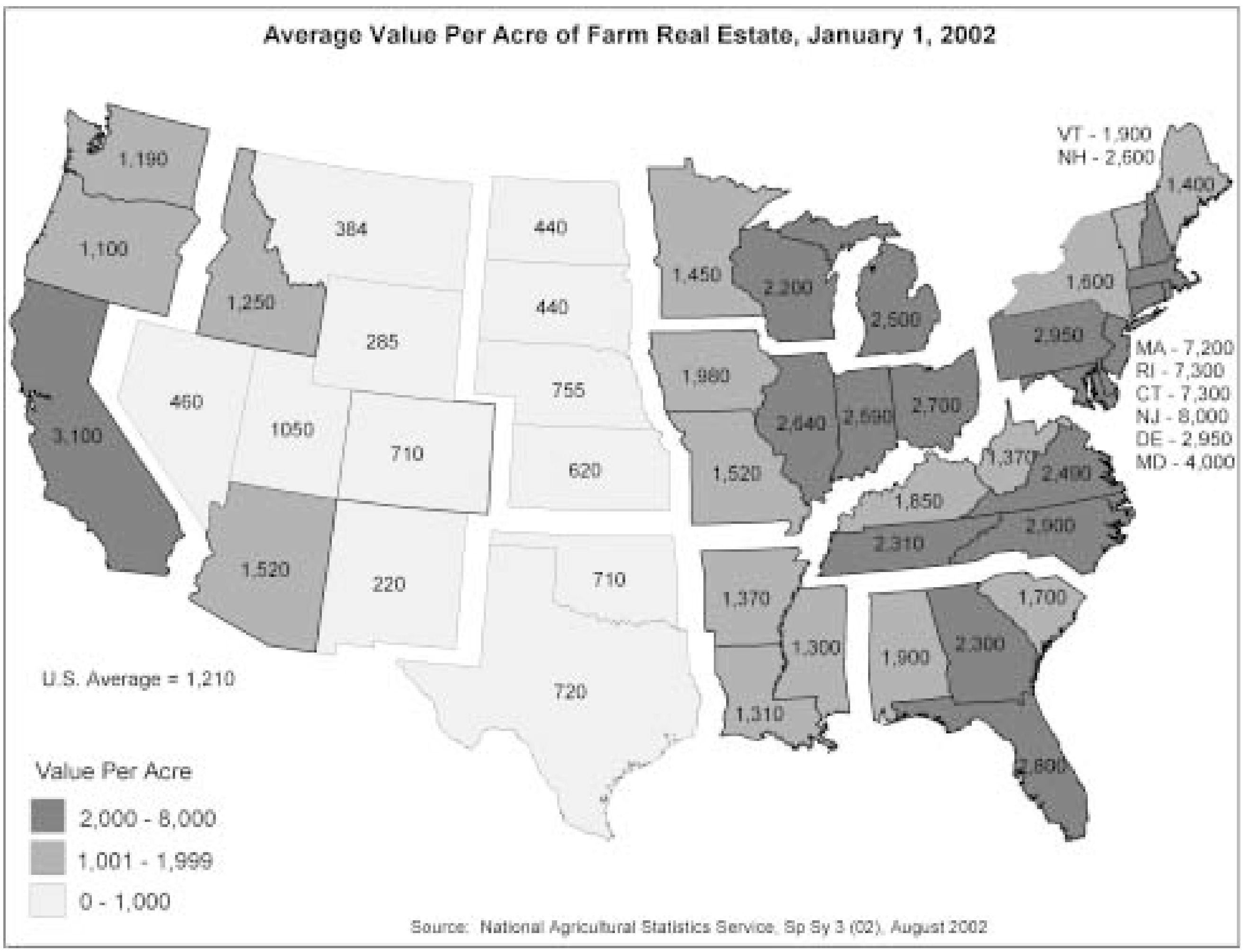


Figure 7-2. USDA map showing state averages of farm real estate value nationwide. The smaller, populated states along the mid-Atlantic and northeastern seaboard tend to have the highest average values, which can place enormous development pressure on agricultural lands.

Scenario 1: Recent Trends

Primary Expectations:

- *Urban and suburban expansion will result in the loss of almost 700,000 acres of agricultural land (Figure 5-4).*
- *With less farmland available to go out of production, agriculture-to-forest conversion could decline, particularly in the Ridge and Valley and Appalachian Plateau provinces.*
- *Demand for undeveloped land will raise prices, fragment farms, and alter the character of rural areas.*
- *Small farmers will find it difficult to make a living from traditional farming as global market trends and other economic forces continue to erode profits.*
- *Existing farms will experience a greater dependence on intensive agriculture.*
- *Technology and globalization will have some positive effects on agriculture.*

If current trends hold for the next three decades, the population will continue shifting to specific growth areas, such as the coastal zone and the fringe of large cities, such as Philadelphia, Baltimore, Washington, Richmond, and Norfolk. One high-growth area, stretching west of Washington, D.C. south to the James River watershed, illustrates the strength of migration into the Piedmont area. The western reaches of the Bay watershed will not experience high growth if current trends continue.

These growth patterns will have enormous impact on agriculture, particularly farming that requires large amounts of land for crops or pasture. Demand for land created by migration to agricultural areas will drive up land prices, fragment existing farmland, and alter the character of farming regions. Specific problems suggested by recent trends include:

- *Increasing difficulty of small farmers to retain sufficient land to make traditional farming profitable.*
- *Conflicts between suburban and farming interests, making driving tractors on the highway more difficult and resulting in complaints about odor and noise.*
- *Continued erosion of profit margins, driven by forces far beyond the Chesapeake region, including global market trends.*
- *Loss of farm-related infrastructure, ranging from feed and seed stores to equipment dealers to grain elevators.*
- *Loss of the agrarian community, as infrastructure disappears and farming areas become fragmented and separated by suburban development and highways.*
- *Continued loss of open space, with concomitant loss of habitat for various edge species and other plants and animals, including some migratory birds.*

The continuation of recent trends will not be all bad. Services will reach farther out to agrarian communities. The information highway—which may require cell towers but no asphalt—will provide new avenues of connection for rural families. Furthermore, current efforts to preserve farming areas or purchase easements will have some positive effect on saving contiguous areas for farming and open space.

In general, however, current programs will make only a small dent in the general trend of intense development in some areas, especially near the Bay and its rivers. These areas will see the continued loss of agricultural land over the next three decades. If current trends hold, they will also experience more dependence on intensive agriculture, such as poultry farms. Some alternative agriculture, such as greenhouses and nurseries, will continue, possibly with increased roles for organic foods or specialty items.

Under the current scenario, market trends for many conventional farming sectors, such as grain production, do not look promising. The outlook for other important agricultural enterprises, such as poultry farming, may depend on whether certain structural problems, especially the handling of waste and reduced environmental impacts, find successful resolution.

Precisely how these factors play out will vary significantly among regions (e.g., the Delmarva versus the Piedmont), and will also depend on large-scale factors such as climate and global markets. By far, the most immediate and potentially controllable impact will be mitigating the spectacularly high rates of land conversion of the past several decades.

Scenario 2: Current Objectives

Primary Expectations:

- *Land preservation efforts of the Chesapeake 2000 agreement will preserve open space and guide development patterns; however, 400,000 acres of agricultural land will still be converted to urban and suburban uses (Figure 5-4).*
- *Even if farmlands are preserved, agricultural industries will face economic difficulties and an insufficient number of people may be willing to farm for a living.*
- *The implementation of soil and water conservation plans on croplands and hayfields will reduce nitrogen loadings by 9 percent and phosphorus by 21 percent.*
- *Nutrient management plans will be successfully applied to half of the tilled cropland and hayfields in the watershed.*

The *Chesapeake 2000* agreement specifically commits the signatory parties to "permanently preserve from development 20 percent of the land area in the watershed by 2010." The agreement also includes the commitment: "by 2012, reduce the rate of harmful sprawl development of forest and agricultural land in the Chesapeake Bay watershed by 30 percent." These efforts have clear implications in terms of preserving open lands for habitat, stream protection, aesthetics, and related ecosystem functions. They may have varying impacts on agriculture itself. Payments for conservation easements and buffer zones, for example, will clearly carry potential economic benefits for farmers. The success of conservation programs, such as Pennsylvania's Farmland Preservation Program or Maryland's Rural Legacy Program[16] which maintain contiguous areas of agricultural land and make farming easier and more economical, will also have a positive impact on the future of agriculture in those areas. Most importantly, such programs could offset the powerful lure of rising land prices and spreading development that will unquestionably threaten agriculture in the watershed during the next three decades.

On the other hand, land preservation efforts—while laudable for protecting open space and guiding development patterns—will not necessarily preserve working farms. Despite efforts to save land from development, agricultural enterprises will still face many difficulties:

- Current global markets have meant such slim profit margins for some growers that improvements to the land, such as conditioning the soil, are not cost-effective and lead to poor management practices or no farming at all.
- As farmers age and retire, their children are often attracted to higher-paying urban jobs and may not carry on the farming tradition, even if the land has been "set aside" for that purpose.
- Environmental problems, such as the buildup of nutrients in the soil and groundwater, can create difficulties for farmers, especially if support

Jeff Vanuga, USDA NRCS

In Washington County, Virginia, a farmer sows corn into a cover crop of barley using no-till planting, a method that reduces soil erosion.

(public subsidies) is not forthcoming for cover crops, waste containment, or other programs.

- Agriculture, like any business, must adapt to changing tastes and trends to remain viable; failure to adapt may mean business collapse.

While current objectives for land preservation will partially offset increasing demand for development of agricultural land, success in farm preservation under current objectives will prove spotty at best without a more integrated approach to agriculture itself.

Scenario 3: Feasible Alternatives

Primary Expectations:

- *Land preservation efforts, in combination with programs that target the economic sustainability of farming, will preserve open space and viable rural communities. Less than 300,000 acres of agricultural land will be lost to new development (Figure 5-4).*
- *Technological advances and policies will resolve animal waste problems, improve efficiency, and provide financial planning and business management aid to farmers.*
- *Various economic and environmental policies along with behavioral changes could further ensure the existence and success of agriculture in the watershed.*

A combination of land conservation measures and programs could help sustain rural farming communities during the next three decades. To preserve agriculture, policies will need to protect and enhance the viability of this livelihood as well as bolster "smart growth" efforts. Such policies could include:

- Increased funding to acquire development rights for agricultural land preservation.
- Examination of the requirements for preserving agricultural land through the acquisition of development rights for agricultural land preservation ensuring that preserved agricultural land remains viable for agricultural production
- Program development to match new or relocating farmers with preserved farms.
- Increased information and assistance to farmers who wish to develop specialty and niche agricultural products.
- Economic development programs to encourage secondary processing facilities and marketing strategies for specialty and niche agricultural products.
- Producer/purchaser networks to link farmers interested in custom production with prospective buyers.
- Increased financial and technical assistance to farmers for implementing agricultural pollution prevention/control programs.
- Development and promotion of Bay-friendly agricultural products.
- Identification of additional ways to lower production costs and increase the competitive advantage for Chesapeake-region farmers.

In addition, the advances discussed in the next chapter on Technological Solutions could:

- Help solve the animal waste problem through the innovative use of animal products. Pelletizing poultry waste to create fertilizer products for high-end retail uses such as lawn and garden maintenance and manipulating feed to reduce phosphorus content are two such uses.
- Increase efficiencies of farm fertilizers and herbicides through more accurate applications, including precision agriculture technologies.
- Aid in the business management of farming through increased use of computer-based financial planning and tracking.

These and other advances may improve the economic efficiency of farming; however, some experts feel that the real changes need to be behavioral and political. For example, do the signatory states include the preservation of agriculture as a viable industry as a stated objective? And for their part, do farmers have an "environmental ethic" to drive decisions that will provide a net benefit, rather than a net loss, to the ecosystem?

Some policies and plans that could make a difference include:

- A shift from commodity-based subsidies to environment-based subsidies, or "green payments," that reward farmers for good stewardship practices, rather than simply paying them for not growing a particular crop.
- Full-cost pricing for responsibly grown food. A very small cost addition to food products—in the range of pennies per item—could help pay for environmentally sound agriculture in the marketplace.
- Additional emphasis on pollution prevention could reduce the need for cleanup and restoration downstream. This cost could be passed from the farmer to other beneficiaries through a nutrient-trading regime, for example.
- A commitment to small towns—including funding for schools, roads, and other infrastructure—could increase the willingness of many to live in these areas, revitalizing the towns and preventing the undesirable spread of development into prime farmland.

Such changes in policy and behavior could reap dramatic benefits. Clearly, pollution prevention is always cheaper than after-the-fact cleanups. With an emphasis on controlling total loadings to streams and rivers, waste treatment plants, power generating stations, or industries may find it worthwhile to consider trading schemes that include agricultural inputs in the same watershed or airshed.

Maryland's Eastern Shore Land Conservancy has crafted a vision statement that aptly captures the potential transformations brought about by this Feasible Alternatives scenario, in which: towns are vibrant and well defined; farms, forests, and fisheries are thriving; and scenic, historic, natural, and riverine landscapes are maintained.

In this vision, small towns would have definable edges and farms, forests, and fisheries would be well managed. We would not lose our scenic landscapes or the character of the region. In short, the future would not lose its link to the past. As one farmer said, "We should always stay connected to our roots." It's a fitting way of ensuring our future.

Endnotes

[1] Hanson, J. 1999. *Trends in Maryland Agriculture*. Maryland Cooperative Extension, University of Maryland, College Park. Economic Viewpoints 3(3): 1-5. See also Tubene, S. 2002. *Agricultural and Demographic Changes in the Mid-Atlantic Region: Implications for Ethnic and Specialty Produce*. University of Maryland Cooperative Extension (FS 793).

[2] Ibid.

[3] Much of the material in this and the following section is borrowed liberally from the Mid-Atlantic Regional Assessment (MARA). Although the analysis was for the entire mid-Atlantic region, the characteristics of the Chesapeake Bay watershed agricultural land and economy are very similar to this region. Fisher, A., D. Abler, E. Barron, R. Bord, R. Crane, D. DeWalle, C.G. Knight, R. Najjar, E. Nizeyimana, R. O'Connor, A. Rose, J. Shortle, and B. Yarnal. 2000. *Preparing for a Changing Climate: The Potential Consequences of Climate Variability and Change*. Mid-Atlantic Foundations. U.S. Global Change Research Program.

http://www.essc.psu.edu/mara/results/foundations_report/index.html#report

[4] USDA National Agricultural Statistics Service. 1999. 1997 Census of Agriculture. *http://www.nass.usda.gov/census.*

[5] Ibid.

[6] National Assessment Synthesis Team. 2000. *Climate Change Impacts on the United States: The Potential Consequences of Climate Variability and Change*. Washington, D.C.: U.S. Global Change Research Program.

[7] U.S. Geological Survey. 1999. Major Land Resource Area. *http://www.cr.usgs.gov/Webglis/glisbin/guide.pl/glis/hyper/guide/mlra*

[8] American Farmland Trust. 1997. *Saving American Farmland: What Works*. Washington, D.C.: American Farmland Trust.

[9] Kellogg, R.L. 1997. Potential Priority Watersheds for Protection of Water Quality from Nonpoint Sources Related to Agriculture. Presentation at 52nd Annual Soil and Water Conservation Society Conference, Toronto, Ontario.

[10] American Farmland Trust rated the Northern Piedmont the second most threatened Major Land Resource Area in the country; the Mid-Atlantic Coastal Plain was rated ninth. Urban expansion and population growth were cited as responsible for the conversion threat. American Farmland Trust. 1997. Farming on the Edge. Washington, D.C. *http://www.farmlandinfo.org/cae/foe2/*

[11] Off-farm employment will continue to be important for many farmers and will undoubtedly play a role in maintaining the economic viability of many small farms.

[12] Stoel, T.B. Jr. 1999. Reining in Urban Sprawl. *Environment* May: 15. Montgomery County, Maryland, just north of Washington, D.C., is home to 800,000 people and has preserved farmland and green spaces more successfully than any other jurisdiction in the area. It relies in part on transferable development rights, a sophisticated mechanism enabling farmers to receive compensation from developers for not developing their land and continuing to farm it.

[13] For information on proposed rules for CAFOs and on the joint USDA and EPA Unified National Strategy for Animal Feeding Operations, see *www.epa.gov/npdes.*

[14] Many of the conflicts will be handled on the local level (e.g., through zoning decisions).

[15] Hanson, J., op. cit.

[16] Chesapeake Bay Commision and The Trust for Public Land. 2001. *Keeping Our Commitment: Preserving Land in the Chesapeake Watershed*. Annapolis, MD: Chesapeake Bay Commission.

Technological Solutions

Jeff Vanuga, USDA NRCS

New technologies have dramatically influenced how humans live and prosper. As a consequence, they have also shaped how humans affect the Chesapeake Bay, for good or ill. In the 19th century, Thomas Jefferson's moldboard plow expanded soil cultivation, causing a subsequent increase of sediment washing into the Bay. Later in the same century, steam-powered vessels allowed industrial-scale harvesting of the Bay's oysters; sewage collection reduced public health risks, but concentrated waste discharges. During the 20th century, increased availability of fossil fuels stimulated remarkable growth in energy consumption, proliferation of automobiles, and the manufacture of chemical fertilizers. Jointly, these transformations supported dramatic population growth, altered the landscape, and injected more nutrients into the Bay. These advances greatly improved human welfare, but had insidious and unanticipated consequences for the Bay—consequences that we are now trying to redress.

Toward the end of the 20th century, the information age presented new ways of treating wastes, observing the Bay, and tracking changes in the Bay over time. New technologies also enhanced communication and public access to information via the Internet. Although emerging technologies may introduce additional new threats, the understanding and societal commitments generated in the late 20th century may well craft the 21st century into an enlightened age in which technology becomes the Bay's ally rather than its foe. The Bay community will use developing technologies to restore and protect the Bay rather than further degrade it.

In this chapter, we consider innovations likely to become important in the stewardship of the Bay ecosystem within the foreseeable future. Our focus, as is the case for much of the Bay restoration effort, is on controlling nutrients entering the Bay. Despite well over a decade of effort, achieving nutrient reduction goals remains a vexing challenge. Maintaining the progress achieved will be particularly challenging as the human population and footprint in the watershed continue to grow. While we do not subscribe to technological optimism in the extreme—blind faith that inventions around the corner will solve all of our problems—substantial improvements in nutrient control technology clearly must become part of the solution to counteract increased pressures of growth and development.

We consider technologies already in use elsewhere that may prove effective in the Chesapeake region, promising technologies under active development, and visionary technologies as yet undeveloped. Since unfavorable economic conditions and resistance to change can hinder development of new technologies, we will evaluate these potential advances with an eye toward these constraints. On the other hand, detailed cost-and-benefit analyses remain beyond the scope of *Chesapeake Futures*. Instead, we merge the scenarios for technological solutions with those projecting the effects of population growth and land development in order to estimate combined impacts on nutrient loading.

Nutrient Sources in Perspective

Nutrients move into the Chesapeake Bay through several pathways from many sources both within and beyond the watershed. Consequently, there is neither a single cause of nutrient pollution of the Bay nor a single solution. This complexity has led to ongoing debates among scientists, as well as the responsible jurisdictions and stakeholders, about the relative importance of different nutrient pollution sources—and the most effective solutions.

To address this complexity, the multi-state Chesapeake Bay Program has developed a sophisticated computer-driven model that estimates nutrient loadings. The Bay Watershed Model accounts for various inputs of nutrients and their loss or storage en route to tidal waters and has proven a useful tool. The Watershed Model answers "what if" questions such as: What nutrient inputs to the tidal waters of the Bay will result due to changes in agricultural practice or land use?

Scientists and managers continuously refine the Watershed Model by incorporating the latest estimates of the sources, land uses, and transformations of nutrients within the watershed. The current version of the watershed model[1] estimates that about 305 million pounds (139 million kilograms) of nitrogen and about 19 million pounds (almost 9 million kilograms) of phosphorus were entering the Bay and its tidal rivers from land, atmosphere, and direct discharges each year around the year 2000. This does not mean that precisely those amounts entered the estuary during the year 2000. First, because total input during a given year is heavily influenced by precipitation and river flow—the higher the flow, the greater the loading of nutrients from the watershed. The 2000 loading estimates are, in fact, normalized to an "average" year based on 1985 through 1994 flow conditions. In actuality, the freshwater inflow during 2000 was well below average (Figure 4-5). Secondly, the model estimates that the practices that have been put into place since the 1980s to control nonpoint sources have actually been as effective as assumed—this has not been independently verified. Finally, the estimates are not adjusted to account for any lag time between when a land-use change takes place or a new management practice is adopted and when the delivery of nutrients to the Bay is affected.

The Watershed Model allows scientists and managers to track various sources of nutrients from their origins in the watershed. Further refinements estimate the quantity of nutrients from croplands, forests, and developed areas. Also important is the significant contribution of nitrogen from the atmosphere, some of which falls directly on the Bay and other water bodies but much of which settles on the croplands, forests, and developed areas. A portion of the nutrient load is "natural," with some entering the Bay even before European settlement of the region (although only about 1/7 as much nitrogen and 1/20 as much phosphorus as today).[2] By reapportioning the nutrient loading estimates from the model into five basic sources from human activities: human and industrial waste disposal, crop production and pastures, animal wastes, development (urban, suburban, roads, etc.), and atmospheric emissions, we can estimate trends and determine which sources have the greatest impact.

The annual anthropogenic loadings of nitrogen and phosphorus—potentially controllable by technologies—total 262 and 20 million pounds of nitrogen and phosphorus, respectively. Agriculture constitutes the largest source of both nitrogen (Figure 8-1) and phosphorus (Figure 8-2), while atmospheric emissions and human and industrial waste disposal contribute similar amounts of nitrogen. Nitrogen oxides (NOx) released from the combustion of fossil fuels (from power plants, vehicles, etc.) comprise the majority of the

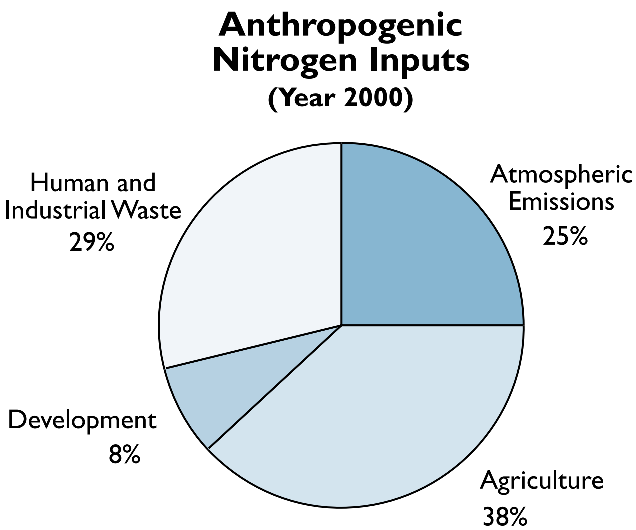


Figure 8-1

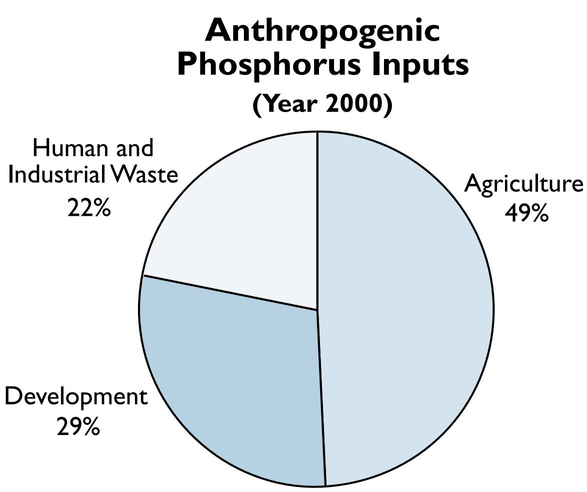


Figure 8-2

Figures 8-1 and 8-2. While agriculture remains a dominant source of nitrogen and phosphorus, other human activities also generate significant amounts of both nutrients. For example, one-quarter of anthropogenic nitrogen comes from the atmosphere.

atmospheric emissions, but ammonia released from animal wastes, fertilizer application, and industrial process also contribute a poorly known proportion (assumed here to be 28 percent). The phosphorus deposited from the atmosphere comes primarily from dust originating from agricultural and developed land uses and is not considered here as a new source.

Human and industrial waste discharges contribute about one-quarter of the nitrogen and phosphorus reaching the estuary. These discharges include so-called point sources—treatment facilities releasing effluent to tidal or flowing waters—and most of these discharges come from municipal waste treatment plants. Previously, point-source discharges contributed a larger fraction of phosphorus inputs; however, elimination of phosphate-based detergents and advanced waste treatment has greatly reduced these loadings. Currently, about 16 percent of the human and industrial inputs of nitrogen reaching the estuary comes through groundwater from septic systems. Such systems contribute little or no phosphorus, however, which tends to be adsorbed within the soil.

Urban and suburban development, including roads, contribute a significant proportion of phosphorus loadings due largely to increased soil erosion. Developed lands also contribute significant quantities of nitrogen—beyond that expected solely from atmospheric deposition on their land area—due to fertilizer application and higher stormwater runoff.

Animal waste constitutes a significant source of nutrients. Manure is applied to fertilize croplands and pastures, contributing to inputs from those land uses. The categorization of nutrient inputs from animal wastes often underemphasizes the importance of animal manure as a pathway for nutrient loading since significant amounts of ammonia nitrogen are released to the atmosphere from animal urine and feces and redeposited on land or water surfaces. This pathway is generally represented under atmospheric emissions.

This account of the present anthropogenic inputs of nitrogen and phosphorus to the estuary sets the stage for considering the reductions potentially achievable through improvements in various technologies. The following sections describe several technologies along with estimates of reductions they may achieve. The potential reductions represent a relatively crude means of showing what may be technologically achievable. Percentage reductions are applied to total loadings estimates for the various sources; they are not applied to geographically specific land uses, practices, or sources as they might be in the detailed Watershed Model. Of course the effectiveness of diverse technologies may vary considerably, based on where they are applied. Also, estimating the net or cumulative effect of several technologies remains a difficult task.

Human and Industrial Wastes

Advanced Wastewater Treatment

The Clean Water Act of 1972 mandated secondary treatment of municipal wastewater effluents and the application of best available technologies for the treatment of industrial wastes. Improved treatment resulted in substantial reductions in loadings of the nation's waters by organic wastes, which consume oxygen, create bottom deposits, and release toxic substances.[3] The nutrient content of treated wastewaters, however, was hardly reduced. The need for more advanced waste treatment to remove nutrients first became apparent for freshwater environments, where phosphorus tends to determine aquatic plant production (as the less available or "limiting" nutrient). Chemical treatment largely eliminates phosphorus. Consequently, removal of this nutrient from wastewaters discharged into such waters as Lake Erie and the tidal freshwater Potomac River below Washington, D.C. produced substantial improvements in water quality. Key in the reduction of phosphorus were laws banning phosphates from detergent.

An especially effective technique, biological nutrient removal (BNR) uses controlled biological systems to remove nutrients from wastewater. Phosphorus-storing bacteria remove most of the excess phosphorus from wastewater; the phosphorus-rich biomass is then removed for final disposal (e.g., as sludge). If needed, simultaneous or subsequent chemical precipitation can further trim the phosphorus concentration in the effluent. Taken as a whole, BNR minimizes waste sludge production and reduces costs compared with removal dependent entirely on chemicals.

For nitrogen, BNR involves a two-step biological process in which microbes first convert ammonia (the dominant inorganic nitrogen form in the wastewater) to nitrate under aerobic (oxygen-rich) conditions. Different forms of microbes under anaerobic (oxygen-deprived) conditions then convert the nitrate to gaseous forms of nitrogen (mainly di-nitrogen gas, N_2). Nitrogen is an important limiting nutrient for plant growth in the brackish Chesapeake Bay and is, therefore, a major water pollutant.

Using biological nutrient removal (BNR) will substantially reduce nutrient inputs to Bay waters.

Advanced waste treatment for nutrient removal may vary on a site-by-site basis. Pennsylvania has adopted nutrient reduction technology (NRT) that borrows BNR methods, combining them with other nutrient reduction technologies to achieve cost-effective treatment solutions. With its efforts to reduce nutrients, the Chesapeake region has become a leader in the application of nutrient removal technologies for nitrogen removal from wastewater. Jurisdictions in Florida have also applied this process to municipal wastewater effluents discharged to Tampa and Sarasota bays, where water quality has improved sufficiently that seagrasses have returned in some areas. Massive investments are also being made to incorporate nutrient removal technologies in the large wastewater treatment facilities discharging into Long Island Sound in order to achieve a 58 percent reduction in nitrogen inputs.[4]

Through the use of BNR in the Bay watershed, reduction of total nitrogen (TN) and total phosphorus (TP) effluent concentrations to 8 mg/L and 2 mg/L, respectively, is both technically and economically feasible and will substantially reduce nutrient inputs to Bay waters. Currently, BNR treats approximately half of the wastewater discharges in the Chesapeake watershed during the warmer months of the year. The Bay states have made commitments to apply BNR to a significant portion of the remaining discharges. Upgrading to the second stage of BNR (Table 8-1) is technically feasible and the incremental costs are small.[5] Achieving third-stage BNR goals or the full limits of technology, however, will prove more expensive.

Wastewater treatment using membrane or reverse-osmosis technology can clean wastewater to a sufficiently high level that it is reusable even for high-quality purposes. Membrane treatment significantly increases costs, but may be the least-expensive choice when used in decentralized treatment since it avoids the costs of sewer and pump station construction and has enhanced reuse potential. Membrane technologies can produce effluents suitable for drinking (i.e., TN < 1 mg/L, TP < 0.1 mg/L, with no pathogenic microorganisms and very low bacteria counts).

The use of membrane treatment technologies will likely be feasible only for decentralized wastewater treatment where water reuse is a consideration. Localized treatment of wastewaters from planned residential and commercial developments, seasonal installations (such as ski resorts and summer camps), and high-rise buildings is already occurring in some parts of the world.

Septic Systems

Approximately one-sixth of the nitrogen reaching the estuary from human and industrial waste disposal comes from septic systems. Newer septic system technologies (anaerobic up-flow filters and recirculating sand filters) are capable of reducing the dissolved nitrogen losses to groundwater by about 50 percent.[6] While these technologies can be established in new installations, retrofitting existing septic systems is more problematic due to cost, the difficulty of social acceptance, and a likely lack of political will.

Level of BNR treatment	TN (mg/L)	TP (mg/L)	Relative cost increase
First stage	8	2	---
Second stage	6	1	Small
Third stage	4	0.5	2–5 times second stage
Limit of technology	3	0.2	4–10 times second stage

Table 8-1. The costs for moving to second-stage BNR are relatively small, but more advanced BNR upgrades will require significant funding.

Crop Production

All plant growth, whether suburban lawn, home vegetable garden, or commercial agricultural crops, can be limited when plant nutrients are deficient. In large measure, the high crop yields (and the consequent abundant, inexpensive supply of food) achieved in modern agriculture resulted from industrially produced fertilizers, which jumped in use dramatically after the 1950s. Although cultivated plants take up a substantial portion of the nitrogen and phosphorus in these chemical fertilizers and a large portion of the nutrients is removed with the harvested crop, these chemicals ultimately work their way into animal and human waste streams. These wastes often end up in surface or groundwater unless first broken down by treatment or natural processes. Inevitably though, some portion of the nitrogen and phosphorus remains in the field in forms that infiltrate deeper into the soil or are transported in surface runoff.

Various nutrient management practices are designed to prevent the over-application of nutrients, but the process of nutrient supply and uptake is never 100 percent efficient. In practice, more nutrients (especially nitrogen) are generally applied than are needed merely to meet the nutritional requirements of the crop. Although efficiencies in fertilizer use (measured as the ratio of nitrogen in the harvested crop to nitrogen in the fertilizer applied) have been increasing slowly in the United States, about one-third of the nitrogen applied is not recovered in the harvested crop.[7] Additional management practices are needed, therefore, to retain the residual nutrients on the field by limiting runoff or (in the case of nitrogen) infiltration below the root zone and eventual migration into groundwater.

Several best management practices (BMPs) maximize crop or animal production while minimizing nutrient or soil losses from farm fields or animal production operations and agricultural, resource conservation, and environmental agencies all promote these approaches. This chapter considers several newer or less widely applied technologies as well as technologies used in current BMPs to reduce nutrient loadings from agricultural sources to the Chesapeake Bay.

Comprehensive nutrient management systems for agriculture include combinations of technologies and practices, often involving both crop and animal production. Standard protocol suggests that one should not rely on a single practice or technology to achieve the desired reduction in nutrient loss. A significant difficulty when designing a nutrient management system, however, is that the effectiveness of combined practices is not necessarily additive or multiplicative and their joint effectiveness is generally difficulty to quantify. As a result, models predicting the effects of BMPs on agricultural nutrient losses provide only rough approximations. Furthermore, the effectiveness of BMPs can vary greatly with environmental conditions, soil types, and terrain differences.

Soil Conservation Practices

Soil and water quality conservation plans, which have traditionally focused on reducing soil erosion, usually include a variety of BMPs. Conservation tillage, a particularly important practice, leaves at least 30 percent of the soil surface covered with crop residue after planting.[8] Major types of conservation tillage include no-till, ridge-till, strip-till, and mulch-till. One of the fastest growing practices in the history of U.S. agriculture, conservation tillage is used on more than half the cropland in Virginia and Maryland, where the practice results in higher crop yields and lower production costs than conventional tillage.[9]

Farmers also use conservation tillage as a BMP for controlling soil and nutrient runoff, because it reduces soil erosion and increases infiltration. A primary goal of conservation tillage is to minimize disturbance of surface plant residues that protect the soil from flowing water and raindrop splash. The resulting increase in infiltration reduces annual surface runoff volumes by about 25 percent

Tim McCabe, USDA NRCS

Surrounded by the residue of a wheat crop, these soybean plants represent a form of no-till agriculture that minimizes soil erosion and holds in moisture, which help the young plants thrive.

compared to conventional tillage. From an agronomic perspective, however, farmers generally prefer placing fertilizers close to plant roots and away from the soil surface where they are subject to loss in surface runoff. This practice is difficult under conservation tillage since typical fertilizer incorporation practices also disturb the plant residues. In other words, when fertilizers are broadcast without tillage, they concentrate near the soil surface and are susceptible to surface runoff or volatilization (for nitrogen). Thus, losses of dissolved nutrients with conservation tillage may not decrease compared to conventional tillage unless increased runoff concentrations are offset by reductions in runoff volume. Since conservation tillage does reduce surface runoff, it will generally lower soil erosion rates and the runoff of particle-bound phosphorus.

Given these complexities, considerable uncertainty exists regarding the effect of conservation tillage on the movement of nutrients to groundwater. One of the chief unknowns is how water flow through soil macropores affects nutrient movement through the vadose zone—that portion of the soil profile below the depth of roots but above the water table. Conservation tillage apparently increases nutrient flow to groundwater compared to conventional tillage because unlike conventional tillage, conservation tillage does not destroy macropores from earthworm tunnels and decayed root channels—pathways that allow rainfall to move into groundwater.

Subsurface Nutrient Application

Subsurface application of nutrients, whether synthetic fertilizers or animal manure, could significantly reduce nutrient loadings from surface runoff and atmospheric losses. Proper subsurface application of fertilizer places nutrients in the root zone where the plants can use them, potentially reducing the amount of nutrients that need to be applied and subsequent loss of these nutrients. Subsurface application of nitrogen in the form of ammonia (NH_3) can almost completely eliminate ammonia volatilization and losses to surface runoff. Similarly, subsurface phosphorus application can substantially reduce phosphorus losses in surface runoff, in both dissolved and sediment-bound forms. Compared to broadcast application, subsurface phosphorus application reduced orthophosphate losses by 39 and 35 percent in conservation tillage and conventional tillage systems, respectively.[10]

The broader use of subsurface nutrient application is deterred by farmers' concerns about yields under the reduced rates of application and the lack of incentive for fertilizer dealers to promote this technology. Nonetheless, this technology holds considerable promise given the agronomic and environmental benefits of subsurface nutrient application over surface application.

Cover Crops

Cover crops, or catch crops as they are sometimes called in Europe, are plants established on fields during periods in which these fields would otherwise be fallow. The purpose of cover crops is to hold the soil and its nutrient inventory and generally improve the soil's physical properties. Favored cover crops include legumes, such as clover, as well as grasses. In the Chesapeake region, many farmers sow cereal grains as cover crops after the fall harvest. As the cover crops grow and overwinter they take up and hold nitrogen available in the root zone that might otherwise leach deep in the soil profile, out of reach of the roots of next spring's crop. This nitrogen (generally in the form of nitrate) would otherwise percolate into the groundwater, from which it can move into surface waters and, ultimately, the Bay. In coastal plain fields, cover crops can reduce losses of nitrate to groundwater by a factor of three or more compared to conventional BMPs,[11] although the advantages of cover crops may be less dramatic in other parts of the Chesapeake watershed.

Jeff Vanuga, USDA NRCS

In Virginia, a farmer uses no-till planting to sow corn into a cover crop of barley. This method leaves most of the soil undisturbed.

While some farmers in the watershed regularly plant cover crops, cost often limits more extensive adoption of this practice. Additional costs include seed, herbicides, labor, and personal effort. Moreover, because farmers generally do not harvest cover crops, the effort generates no direct income. Exceptions do exist, as when dairy operations use grains grown as cover crops to feed cows, but the agricultural community should explore additional ways to profit from cover crops. At present, some state programs provide limited support for cover crops, but such subsidies fall far short of the need. To boost cover crop usage, state and federal agencies could provide significant subsidies to reward environmental performance. For example, farmers could plant cover crops in environmentally sensitive areas to protect specific stream segments. In addition, improved methods—such as better plant materials and highly efficient technologies—could help increase benefits to the farmer, including reduced fertilizer cost and improved soil quality, thus increasing the incentive for planting these crops.

Precise Nutrient Management

The perennial question faced by the farmer is how much fertilizer to apply and when to apply it to maximize crop yield without wasting money by applying more than needed. Since the costs of fertilizer application are relatively inexpensive compared to the loss of income due to a poor yield, prudent farmers naturally tend to apply somewhat more fertilizer than the crop actually needs. In fact, prescriptions provided by agricultural agents or fertilizer companies have such a margin of error built into their calculations. In some cases, individual farmers may exceed the prescription as a perceived safety factor.

From a water quality perspective, however, the application of excess nutrients has major consequences. A greater proportion of this excess "insurance" fertilizer becomes lost to surface water and groundwater. Even the last increments of fertilizer applications needed to reach economically optimum yield (the crop yield at which further fertilizer addition costs more than the benefits of increased yield) result in significant losses of nitrogen to the environment. Decreasing the economically optimal yield by only 5 percent can reduce the amount of fertilizer nitrogen not recovered in the crop harvest by 20 to 30 percent.[12] Consequently, nutrient management technologies that narrow the difference between fertilizer applications and crop nutrient requirements could pay back considerable dividends in cost savings and water pollution reductions. Narrowing this difference requires more precise knowledge of the nutrients available to the plants, along with the timing and level of crop requirements.

Determining how much nutrient is available to meet the requirements of a profitable field crop remains complex. Conventional nutrient management plans that aim to maximize crop yield while minimizing nutrient losses must consider residual nutrient status as well as tillage, crop, and soil conditions. The residual nutrient status and other soil properties vary greatly, however, even within a single farm field. Soil testing, along with the appropriate choice of application timing and nutrient source (e.g., urea versus ammonium nitrate), as well as maintenance of proper nutrient ratios and effective placement of fertilizer and manure, can significantly reduce nutrient losses to the environment.[13,14] Controlled-release fertilizers and nitrification inhibitors can help ensure that nutrients remain available during plant growth, also minimizing the loss of nutrients from the field.

Agricultural fields generally show significant variability in properties such as soil texture, soil moisture, fertility level, and topography. Traditional practices also vary widely. This spatial variability creates uneven patterns of soil fertility and crop growth and production. It also reduces the use-efficiency of fertilizers, thus increasing losses of nutrients applied uniformly over the entire field.

Precision farming technologies offer an opportunity to protect land and water resources while enhancing agricultural profitability. Precision farming tailors production systems to specific sites by matching agricultural inputs such as tillage, seeds, fertilizers, weeds, insect and disease control, and irrigation to characteristics in the field. Recent advances in microelectronics and computer software using Geographic Information Systems (GIS), coupled with access to the highly precise Global Positioning System (GPS), have allowed the development of such precision management technologies. These technologies provide the ability to measure and quantify yield variability and soil properties, thereby determining fertilizer requirements on a highly localized scale within the fields.

Techniques to collect data for evaluation and implementation of precision farming include grid (manual) sampling, real-time measurements, and remote sensing. While grid sampling can characterize soil parameter variation, it is time-consuming and expensive. Some real-time systems are already in wide use—to monitor crop yield, for example—while others are under development, including systems to measure soil organic matter, texture, available nutrients, and soil compaction. All of these techniques will greatly advance precision farming as a tool in nutrient management and water pollution control. Already, current technologies are capable of reducing nitrogen losses from croplands by 10 to 25 percent. With the development and application of real-time sensors of soil properties, these reductions could jump up to 35 percent for nitrogen and 10 to 25 percent for phosphorus.

Animal Production

Nearly 70 percent of the crops grown in the United States goes to feed animals rather than humans.[15] Consequently, most of the nitrogen and phosphorus incorporated in these crops is also going to the animals. In general, the quantity of nutrients released to the environment through animal waste rivals that lost from artificial fertilizers used in crop production. Much of the animal production in the Chesapeake watershed, especially poultry, depends on the import of feedstuffs from the Midwest and elsewhere. The waste-product nutrients, however, are retained in the Chesapeake Bay watershed, with most of these wastes applied to fertilize farm fields. Recent documentation of phosphorus buildup in agricultural soils within the basin has made it clear that this level of animal food importation is not sustainable without removal of some nutrients from the waste stream or transportation out of the watershed for use in other regions. Technologies to reduce the loss of nutrients to the environment from animal wastes include nutrient management of croplands and pastures (described in the previous section), waste processing for other uses, wastewater treatment from animal feeding operations, and dietary technologies that reduce the nutrient content of animal waste.

Using Animal Waste

Great potential exists for transporting tremendous quantities of animal waste from the area of production. Such efforts, however, are currently constrained by inadequate markets, low market values, and high transportation costs. Processes such as pelletization and extrusion of poultry litter (excrement, sawdust, etc. removed from poultry houses) have the potential to improve packaging and marketing while conserving the nutrient qualities of raw waste. Many of these technologies entail economic costs that slow their adoption, but environmental and regulatory demands will likely require that growers adopt these and other evolving technologies. A major problem with many classes of animal waste is their initial low nutrient density, making it difficult

Jeff Vanuga, USDA NRCS

Rotational grazing along the Creeper Trail on the South Fork of the Hoston River Project in Virginia. Such grazing protects pasturelands and helps prevent soil erosion.

economically to justify transporting the waste appreciable distances. By processing the animal waste to increase nutrient density, the waste becomes more attractive for long-distance transport. In addition, farmers can generally spread pelletized manure more easily than raw or composted manures.

When processed by an acceptable method, poultry litter is an economical and safe source of protein, minerals, and energy for beef cattle and a good protein supplement for brood cows and growing calves.[16] Litter is also an economical substitute for hay, especially during drought years when hay supplies are short. Nationwide, the amount of poultry litter used in this way is estimated at less than 5 percent of the total produced. Although extensive research has proved the safety of the practice, public perceptions regarding use of litter-based feedstuffs could constrain significant expansion of this option, particularly in the post-"mad cow disease" era.

Acceptable methods of processing litter for cattle feed include stacking and ensiling, during which bacterial action causes the stack to heat to a temperature between 140°F and 160°F for a minimum of three weeks. This method is sufficient to kill pathogens such as *E. coli* and *Salmonella* that may exist in raw litter. Pelletizing and extrusion also facilitates storage, handling, transportation, and subsequent use of the feedstocks. Other ingredients may be added, for example, compounds for odor-reduction treatment, fats for feed ingredients, or chemical fertilizers to balance nutrient composition.

Composting offers another process to produce pathogen- and odor-free products, although the conservation of nitrogen within the waste is not as effective. Although nitrogen is lost from the waste due to volatilization, composting does offer several important benefits. The process can be used for a wide variety of materials, including animal wastes and high-carbon woody wastes, and co-composting with many different municipal and industrial wastes is also possible. Waste products can be effectively stabilized and sanitized and waste volume can be greatly reduced, concentrating nutrients for better handling efficiency.

Technologies for direct combustion, gasification, and cogeneration are most applicable to solid poultry wastes such as broiler or turkey litter. These technologies can produce heated air for space heating or crop drying as well as steam for thermal application or electricity production. Compared to existing conventional power plants, however, animal waste-fired systems generally carry higher capital and operating costs (on a per-energy-unit basis) and present serious logistical challenges in terms of raw material supply. Ash management presents another major issue for centralized litter-fired energy systems. Poultry litter has high ash content, typically ranging from 15 to 30 percent. All of the phosphorus and potassium in litter passes through the energy system and is consolidated in the ash. Most, if not all, of the nitrogen is lost during the process.

Treating Animal Wastewaters

Improving the level of treatment of more-liquid animal wastes, such as cattle or hog manure, is essential to control nutrients from farms. Typically, such wastes are held in anaerobic lagoons or storage structures prior to land application of the effluent by spraying or spreading onto fields. Problems with the present systems include odor control, limited effectiveness in pathogen destruction, volatile losses of nitrogen, and the retention and buildup of nutrients in the receiving watershed.

Many systems now under development involve some method of aerobic treatment.[17] Techniques often include a combination of physical separation of liquid fractions, composting or other treatment of separated solids, chemical enhancement to remove dissolved and suspended solids by sedimentation, aeration of the liquid, or biological removal through nitrification and denitrification. Many of these techniques could produce a by-product that, with further processing and development, could be sold for reuse. The most cost-effective of these approaches, however, remains approximately three times as expensive as the lagoon/spray field system. It appears, then, that substantial incentives are needed for any adoption of these advanced treatment technologies.

Tim McCable, USDA NRCS

This farm in Maryland illustrates the problem of animal waste escaping from inadequate storage facilities and ultimately degrading the water quality of any nearby streams.

Reducing Nutrients in Animal Wastes

While the number of dairy cattle and pigs within the Chesapeake watershed has barely changed over the past few decades, the number of broilers and turkeys produced has gradually increased. Over the past two decades, the number of farms engaged in animal and poultry production has decreased while the size of the units and intensity of production has sharply increased with the formation of some very large production units. While future economic forces may make some kinds of animal production less viable within the watershed, they are unlikely to reverse this trend toward production intensification.

Problems caused by intensive application of manure to nearby fields and costs of waste handling and transportation have focused attention on technologies that reduce the nutrient content of poultry waste. While nutrition and feeding technologies can improve nutrient utilization and reduce nutrient excretion, implementation of many of these technologies depends upon accurate estimates of the amount of available nutrient required by a given type of animal. Some proven technologies can be implemented in the near-term (within the next five years) that reduce nutrient excretion by up to 50 percent without major risk of reducing production and profit. Other technologies may be feasible in the longer term (five to 20 years) with an additional 10 to 20 percent reduction possible, although some of these technologies would likely reduce production, product quality, or profitability.

Near-term technologies include:

- *Reduction of nutrient excesses in feed*. Excess nutrients have traditionally been fed to pigs and poultry to provide a large "safety factor" believed necessary to compensate for uncertainty about the available nutrient requirements of the particular animal. Reductions of 10 to 20 percent in nutrient content can be achieved with little risk of malnourishment.
- *Use of crystalline amino acids and high-quality protein*. Lowering the dietary protein level and supplementing diets with crystalline amino acids (lysine, methionine, threonine, and tryptophan) is a well-established means to achieve a more ideal amino acid nutrition and is very effective in reducing nitrogen excretion. Nitrogen excretion can be reduced up to 15 to 30 percent with only a small risk of economic impact.
- *Enhancement of nutrient utilization through the addition of enzymes and ingredient processing*. Grinding cereal grains and pelletizing the meal can reduce phosphorus in fecal excretions by 10 to 20 percent in pigs and poultry, with lesser improvements possible in cattle. Inorganic phosphorus is often added to the feed to meet nutritional needs. Substitution of microbial phytase to pig and poultry diets, however, allows the animals to assimilate phosphorus in the grain and can result in a 25 to 40 percent decrease in phosphorus excretion. Several proteases, lipases, and carbohydrases also have potential in diets based on wheat and barley.
- *Phase and separate-sex feeding*. The requirement of animals for most amino acids and minerals

decreases as the animals grow. Phase feeding takes advantage of these differences by changing feed composition as the animals mature. Ten to 15 percent reductions in nitrogen and mineral use can be obtained when diets are changed from four to nine times during the grow-finish period. In some animals, differences also exist between males and females. Pigs can be more precisely fed if the sexes are separated during growing and finishing, with resultant reductions in nutrient excretion up to 5 percent.

- *Improved feed efficiency*. Improvement in the genetic potential of animals to assure enhanced feeding efficiency could result in nutrient excretion reductions of 5 to 15 percent.

Longer-term technologies include:

- *Use of the principle of diminishing returns in formulating diets.* The response of animal performance to dietary nutrient inputs is a matter of diminishing returns. The effectiveness of inputs decreases as maximal yields are approached. The formulation of animal diets for *optimum* (90 to 98 percent of maximum response) rather than *maximum* performance produces greater profits when combined with improved feed efficiency, amino acid supplementation, and appropriate calcium/ phosphorus balance.
- *Formulation of diets based on bioavailability estimates.* Improved estimates of the requirements of available nutrients for various species and classes of livestock will allow the development of bioavailability estimates for the various feedstuffs. With this information, diets can be formulated that precisely meet the nutrient needs of the animal, with consequent reductions in nutrient excretion.
- *Genetic modification of feedstuffs.* Great potential exists in development of genetically modified feedstuffs with improved nutrient content and bioavailability. In low-phytic acid corn, for example, 50 to 70 percent of the phosphorus is available compared with 15 to 20 percent in conventional corn. Genetically modified feedstuffs can more nearly meet an animal's needs for amino acids, fats, and minerals. Genetic modification of microorganisms can be used to produce enzymes to break down the more fibrous components of feedstuffs to liberate carbohydrates, fats, amino acids, and minerals that may be bound in poorly available forms.

Integrating Animal and Crop Production

Effective management of animal wastes must play a big part in reducing nonpoint-sources of nutrients from agricultural activities. Animal wastes account for far more than the 3 percent of nitrogen and phosphorus loadings attributed to them by the Bay Watershed Model, with significant additional contributions to nutrient losses from fields and pastures where manure is applied and to atmospheric deposition of ammonia. Adequate technological solutions require approaches that


Tim McCabe, USDA NRCS

An Eastern Shore farmer discusses his hog waste lagoon plans with a soil conservationist.

integrate plant and animal production, nutrient management of croplands and pastures, and animal waste minimization and treatment.

Many of the nearly 2 million hectares of land under pasture in the Chesapeake Bay watershed border streams, and many of the livestock in these pastures have access to stream channels. A monitored stream in southwest Virginia showed that providing alternative off-stream drinking sources to pastured animals reduced sediment, total nitrogen, and total phosphorus loadings by 90, 54, and 81 percent, respectively.[18] By supplying a separate drinking water source, farmers can guide animals away from streams, reducing the need for streambank fencing. Further, providing a cleaner source of drinking water can reduce the incidence of disease and parasite infections in animals and increase productivity.

Controlling Runoff from Developed Land

Sources of nutrients in urban runoff include automobile exhaust, other atmospheric deposition, erosion, deterioration of pavement and structures, fertilizer application, and miscellaneous wastes.[19] In some cities, storm water is captured in combined sewer systems and treated in wastewater treatment plants. Combined sewer overflows, however, allow nutrients in human waste streams to bypass treatment facilities during periods of heavy runoff. Consequently, controlling combined sewer overflows remains an essential part of reducing urban nonpoint sources of pollution.

Many options exist for controlling runoff from developed lands such as buildings, parking lots, roads, and highways. Passive treatment controls include vegetated areas, detention basins that dry between storm events, wet ponds, infiltration devices, filters, and constructed wetlands. These treatments, however, more effectively trap particulate matter than dissolved nutrients. Retention ponds, for example, might remove 50 to 60 percent of total phosphorus (which often adheres to particulates), but only 30 to 40 percent of total nitrogen (which is largely dissolved).[20] Wet ponds more efficiently remove nitrogen than dry ponds. Also, the amount of phosphorus permanently removed by a dry pond will depend on how much of the temporarily stored storm water infiltrates the soil. If phosphorus adheres to trapped sediment, major storms can eventually wash it out. Removal efficiencies very much depend on nutrient concentrations in the inflows and continued maintenance of control systems. While well-engineered and maintained stormwater management systems using the best available technologies can and should be incorporated in new developments, retrofitting cities and other already developed areas remains a more difficult challenge.

The severely altered hydrology of developed lands becomes a critical limiting factor in controlling runoff from these landscapes. As discussed in Chapter 5 (Development and Sprawl), large areas of impervious surfaces that prevent natural infiltration into soils have increased the amount and velocity of stormwater runoff. The increased and often torrential runoff scours stream channels in some reaches and deposits sediment in others, degrading the ability of the stream ecosystem to remove nutrients. Constructed and restored wetlands and riparian zones along with stream rehabilitation must, therefore, become important elements of nutrient runoff control strategies for developed land.

Atmospheric Emissions

Atmospheric deposition of nitrogen (nitrogen oxides, nitric acid, ammonia, and organic nitrogen) constitutes approximately 25 percent of the anthropogenic nitrogen loading in the Chesapeake Bay. The principal sources are: nitrogen oxides (NOx) formed by high-temperature combustion of fossil fuels; and ammonia volatilized from animal wastes, fertilizers, and wastewater treatment facilities, released from refrigeration compressors and industrial operations, or formed in the atmosphere from NOx.

Because nitrogen oxides can be transported longer distances than ammonia, a significant amount (38 percent) of the NOx deposited on the Chesapeake Bay watershed originates outside the watershed boundaries. Designated the Chesapeake airshed, this larger area contains portions of New Jersey, Pennsylvania, Ohio, Indiana, Kentucky, Tennessee, and the Carolinas. Provisions of the Clean Air Act mandate reductions in NOx emissions on the national scale and a new regional NOx transport rule regulates these emissions for 22 eastern states.[21]

Several other recently promulgated federal regulations mandate further reductions of power plant emissions, reduction of fine particulate matter emissions, provision of low-sulfur diesel fuels that makes catalytic conversion feasible for trucks and other heavy equipment, and improvement of visibility in national parks. All of these regulations will result in reductions in NOx deposition, although these new regulations may be rescinded or delayed due to renewed concerns about the national energy supply. Such reductions of atmospheric NOx emissions provide classic examples of how regulations that initially appear unachievable can drive the development of new technologies to achieve them. In this case, the drive for new technology came about due to air quality and acidification rather than water quality issues.

Michael Fincham, MD Sea Grant

Despite emissions from local power plants, such as Chalk Point (above), more than a third of the nitrogen oxides coming into the watershed originates outside its boundaries.

For stationary sources such as power plants, technologies currently capable of reducing NOx formation include combustion modifications (various burner alterations that reduce the formation of NOx) and post-combustion processing (catalytic or noncatalytic reduction, carbon adsorption, and NOx recycling and decomposition). Newer technologies are emerging that increase the efficiency and cost-effectiveness of NOx emission reduction, including catalytic oxidation, flameless oxidation, and gaseous electrical discharge.

Mobile sources of NOx include emissions from automobiles, trucks, aircraft, ships, and vehicles such as farm equipment, bulldozers, lawnmowers, compressors, and construction machinery. These include both diesel and ignition-fired engines. The Clean Air Act mandates reductions in emissions from mobile sources as well as stationary ones. Since most of these reductions become implemented through the application to new vehicles, the effects of these changes will be slow. With the current average lifespan of a vehicle at eight years, it will be at least 2016 before 90 percent of the present fleet leaves the road. On the other hand, by 2030, virtually all of the vehicles on the road will be equipped with post-2000 technologies. Thus, opportunities for reductions in NOx emissions—once included under "uncontrollable" sources of nitrogen inputs to the Bay—present the potential for significant headway.

Major reductions in NOx emissions from gasoline-powered automobile engines have been achieved over the past years through fuel efficiency requirements, fuel formulations, combustion technologies, and emission controls. Future reductions in NOx emissions from mobile sources will depend primarily on holding down the dramatic growth in vehicle miles driven, extending effective NOx emission controls to trucks and heavy equipment, using alternative fuels, and assuring a reasonably quick transition away from the internal combustion engine.

The transportation systems of the major metropolitan regions of the Chesapeake watershed are, to varying degrees, reaching crisis conditions. For example, the greater Washington region has the third most congested traffic in the nation.[22] But efforts are underway to increase the use of mass transit systems. Ridership on Washington's Metrorail increased by 20 percent from 1995 through 2002.[23] By 2030, significant new mass transit capacity—circumferential rail connections and perhaps high-speed magnetic levitation trains connecting major population centers—will likely be in use. Furthermore, advances in information and communication technologies are making distributed workplaces, telecommuting, and online shopping increasingly feasible, which can also alleviate some pressure on road transportation.

The sulfur content of diesel fuels has limited the application of some NOx emission control technologies, particularly catalytic conversion, in trucks and heavy equipment. The U.S. Environmental Protection Agency recently promulgated regulations that require the manufacture and use of next-generation diesel fuels, which have much lower sulfur content. Although, it will take some time for the present fleet to turn over, significant reductions in NOx emissions from diesel vehicles will occur over the next two decades. Other alternative fuels also offer promise for reduced NOx emissions, particularly the expanded use of compressed natural gas (CNG). Already the use of CNG for buses and other fleets is rapidly growing. Establishing additional dispensing points would allow wider use in internal combustion engines modified with simple conversion technology.

Perhaps the most exciting technologies with the potential for significant reduction in NOx emissions are those that will effect the transition from the internal combustion engine to electricity and fuel cells. Concerns about energy supply, the buildup of greenhouse gases, and climate change may drive development of these technologies, but significant benefits will result in terms of air and water quality.

In 2000, the first two hybrid (gasoline-electric) automobiles, the Toyota Prius and the Honda Insight, arrived on the U.S. consumer market; in 2002, Honda introduced a hybrid Civic. These vehicles offer fuel efficiencies of 50 to 70 miles per gallon. Hybrid vehicles incorporate both a smaller gasoline-powered engine and an electric motor, which operates off batteries charged by energy produced by the gasoline engine. Other manufacturers are preparing to introduce additional models, including sport utility vehicles, within the next few years. Hybrid vehicles constitute only a small fraction of new car sales, but demand already exceeds supply. State and federal energy policies increasingly include tax incentives to promote the use of high-mileage, hybrid vehicles.

Honda Motor Co., Inc.

The Honda Insight combines an internal combustion engine with an electric motor and achieves about 70 miles per gallon in highway driving.

Because of resource limitations and actions taken to reduce CO_2 and other greenhouse gas emissions, by 2030 we should be well along in the transition from a hydrocarbon-based economy to a hydrogen-based economy that relies heavily on fuel cells.[24] Fuel cells provide even greater energy efficiency and lower NOx emissions than hybrid vehicles. While these cells supply energy through the reaction of hydrogen and oxygen to produce water, they still require a hydrogen source. Hydrogen is typically obtained by processing propane, methane, alcohol, or some other fuel with a high-temperature catalyst. Because nitrogen and other gases interfere with fuel cell processes, these catalytic reactions must be engineered to prevent the formation of nitrogen oxides. Fuel cells are being developed with several technologies for diverse purposes, ranging from medium-sized power plants to vehicular transportation to power sources for remote instruments. Costs currently limit their applications, but such limitations should diminish over the next ten years through improvements in technology and the economies of mass production.

The extent to which volatilization of ammonia contributes to nitrogen loading of the Bay is just beginning to be appreciated. Few efforts are yet underway to control its sources, although subsurface application of manure and chemical fertilizers to farm fields significantly reduces the loss of nitrogen to the atmosphere via volatilization of ammonia. Loss of ammonia from animal manures can be substantial—as much as 60 percent of their nitrogen content[25]—and cause odor and animal health problems. Digestive and acidifying agents, adsorbents, and other additives can reduce ammonia losses from manure. Alum added to poultry litter, for example, can reduce health risks to the birds, stabilize nitrogen in the litter, and avoid environmental losses when the manure is used to fertilize crops. Technological control of ventilation systems and handling of animal wastes (adding water to create waste slurries, for example) can also affect ammonia losses. In urban areas, the recapture of ammonia used as refrigeration coolants can also reduce ammonia losses.

Environmental Rehabilitation Technologies

In addition to pollutant source controls, the future of the Chesapeake Bay depends on the success of efforts to protect and restore wetlands, riparian buffers, SAV, and oyster reefs—habitats that play an inordinate role in the resiliency and productivity of the estuary and its watershed. The *Chesapeake 2000* agreement includes specific goals for increases in oysters, submerged aquatic vegetation, wetlands, and riparian forests. These goals were set not only because they directly support living resources, but also because the resulting ecological improvements will further modulate nutrient and other pollutant inputs, remove excess nutrients from the estuary, and improve water clarity.

While not included in the estimates of nutrient load reductions achievable through new technologies, the environmental rehabilitation efforts described below must play an important and complementary role in the Chesapeake future. The success of such efforts also will depend on the application of technologies, although they may be "soft" technologies rather than the hi-tech or engineering solutions we usually consider.

Wetlands and Riparian Buffers

The *Chesapeake 2000* agreement calls for a net increase of 25,000 acres of tidal and non-tidal wetlands and restoration of 2,010 miles of riparian forest buffers by 2010. Perhaps the most important contribution that technology can make toward these goals is targeting where restored lands will be most effective in reducing nutrient inputs to the Bay. Geographical information systems, analyses of landscape relationships, and hydrological modeling are some of the most useful tools in such an investigation. Selection of superior plant materials highlights another area in which technology may play an important role. Down the road, one can imagine "smart" approaches to the management of retentive habitats, such as wetlands, in which water levels are regulated through sensor technologies to maximize wetland performance efficiency.

Submerged Aquatic Vegetation

The *Chesapeake 2000* agreement recommits to the goal of restoring 114,000 acres of submerged aquatic vegetation, a goal originally set in 1990 that has remained elusive. Under the agreement, further goals are to be determined but have not yet been defined as of this writing. Achievement of the submerged aquatic vegetation (SAV) goal depends primarily on success in reducing nutrient and sediment inputs that cloud the water. The recognition of this crucial link between water quality and SAV recovery is evident in the new criteria established by the Chesapeake Bay Program for water clarity, algal abundance (chlorophyll), and dissolved oxygen. Physical restoration of grass beds is unlikely without concomitant improvements in water quality. Even in marginal conditions, planting vegetation to establish self-propagating populations in areas that once hosted these species may be important in an overall restoration strategy. Technology can contribute to improved propagation and planting methods, more robust plant materials, and more effective procedures to stabilize sediments until the plants take hold.

Oyster Reefs

Although long recognized as a major commerical fishery in the Bay, oysters are now greatly valued for their role as filter feeders capable of removing large quantities of algae and particulate matter from the water. The *Chesapeake 2000* agreement lays down the goal of a ten-fold increase in native oysters by 2010. In addition to increasing the number of oysters, understanding the architecture of the restored oyster reefs is critical to reestablishing the system's ecological function in the Bay. The scientific community has come to the consensus that oyster restoration should include reconstructed reefs with significant vertical relief to serve as reservoirs of populations of oysters resistant to diseases.[26] Technology can improve the design effectiveness of reconstructed reefs and advance the disease resistance of seeded oysters through the development of strains. The reefs will also provide habitat for a variety of other species, many of which may also remove particulates from the water.

Observation and Prediction Technologies

In addition to employing technologies to reduce pollutants and restore Chesapeake Bay habitats, existing and emerging technologies will allow the technical community to make major advances in how scientists observe the ecosystem, interpret its changes, and predict its future. These advances are important for improving the Bay's health because observations and predictions (monitoring and modeling) are critical in determining whether goals are being met and which management actions are proving most effective.

Measurements taken at the right space and time scales are central to understanding the behavior and responses of the Bay ecosystem. In addition, integration of measurements or predictions for different parts of the entire ecosystem will prove critical. Remote sensing on large scales, nearly continuous observations of many ecosystem properties, and the ability to manage and analyze vast amounts of data are already allowing scientists to address the challenge of monitoring and modeling the Bay's fundamental physical and biological parameters. This wealth of information should generate even more significant advances over the next 30 years.

Tim McCable, USDA NRCS

A constructed wetland in Wicomico County, Maryland. Although not as visually appealing or ecologically diverse as a natural wetland, this area provides good habitat for migrating waterfowl.

Remote Sensing

Remote sensing of the Bay and its watershed from satellites and aircraft has made major contributions to Bay science and management since the late 1980s. Satellite imagery has provided increasingly detailed resolution of land-cover characteristics and land uses. New techniques resolve different vegetation types and electronically interface these spatial data into Geographic Information System databases, without labor-intensive interpretation and delineation. Researchers apply medium-resolution maps developed from Landsat images to classify and categorize the watershed for use in

Photo courtesy of NASA

Mostly clear skies over the Chesapeake and Delaware bays allow this SeaWiFS image of the area on January 6, 2000. Images such as this one provide data on phytoplankton quantities and composition.

the Bay Watershed Model and management programs. Sensors on newer satellites offer greater resolution, with enhanced spectral differentiation and improved accessibility. These new technologies will continue to allow more frequent and more accurate assessment of the changes in land development, agriculture, wetlands, and other areas. Products, such as baywide maps of land use change, will become routine and indispensable tools for land use planning and resource management as well as basin-scale management.

Aircraft remote sensing has also played an invaluable role in tracking changes in the plant life of the estuary. Spectral sensors will increasingly supplement aerial photography to improve the accuracy of submerged plant surveys and allow differentiation of species. Scientists are also using aircraft remote sensing to measure chlorophyll levels—a measure of the density of phytoplankton—in surface waters of the Bay and its tributaries. The entire Bay can be covered within a day and sampling can be conducted more frequently than from a vessel. The color radiometer currently in use is the Aircraft Simulator of the Sea-viewing Wide Field-of-view Sensor (SeaWiFS). A polar-orbiting satellite bearing a SeaWiFS system was launched in 1997 and provides complete coverage of the globe in about two days. SeaWiFS supplies imagery that has revolutionized our understanding of the patterns and dynamics of primary productivity in the ocean. The complex optical properties of estuaries, however, make recovering chlorophyll concentration data from these environments problematic. Nonetheless, recent data processing improvements give reasonable recoveries of directly measured concentrations, although not of the same spatial resolution as those from aircraft-borne sensors. The satellite-borne SeaWiFS may remain operable until 2007.

NASA's recently launched TERRA platform carries the Moderate-resolution Imaging Spectrophotometer (MODIS), which is making higher-resolution fluorescence measurements of both marine and terrestrial environments. Attributes of MODIS make

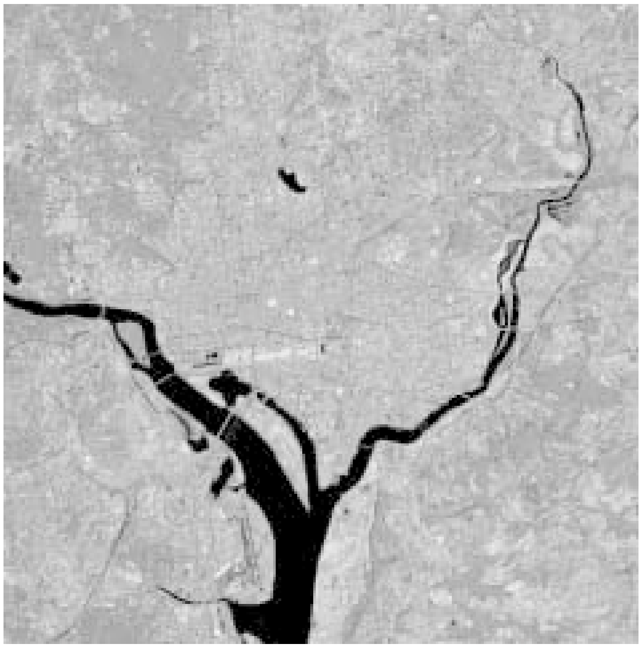


Photo courtesy of NASA

This Landsat 7 photograph of the Washington, D.C. metropolitan area taken on April 17, 2000 yields visual information on land use.

it particularly appropriate for estuaries; its data and products are more readily available than those for SeaWiFS. Other remote sensors, such as the Single Event Imager (SEI), are scheduled for launch in the coming decade and will provide higher-resolution measurements of chlorophyll, temperature, and other properties.

Automated Observation Systems

Most monitoring measurements in the Chesapeake Bay are taken from vessels at specific sampling sites or stations, at intervals of two weeks to several months. Analysts inferentially interpolate between the sampling dates or among the relatively sparse network of stations. Yet, many physical and chemical properties vary more frequently or more finely over the Bay than the traditional sampling from stations can capture. Remote sensing of chlorophyll levels, as discussed above, depicts the continuous mosaic that is inadequately represented through station sampling. But how can one measure the more dynamic properties that may change daily or even hourly?

In the early 1990s, scientists placed the first automated buoy of the Chesapeake Bay Observing System (CBOS) in the upper Bay. This system has gradually expanded into a network of continuous observation posts extending the length of the Bay and onto the shelf off the Bay mouth. The CBOS instruments measure, at a minimum, winds, air temperature, solar irradiance, water currents, salinity, and temperature. Other sensors can be incorporated to measure dissolved oxygen, chlorophyll, and an expanding array of properties determined electrochemically, optically, or acoustically. Sensors under development will perform genetic analyses *in situ* and allow identification of specific organisms in the water, such as toxin-producing algae. Acoustic technologies can measure tidal or other current velocities all through the water column; they can also measure the passage of fish. Data collected by CBOS are telemetered to base stations where they are stored, processed, and made available over the Internet in near-real time.

Continuous measurement systems are already used to monitor flow and water quality in streams and rivers as well. One can imagine a not-too-distant, fully wired future in which anyone can access real-time data that represent an expanding set of parameters for the Bay and its watershed.

Bay researchers have deployed instruments on or from vessels to provide continuous measurements of properties ranging from salinity and temperature to plankton and fish density. Such instruments may be incorporated into towed vehicles programmed to undulate from top to bottom. If these top-to-bottom scans follow back-and-forth cruise tracks, the entire length of the Bay may be surveyed within about four days. The two sets of data—vertical and horizontal—yield a quasi-synoptic, three-dimensional representation of the Bay. In the future, autonomous underwater vehicles—operating free from surface vessels and programmed to travel over certain courses or respond to certain environmental conditions—may completely replace these towed vehicles.

By 2030, scientists will have capabilities, presently unimagined, to remotely, continuously, and automatically observe the Bay and its watershed. Researchers and others may even be able to “watch” through a network of acoustic observing posts as schools of fish swim up the Bay, observing how these fish respond to environmental conditions measured at the same time. Taking full advantage of this technological revolution without being overwhelmed by the enormous volume of data will require the use of highly sophisticated integrated systems.

Integrated Analysis

The rapid development of information technology that characterized the last third of the 20th century will certainly continue during the first third of the 21st century, allowing more massive storage of data, higher-speed computation, and greater bandwidths to hasten communication. Increasingly, imagination and ingenuity, rather than any boundaries inherent in information technology, will form the limits of our ability to interpret the extensive and complex data generated by modern observation systems. Already, scientists are developing integrated observation and prediction systems for coastal environments that capture, process, and represent diverse data from remote and continuous measurements. "Nowcast" and forecast models that can assimilate these data in near-real time will yield tactically and strategically useful products. Powerful pattern recognition and visualization technologies will display observations and model results in highly revealing ways.

Although scientists and managers are already using some of this new technology for the Bay and its watershed, existing technologies are not employed to their full potential. In fact, a lag time often exists between the availability of a new technology and its adoption. Just ten years ago, for example, the Chesapeake Bay Program hotly debated use of the Internet as a common communication and information medium. Now it is taken for granted. With continuing advances in information technology, one can imagine that within the next thirty years, virtual meetings empowered with dramatic visualizations will displace physical meetings with paper handouts and Powerpoint presentations. Environmental and resource managers may directly query databases and models without the need for "middlemen" to access and use the technology. In short, one can imagine a more informed and wiser course of environmental restoration and resource management for the Chesapeake Bay.

Scenario Assumptions

Table 8-2 summarizes the estimates of nutrient loading reductions that are technologically achievable within the next thirty years under the Current Objectives and Feasible Alternatives scenarios. The estimates are not rigorously quantitative forecasts and each scenario section details the assumptions involved. Obviously, great variance and uncertainty regarding the effectiveness of each of the technologies exists. In addition, crude assumptions are made about the additive effects of applying multiple controls. Most importantly, even the Current Objectives scenario assumes ambitious pursuit of these commitments. Reductions attainable under Feasible Alternatives would require extensive and conscientious application of the array of technologies available for each of the sources.

To estimate the effects of technological advances on nutrient loadings in the face of population growth and land development, estimated reductions due to technology are applied to current loadings. Then, loadings from nonpoint and point sources resulting

	Nitrogen		*Phosphorus*	
Source	**Current Objectives**	**Feasible Alternatives**	**Current Objectives**	**Feasible Alternatives**
Waste disposal	30%	58%	35%	77%
Crops & pastures	18%	56%	39%	65%
Animal wastes	15%	55%	20%	40%
NOx deposition	27%	70%	—	—
Ammonia deposition	15%	60%	—	—
Urban/suburban	15%	30%	25%	47%

Table 8-2. Technologically achievable reductions in nutrient loadings used in the Current Objectives and Feasible Alternatives scenarios.

from population growth and development (from the Development and Sprawl chapter) are added to these totals. Loadings projected for Recent Trends use estimates from the Watershed Model for 2000 as a base, with the loadings from new development but without additional applications of technology beyond those in use. Since developed lands will likely replace some farmland, agricultural loadings were also reduced in proportion to the area of agricultural lands lost to development (see Development and Sprawl chapter). No adjustments were made for agricultural land lost from abandonment and reforestation because the amount of such land use conversion was not estimated (see Forests in Transition chapter). Because most of these changes will likely occur on marginal upland agricultural areas, the effects of farm loss on nutrient loadings should prove relatively small compared to agricultural lands lost to development nearer to the Bay and its major tributaries.

Other than as related to development, these loading estimates include no major increases that could result, for example, from profligate energy consumption or potential expansions in components of the agricultural sector, such as intensive animal production. On the other hand, these projections do not include estimates of reduced nutrient loadings due to restoration of wetlands and riparian buffers within the landscape, other than those that may be part of specific nonpoint-source controls for developed lands.

Scenario 1: Recent Trends

Primary Expectations:

- *Total loadings of nitrogen to the Bay, from all sources, will grow by about 30 million pounds or nearly 10 percent by 2030, with the loss of more than one-half of the load reductions estimated to have been achieved since 1985. Total phosphorus loadings will grow by about 3 million pounds or nearly 15 percent, losing over one-third of the reductions projected since 1985.*
- *These nutrient loading increases will be driven by population growth and land development coupled with lack of progress in reducing other nutrient inputs beyond those already achieved.*
- *Riparian, wetland, and oyster restoration goals will remain unrealized. Loss and degradation of wetland and riparian habitats from land development will exceed gains realized through restoration programs. Rebuilding of oyster populations will show little progress as restoration efforts remain modest in scale and limited by diseases and worsening water quality.*
- *Modeling and monitoring will continue to be largely decoupled and limited by the inability to measure changes in the Bay and watershed on appropriate spatial and temporal scales, with negative consequences for managment.*

The Chesapeake Bay Watershed Model estimates that between the late 1980s and 2000, total nitrogen loadings dropped by 15 percent and total phosphorus declined by 31 percent.[27] To place these numbers in context, the 1987 Chesapeake Bay Agreement committed to a 40 percent reduction of "controllable" inputs of both nitrogen and phosphorus by the year 2000. The 40 percent goal translated to a reduction of total land-based inputs of nitrogen by 22 percent and phosphorus by 35 percent. Some anthropogenic sources—such as atmospheric deposition and sources in the watershed outside Pennsylvania, Maryland, Virginia, and the District of Columbia—were excluded from this definition of controllable sources.

Under the Recent Trends Scenario, achieved reductions in nutrient loadings are assumed to hold, however, no further progress in reducing existing nutrient sources will occur. Since population numbers will almost certainly grow, additional nutrient loadings due to population growth and development become crucial parts of the mix. Specific assumptions are as follows:

- ***Waste Disposal.*** Based on engineering evaluations of 51 wastewater treatment plants in the Chesapeake Bay watershed, reducing effluent total nitrogen concentrations to 8 mg/L will lower point source nitrogen effluents by 60 to 70 percent.[28] Approximately half of the point-source effluent discharged to the Bay is currently treated to this standard. Under the Recent Trends

Scenario, the level of treatment for current discharge volumes remains the same; however, all of the increased volume of collected wastewater due to population growth is treated to the 8 mg/L standard (see Development and Sprawl chapter). Also under this scenario, no retrofitting of existing septic systems occurs, few existing septic systems are connected to sewer, and a limited number of new septic systems conform to advanced nutrient removal design.

- ***Agriculture.*** Nutrient loadings from agricultural activities, including crops and pastures, animal wastes, and ammonia volatilization, remain as they are today, except that crop and pasture loadings are reduced in proportion to the area of agricultural land lost to new development.
- ***Atmospheric Deposition.*** As a result of Clean Air Act regulations, NOx concentrations in the Chesapeake airshed have shown small but statistically significant decreases between 1988 and 1997.[29] This downward trend will level off, however, as additional efficiencies in source controls are offset by the increasing energy and transportation demands of a growing and spreading population. Also, ammonia deposition remains unchanged as efforts to control volatilization of ammonia from agricultural and other activities remain weak.
- ***Urban and Suburban Nonpoint Sources.*** The pace of sprawling land development continues, resulting in nonpoint source loadings that are greater than those loadings from the displaced land uses.
- ***Environmental Rehabilitation.*** Conventional technologies are applied, but rehabilitation efforts are limited to current levels.
- ***Observations and Predictions.*** The Chesapeake Bay Monitoring Program continues to use point sampling as its primary technique during periodic cruises, but the level of effort declines due to competition for financial resources. Modeling activities are further refined, however, they are not coupled with monitoring program data streams.

Scenario 2: Current Objectives

Primary Expectations:

- *Total loadings of nitrogen to the Bay will decline by over 45 million pounds or about 15 percent by 2030. Continued pursuit of the objectives would eventually reduce loadings below the 40 percent of "controllable sources" goal set in 1987, but not by much. Total loadings of phosphorus will decline by 4 million pounds or 21 percent of estimated 2000 levels.*
- *Increases in loadings from population growth and land development will offset a significant part of reductions achieved by technological solutions, limiting progress toward nutrient loading reduction goals.*
- *The 2010 goal for riparian habitat restoration is met in terms of the number of miles restored but its effectiveness is limited because most of the restored habitats were not in the most sensitive areas for agricultural and urban nonpoint sources. Tidal wetland acres will continue to decline due to sea level rise; nontidal wetlands will also experience losses indirectly resulting from development. While some remain optimistic, the goal of increasing oyster biomass ten-fold by 2010 will not likely be met due to disease pressure and the lack of suitable materials for reef reconstruction.*
- *Monitoring and modeling systems will be incrementally improved, resulting in more effective predictions of future conditions and a more detailed understanding of the long-term improvements in the Bay.*

The Current Objectives Scenario assumes implementation of currently available technologies as included in agreements or regulations. Where specifically stated, nutrient reductions go beyond the goals set by the Tributary Strategies of the 1987 Bay Agreement and include those specified in the *Chesapeake 2000* agreement. Specific assumptions are:

- ***Waste Disposal.*** Under this scenario, the vast majority of remaining wastewater treatment plants begin using advanced wastewater treatment technologies that reduce nitrogen concentrations to 8 mg/L. Assuming a 60 percent

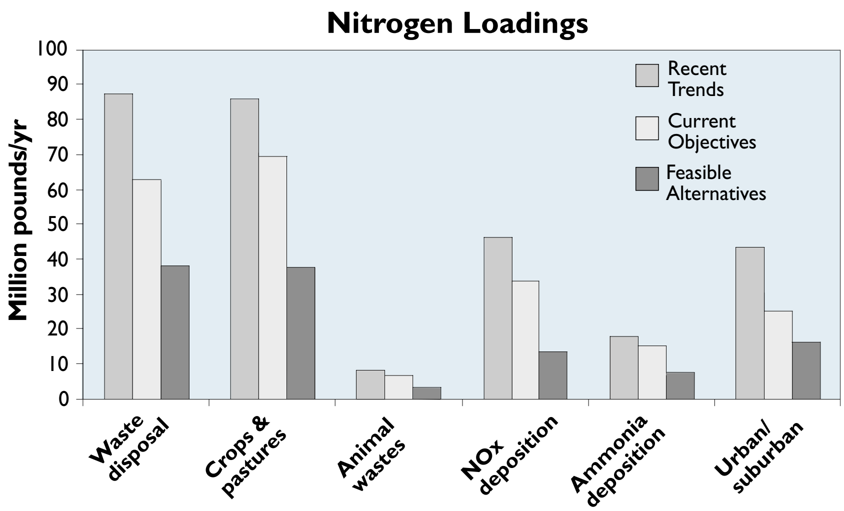


Figure 8-3. Implementation of creative and aggressive programs (Feasible Alternatives) could cut nitrogen loadings in half or more compared to Recent Trends.

reduction in nitrogen emissions for the facilities receiving these improvements, a 43 percent reduction in total nitrogen emissions from point-source treatment facilities would result, based on present wastewater volumes. While no septic retrofitting is expected, a small fraction of existing homes on septic systems will be connected to sewers with their waste streams treated by BNR. Additional waste loads will result from population growth as projected in Chapter 5, both from point sources and septic systems. When this additional load is considered together with the technological reductions of present loads, nitrogen loadings from wastewater treatment plants and septic systems will be reduced by 15 percent (Figure 8-3).

- ***Agriculture.*** The effectiveness of implementing Soil and Water Conservation Plans (SWCPs) varies with tillage practices and cropping (including hay production or pastures). The Chesapeake Bay Program estimates that fully and rigorously implemented SWCPs can reduce losses under conventional tillage by 10 percent for total nitrogen and 40 percent for total phosphorus, but only by 4 and 8 percent, respectively, under conservation tillage where runoff is already lessened.[30] When accounting for tillage and cropping practices currently applied in the watershed, total reductions of nitrogen could be 9 percent for total nitrogen and 21 percent for total phosphorus. With subsidies and incentives encouraging greater use of cover crops, it is assumed that cover crops are applied to 15 percent of the cultivated land and that they reduce nitrogen loss by an average of 40 percent. Nutrient management plans are successfully applied to half of the tilled cropland and hayfields in the watershed. For nutrient losses directly from animal feeding and waste storage facilities, waste treatment and reuse technologies will potentially reduce nitrogen loadings by an estimated 15 percent and phosphorus loadings by an estimated 20 percent (Figure 8-4).

- ***Atmospheric Deposition.*** Model simulations using the Chesapeake Bay Watershed Model suggest that implementation of the Clean Air Act will lead to reductions of up to 13 percent in nitrogen loadings to the Chesapeake Bay. For the sake of this analysis, however, it is assumed that new mass transit capacity and telecommunications can offset the growth in transportation needs but do not reduce the present level of road usage. In other words, this technology analysis assumes that vehicle miles driven would soon level off. The remaining effects of technological improvements, therefore, will depend on further emission controls and reduced dependence on internal combustion. In addition to the reductions resulting from the Clean Air Act, several other recently promulgated federal air quality regulations (including low-sulfur diesel fuels mandated by the EPA) will result in a potential NOx reduction of 27 percent. Current objectives do little to stem emissions of ammonia, however, except through current programs for manure and agronomic nutrient management. If fully implemented, these efforts could reduce ammonia emissions by 15 percent.

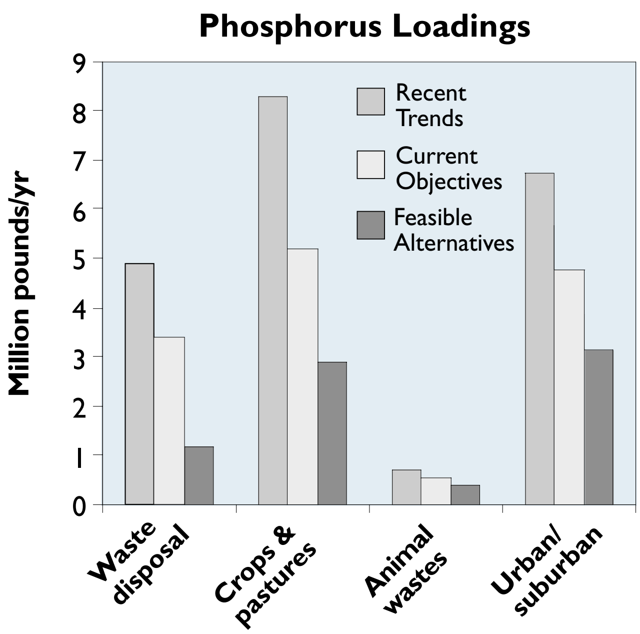
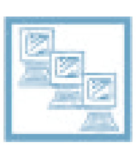


Figure 8-4. Like nitrogen, phosphorus loadings decline with aggressive reduction approaches. Declines could be particularly dramatic with programs for waste disposal and crops and pastures.

- ***Urban and Suburban Nonpoint Sources.*** Increased nonpoint-source inputs will result from new development (see Chapter 5). Remedial improvements in stormwater management (largely using existing technologies), however, would remove 15 percent of the total nitrogen and 25 percent of the total phosphorus from storm water.
- ***Environmental Rehabilitation.*** Some goals, such as the one for riparian forest buffers, are met and advanced, but others, including those for wetlands and oysters, remain elusive.
- ***Observations and Predictions.*** The Chesapeake Bay Monitoring Program is sustained and becomes more effective though better model integration and continuous observation systems.



Scenario 3: Feasible Alternatives

Primary Expectations:

- *Total loadings of nitrogen to the Bay will decline by 143 million pounds or 53 percent by 2030. Total loadings of phosphorus will decline by 10 million pounds or 53 percent. From an assumed 1985 maximum level, total nitrogen loadings would drop by about half and total phosphorus by two-thirds.*
- *Increases in loadings from population growth and land development will be constrained, while technological solutions achieve significant reductions.*
- *Present goals for riparian habitat restoration and for wetlands will be exceeded, resulting in additional removal of in-stream nutrients. Significant restoration of oyster reefs will result in tangible improvements in estuarine water quality and provide important fisheries habitat.*
- *Monitoring and modeling of the Chesapeake Bay and its watershed will become fully integrated and technologically advanced, providing real-time data on several spatial scales and allowing accurate forecasts as well as strategic predictions.*

The Feasible Alternatives Scenario includes the broader application of presently available technologies and the implementation of technologies likely to emerge over the next 30 years. Such effective and emerging alternative technologies will have to be applied in order to achieve the environmental restoration goals of the *Chesapeake 2000* agreement. We do not include any specific assessments of the economic feasibility of these technologies; it is our judgment that most, if not all of the alternative technologies, will approach the realm of viability within this 30-year time frame. Specific assumptions include the following:

- ***Waste Disposal.*** Under this scenario, nitrogen concentrations in virtually all point-source wastewater discharges are reduced to 3 mg/L, lowering nitrogen loadings between 76 and 86 percent after secondary treatment. Since roughly half of the effluent already passes through first-stage nutrient reduction treatment, the loadings of nitrogen from point sources would drop 65 percent from present levels under this scenario assuming 83 percent efficiency. (This level of advanced treatment is also capable of reducing total phosphorus concentrations to 0.075 mg/L—a reduction of nearly 78 percent.) It is assumed that half of all existing septic systems will be retrofitted with septic denitrification technology. With the 50 percent reduction in nitrogen losses in these retrofitted systems, the total load reduction from septic systems would be 25 percent. No benefits are realized in terms of reduced phosphorus loadings because this less soluble nutrient tends not to travel in groundwater. Combined reductions in loadings from wastewater treatment plants and septic systems would total 58 percent.

- *Agriculture.* This scenario assumes broader use of subsurface nutrient application, which can reduce nitrogen losses by about 20 percent and phosphorus losses by 30 percent in land under both conventional and conservation tillage. Less nitrogen is lost via groundwater and surface runoff while losses to the atmosphere are minimized through the reduction of ammonia volatilization. Cover crops are applied to 70 percent of cultivated land. A more rigorous regime of nutrient management for 80 percent of the tilled cropland and hayfields in the watershed, along with the development of new technologies for real-time soil testing, slow-release fertilizers, and other innovations, could enhance the reduction of total nitrogen losses by 40 percent and total phosphorus losses by 30 percent. Integration of animal and crop production, additional animal waste treatment and reuse technologies, and improvements in animal nutrition would reduce total nitrogen loadings by 55 percent and total phosphorus loadings by 40 percent from direct animal waste sources.

- ***Atmospheric Deposition.*** Required application of existing technologies, together with the incorporation of emerging technologies that increase efficiency and cost-effectiveness, could result in a 70 percent reduction of NOx emissions from stationary sources. Along with the Clean Air Act regulations considered in the Current Objectives scenario, technological advances in alternative fuels and vehicles could potentially reduce atmospheric deposition from mobile NOx emissions by 70 percent by 2030. More concerted efforts in animal waste management and the greater use of subsurface application of manure and volatile chemical fertilizers would result in more significant reductions, as much as 60 percent of ammonia emissions.

Tim McCabe, USDA NRCS

Riparian buffers (in the background of the photo) and wetlands (in the foreground) are critical land types that reduce the amount of nutrients and sediment reaching Bay waters. Rehabilitating damaged riparian and wetland areas can help restore the Bay ecosystem.

- ***Urban and Suburban Nonpoint Sources.*** Additional nonpoint sources from new development are estimated under the most compact growth scenario (Chapter 5). With more aggressive application of existing stormwater management technologies, as well as the use of emerging technologies, 30 percent of the total nitrogen and 45 percent of total phosphorus would be removed from storm water. These results suggest that major reductions in nutrient loadings from human activities are ultimately achievable (57 percent for total nitrogen and 60 percent for total phosphorus) through the rigorous use of existing and emerging technologies.

- ***Environmental Rehabilitation.*** Large-scale oyster restoration provides significant filtration, particularly in tidal tributaries, and present goals for restoring nontidal wetlands are exceeded.
- ***Observations and Predictions.*** Management is given assessments of present conditions and forecasts of future conditions of the Bay, allowing truly adaptive management of Bay resources.

April Bahen, NOAA

Young adults plant oysters in Virginia's York River during June, 2000. These oysters were grown on floats at the York River State Park.

In summary, the biggest gains in nitrogen loading reductions, compared with those projected for Current Objectives, are for crops and pastures. Reductions achievable for waste disposal and NOx deposition follow and are roughly equivalent. On the other hand, reductions from urban and suburban developed lands are more recalcitrant. Given the trends in land development, nitrogen sources from developed lands could rival cropland and pasture runoff and wastewater as a major source of nitrogen loadings to the Bay by 2030. Phosphorus is similar to nitrogen, with the largest achievable reductions in phosphorus loads from croplands and pastures, followed by developed lands and wastewater treatment plants. Land development is likely the only significant source of increasing phosphorus inputs, particularly due to soil erosion associated with development.

From advanced waste treatment to agricultural management practices to atmospheric emissions reductions, technologies are being employed to reduce nutrient and other pollutant inputs to the Chesapeake Bay. Since the 1980s, these technologies have not only helped offset increases in pollutant loadings associated with population growth and development, but have also started lowering total loadings. As demonstrated by this scenario analysis, the potential for further offsets and reductions is substantial. Most of these benefits can be achieved by existing technologies, given improvements in their cost-effectiveness and public acceptance. Emerging technologies and new technologies developed during the first part of the 21st century will provide additional opportunities.

Assumptions for nutrient source reduction for the Current Objectives and the Feasible Alternatives scenarios are aggressive. The estimated load reductions, however, do not include those achievable through the rehabilitation of wetlands, riparian zones, and watershed streams other than the control of runoff from developed land. Consequently, the total load reductions estimated here could realistically be achieved by implementing some but not all of the technological solutions coupled with active watershed rehabilitation.

Application of the technologies discussed here should not be taken for granted. Even those gains estimated under the Current Objectives Scenario should not be assumed, since they depend on overcoming many practical and financial obstacles. Technologies and their level of application assumed under the Feasible Alternatives scenario are just that—feasible alternatives from which to choose one of many possible Chesapeake futures.

Endnotes

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[28] Randall, C. 1999. op. cit.

[29] U.S. EPA. 1998. *National Air Quality and Emissions Trend Report 1997*.

[30] Brinsfield, R. 2003. Pers. comm. Actual rates for nitrogen and phosphorus loss from both conventional and no-till cropland can vary widely, depending on soil type, topography, and other factors. While soil conservation practices reduce surface runoff, without the use of cover crops and vegetated buffers that take up excess nutrients, dissolved nitrogen and even some dissolved phosphorus can escape through groundwater to the Bay.

Once and Future Bay

Estuaries are very changeable places. Some years bring little rain forcing rivers far up in the watershed to run shallow. Other years bring torrential storms, rivers swell to flood stage and heavy loads of silt come roaring downstream, filling channels with sediment. Across open waters high winds and waves, brought by nor'easters or tropical depressions, eat away at the shoreline. Whole islands eventually slip beneath the surface. The Chesapeake Bay, like all contemporary estuaries, is a geological youngster but is aging rapidly as it fills in with sediments from land and sea.

Dynamic forces—both external and internal—will continue to shape the future Chesapeake. External influences include sea level changes, exchanges with the ocean, inputs of nutrients, sediment, toxic compounds, and deposition from the air. Internal physical and biological processes will determine the removal and recycling of materials; sedimentation and water clarity; construction of structural habitats such as oyster reefs, wetlands, and aquatic grass beds; and the quantity and quality of living resources.

Humans can and do affect both external and internal forces by changing the materials they put in and the living resources they take out, and by altering the physical characteristics of the estuary. By changing the global climate, humankind may also further alter the physical forces that drive and shape the Bay. But, the estuary will face variability and change even without human influences. That reality, coupled with the pressures of a growing human population and shifting resource consumption patterns, creates a moving target, both for forecasting future conditions of the Chesapeake ecosystem and for our management efforts. Like Lewis Carroll's Red Queen, we find ourselves having to run faster just to stay in place.

> *"A slow sort of country!" said the Queen, "Now, here, you see, it takes all the running you can do, to keep in the same place. If you want to get somewhere else, you must run at least twice as fast as that."*
>
> *— Lewis Carroll, Through the Looking Glass*

The previous chapters assess changes anticipated due to population growth and land development, fluctuating forest coverage, and changing agriculture. But, the core of *Chesapeake Futures* is the Chesapeake Bay itself, with its stripers and blue crabs, great blue herons fishing along the shoreline at sunrise, and tributaries

Keith Weller, USDA NRCS

The Bay in Space and Time

When gauging the condition of the Chesapeake Bay—past, present, or future—we must think of space and time. We must consider not only the passage of time but the remarkable variability of the Bay and the climatic factors that affect it, from year to year, month to month, day to day, hour to hour. Temporally, when we say "the Bay," do we mean the Bay in winter, spring, summer, or fall? Do we mean the Bay during dry years, or wet years? The Bay will look quite different—in terms of algal blooms, for example—depending on when we look. Spatially, when we say "the Bay," do we mean primarily the northern Bay, where large rivers such as the Susquehanna, have such great influence, or the southern Bay, where ocean currents move heavier salt water into the estuary along the bottom? Or, the middle Bay, where mixing of fresh and salt waters is often greatest? Do we mean the main body of the Bay or the many rivers and creeks that extend into the watershed?

How the Bay is faring depends on when and where we look. But the Bay is also an interconnected nexus—a remarkable estuarine ecosystem—and this summary focuses on the "whole Bay," while still recognizing its daunting variability in both space and time.

stretching out into the far reaches of the watershed. Changes on the land will certainly be of considerable importance to the Bay, manifest as changes in nutrient and sediments loads, shifting forest cover, and the existence of wetlands as water quality filters and habitat. Lifestyle choices of people living in the region will also impact the Bay, either directly or indirectly. The amount of time people spend in their cars, for example, will likely affect the amount of toxics entering the water and the amount of atmospheric nitrogen deposited on the watershed. Finally, our management of the living resources of the Bay through fishery regulations or the introduction of exotic species represents our most direct influence on the status of the ecosystem. Changes in landscape and lifestyle may appear quite dramatic to those living in the watershed, but the Bay itself, which lies downstream from that shifting landscape, will register the long-term consequences most acutely.

This chapter examines likely future trajectories of the Bay ecosystem over the next three decades and beyond under the three scenarios of Recent Trends, Current Objectives, and Feasible Alternatives. Such an undertaking poses a daunting challenge, not only because of the uncertainties in the assumptions of the three scenarios, but also because of the ecosystem's physical, chemical, and biological complexity and limits in our current ability to predict its responses.

Analysts within the Chesapeake Bay Program are attempting to make such forecasts based on detailed mathematical models simulating how the Bay ecosystem will respond to changes in nutrient loading. The *Chesapeake Futures* assessment is less immediately quantitative since literature and the experience and judgment of the scientists who contributed to the synthesis form the basis for the analysis. The project, however, has a broader frame of reference because it addresses a range of changes in addition to those related to nutrients.

Physical Characteristics

The physical outline of the Chesapeake Bay stretches from its mouth at the Atlantic Ocean in southern Virginia to the tips of the creeks and rivers in upstate New York that feed the Susquehanna River. Water flows to the Bay through the forests of the Appalachian Mountains as far west as West Virginia, off farmlands on the eastern shores of Maryland and Virginia, through the streets of Washington, D.C. and the watershed's other urbanized landscapes. At its greatest depth, the Chesapeake reaches 174 feet at the deep trench just below the Bay Bridge near Kent Island, Maryland, and averages only 22 feet throughout its tidal waters. The Bay's web of coves and inlets, rivers, streams, and small creeks comprises more than 11,000 miles of shoreline.

But, the physical nature of the Chesapeake is not limited to its size, shape, and volume. Weather and the character of the Bay's waters change over time; both the flow of fresh water from the tributaries and the influx of salt water from the ocean significantly impact the Bay. As part of this dynamic, sediment constantly erodes from the land or resuspends in the water column from the bottom. Wetlands that fringe the Bay migrate and shift over time with profound effect, because they provide an interface between aquatic and terrestrial environments, functioning as filters for sediments, nutrients, and toxic compounds, while providing critical habitat for many species.

Sea Level Rise

Following the last glaciation, a relatively rapid rise in sea level flooded the Susquehanna and other river valleys and created the Chesapeake Bay. Inundation of the tributary valleys began about 7,000 years ago, and the Bay reached its current configuration only about 2,000 to 4,000 years ago.[1] Since then, the rate of change of the mean tide level with respect to surrounding lands has been slow, resulting mainly from subsidence of the land mass rather than expansion of the ocean's volume. This recent relative sea level rise—about 1 foot during the 20th century—was not inconsequential, however, and resulted in retreat of shorelines, inundation of some tidal wetlands and low-lying coastal lands, and release of eroded sediments into the Bay. The relative sea level rise of 3 to 4 mm/yr during the 20th century[2] was somewhat higher than the rate over the last millennium of only 1 to 2 mm/yr.[3] Some tide gauges have recorded even faster rates of relative sea level rise (up to 10 mm/yr) for a few years,[4] probably the result of wind-forcing over the open ocean associated with climate cycles such as the North Atlantic Oscillation.

As discussed in the chapter Changing Times, global warming is expected to increase the rate of sea level rise with reasonable certainty. Climate scientists generally concur that the oceans will expand their volume, resulting in an 8- to 12-cm (3- to 5-in) rise in sea level. This rise, coupled with the regional rate of land subsidence (which does not change), will result in a relative rise in mean Bay water levels of 13 to 17 cm (5 to 7 in) by 2030.[5] Even more rapid rises in relative level are likely later this century, which will cause Bay water levels to rise from 38 to 87 cm (15 to 33 in) higher than present levels by the year 2100.

Continued and possibly accelerated erosion of the Bay's shoreline and its tributaries will occur over the next 30 years. Some 13 charted islands have already slipped beneath the waves, and islands such as James, Barren, Holland, Smith, and Tangier will be further threatened. In an effort to preserve island habitats and dispose of sediment dredged from upper Bay channels, costly restoration projects (on the order of $1 billion) are likely for James or Barren islands, similar to efforts currently underway at Poplar Island. Accelerated erosion will increase the pressure for hard approaches (bulkheads and rip rap) to shoreline stabilization throughout the Bay region. On one hand, shoreline hardening reduces the value of shallow-water habitats and prevents the landward retreat of tidal wetlands as sea level rises. On the other, failure to abate shoreline erosion results in the release of additional sediment to tidal waters, attrition of island terrain, and the loss of both public and private property.

Reducing the rate of relative sea level rise obviously lies outside the realm of local management control. Even dramatic reductions in global emissions of greenhouse gases will have negligible effects on sea level rise by 2030—this rise is already set in motion. Coastal management approaches dealing with rapid sea level rise, along with the shoreline erosion and inundation that accompany it, are just beginning to be considered. The Recent Trends scenario assumes that landowners and communities will respond with hardened structures. The Current Objectives scenario assumes that regulatory controls will strongly limit structural approaches and obstacles to wetland retreat. The Feasible Alternatives scenario presumes that affected parties would adopt yet-to-be defined adaptive management approaches that involve intervention combinations: the slowing of shoreline erosion, abandonment to retreat and inundation, and proactive enhancements such as active marsh restoration.

Freshwater Inflows

Along with the seasons, change in freshwater inflows is one of the most distinctive sources of environmental variation in the Chesapeake Bay.

Freshwater inflows vary seasonally, with greater flows in the spring and lower flows in the fall. This pattern mostly results from the greater losses of water to the atmosphere due to evaporation and plant transpiration during the warmer months rather than any strong, consistent pattern of seasonal precipitation. Spring floods may come early when warm winters limit the temporary storage of water in snow and ice; floods associated with extratropical storms may produce stronger summer freshets. Importantly, large year-to-year variations do occur (Figure 4-5), some of which appear related to multi-year climate cycles of ocean basin or even global scale. The 1950s and 1960s, for example, were characterized by annual flows mostly below average, including a multi-year drought during the mid-1960s. The 1970s and 1990s, on the other hand, included many years with much higher-than-average freshwater inflows.

Freshwater inflows are enormously important to the Chesapeake Bay and its tributary sub-estuaries. They influence the distribution of salinity along the estuary, which in turn determines suitable habitats for oysters (and their predators), the extent of spawning and nursery grounds for striped bass, and the degree of up-estuary intrusion of stinging nettles. The inflows also carry sediments, nutrients, and toxic contaminants from their catchments. Freshwater discharges drive the extent of up-estuary inflows from the ocean—the greater the inflows, the more robust the circulation, as more ocean water is brought up the estuary. The amount of discharge also influences the density stratification of water masses.

Humans influence freshwater inflows in several ways: clearing forests; developing land with roofs, driveways, parking lots, and roads; and channelizing runoff and riverflows. These disruptions speed the delivery of water to the Bay and result in reduced water infiltration to soils and groundwater and less plant transpiration, causing an increase in the proportion of precipitation actually flowing to the Bay. On the other hand, some human uses of water, such as irrigation and cooling, are consumptive and send more evaporated water into the atmosphere. Storage of water in reservoirs influences the seasonal timing of the delivery of streamflows to the estuary. Finally, in some places water may be withdrawn from one location (the Susquehanna River, for example) and released in another basin (the Back River, for example).

Human population growth, land development, and growing demand for electrical power and irrigation over the next 30 years are likely to increase consumptive uses and wastewater flows, exacerbate flashy surface runoff, and increase demands for inter-basin water transfers (Recent Trends scenario). The scale of these changes to freshwater flows will likely not result in significant changes to the mainstem Bay, but may cause considerable change to the tributary sub-estuaries. Water conservation practices occasionally put into place in the Chesapeake region—modest in comparison with practices in areas with chronic water shortage problems (e.g., Florida and California)—are included in our assumptions for the Current Objectives scenario.

Water shortages already limit development in some areas and will become an even greater factor in the future. In addition, the growth management provisions under Current Objectives will also mitigate flashy runoff, a problem that results from increasing amounts of impervious surfaces due to development. Under the Feasible Alternatives scenario, not only will land development be greatly constrained, but urban redevelopment will ameliorate flashy runoff. This scenario also assumes only minor increases in consumptive use, as water and energy conservation practices offset the increased demands of a growing population.

Climate change represents a wild card regarding future freshwater inflows. While global warming from the buildup of greenhouse gases will almost certainly result in warmer and wetter conditions on average, predicting future climate is difficult on regional scales. Such predictions are particularly true for precipitation patterns governed by regional-scale meteorological processes. Climate models for the mid-Atlantic show considerable variation in their precipitation projections, with some indicating reduced precipitation later this century. Most models project modest increases in annual precipitation by

2030, with greater increases in the winter-spring than in the summer.[6] With greater evapotranspiration during the summer, the proportion of precipitation that joins streamflows should decrease, further exaggerating seasonal differences in inflows to the Bay. Furthermore, various climate assessments indicate that rainfall increases would come primarily from extreme precipitation events. Together, these projections suggest that average freshwater inflows during late winter and early spring will increase by 10 percent or more by 2030. Larger increases in freshwater inflows are possible late this century.

Sediments

As part of a long and slow natural process, the Chesapeake Bay is gradually filling with sediment. Sediment washing off the vast watershed ultimately ends up in tidal waters, mostly to be deposited in the upper ends of the Bay, tributary sub-estuaries, and myriad tidal creeks. Sands swept in through the mouth of the Bay by swift tidal currents have filled in much of the lower Bay. The continued rise in sea level gnaws at the shores of rivers, coves, and creeks, eroding sediment for deposit throughout the estuary. During the one hundred years ending in the 1950s, an estimated 1 to 3 million metric tons of sediment accumulated in the Bay, 40 percent of which was sand swept in from the ocean.[7] The rivers account for most of the muddy sediments that washed into the Bay.

This slow process is frequently punctuated by violent storms, such as powerful hurricanes and nor'easters, that may dump many inches of rain (e.g., about 15 inches of rain from Hurricane Floyd in 1999). The powerful surges of water strip soil from the land, erode stream banks, and wash sediment stored in river beds downstream. High winds can drive storm surges and waves into the Bay's shoreline, moving many tons of new sediment into the Bay.

In addition to these natural processes, human activities also increase rates of sediment deposition. As described in the chapter Chesapeake Pasts, sedimentation increased dramatically after European colonists cleared the land for agriculture, rapidly filling many smaller tributaries that served as colonial-era ports. Agricultural lands are not currently increasing in extent and minimum tillage and other soil conservation practices have reduced agricultural soil losses, thus sediment inputs to the Bay from agriculture are no longer rising. Some reductions in soil losses are still possible, however, within current agricultural land uses.

Land Use Type	Average Sediment Yield (tons/mi^2/yr)
Agricultural	300
Construction	32,000
Forested	20
Mixed	750
Rural	300
Established Urban	70

Table 9-1. Average sediment losses from different types of land use in tons per square mile per year.

Additional impacts on the land have resulted from massive earth moving for construction in many parts of the watershed. Development has also resulted in large areas of impervious surfaces, which gather water and deliver it at high velocity to receiving streams, causing scouring and high-volume sediment transport. These land use changes result in sediment yields to surface waters during land development and from recently developed sites that are far greater than those from agriculture on a unit-area basis (Table 9-1). These human-induced effects are of great consequence to the watershed as a whole, affecting the quality of the Bay's streams and tributaries, filling in smaller tidal creeks, and contributing to the attenuation of light in open Bay waters.

Excluding the sediments swept in by flood tides from the ocean, about 60 percent of the sediments depositing in the Bay comes from shoreline erosion and 40 percent from the rivers (Table 9.2). Approximately 4.5 million cubic yards of sediment is dredged from Bay channels each year. Assuming a bulk density of this sediment of 570 kg/cubic meter, dredged sediment equals 1.9 million metric tons, or nearly half of the amount discharged by rivers. The impacts of sedimentation vary significantly, of course, depending on location. For example, more than 90 percent of the sediment that normally comes down the Susquehanna is deposited in the Bay north of Baltimore.[8] The amount of sediment that has to be dredged to maintain upper Bay shipping channels, therefore, depends greatly on the amount of sediment discharged by that river.

Current rates of sedimentation require significant human intervention to keep sediment out of navigational channels and to prevent valuable shoreline from eroding away. The first problem necessitates extensive dredging, while the second stimulates extensive use of bulkheading, groins, rip rap, gabions, and other structures, as well as the proactive planting of grasses and other shoreline vegetation. The amount of sediment that has to be dredged to maintain upper Bay shipping channels will be greatly dependent on the quantity of sediment discharge by the Susquehanna. Recent legislation prohibits overboard disposal of dredged material in Maryland, and the capacity of placement sites for upper Bay dredged material will be reached before 2015. Consequently, a concerted effort exists to bring new placement options on line, emphasizing beneficial uses (e.g., island and wetland habitat creation) and innovative reuses (e.g., soil amendment, fill for abandoned mines and quarries, or building materials). These propositions are costly, however, and the costs and environmental restrictions are likely to force reductions in dredging to the amount needed to maintain essential channels. Nonetheless, with the likely restoration of one or more disappearing Bay islands, similar to the effort to save Poplar Island, opportunities may exist to use some dredged materials to nourish the soil-building processes within deteriorating tidal marshes.

Source	Volume (million metric tons)
River inputs (total)	4.3
Susquehanna River	*(1.2)*
Potomac River	*(2.0)*
James River	*(0.6)*
Rappahannock River	*(0.5)*
Shoreline erosion	6.3
Major inputs	**10.6**
Removal by dredging	1.9

Table 9-2. Estimates show that dredging removes nearly 20 percent of major sources of sediment entering the Bay.[9]

Flood events may, however, overwhelm both the ecosystem and the Corps of Engineers' abilities to maintain upper Bay channels. Such a situation occurred following Tropical Storm Agnes in 1972. In addition, most of the reservoirs above hydroelectric dams in the lower Susquehanna are approaching their capacity to retain sediments, a fact that further compounds the problem. The Conowingo Dam on the Susquehanna River currently captures 50 to 70 percent of the sediment traveling past that point in the river each year.[10] Sometime during the next 30 years, the reservoir behind Conowingo is expected to reach its sediment-trapping capacity; subsequently, all of the sediment flowing down river would pass over the dam and be deposited in the Chesapeake. If this situation occurs, annual sediment delivery to the Bay from the Susquehanna would greatly increase.

Under normal flow conditions, sediment releases will continue at a fairly even rate. Over the years, therefore, we would probably see increases similar to those witnessed during the 1990s. Most of the sediment from the Susquehanna is expected to accumulate in the upper Bay, as it does now. The loss of the Conowingo as a sediment trap then, might not directly affect dredging as a whole as dramatically as will changes in loadings elsewhere. The impact of increased sediment loads on the living resources of the upper Bay, however, could be significant. Increased light attenuation and sediment deposition on the leaves of plants, for example, can significantly stress submerged aquatic vegetation. Furthermore, because phosphates tend to adsorb to sediment particles, greater bypassing of reservoir traps would increase phosphorus loading to the upper Bay.

Efforts to reduce soil erosion from farm fields and construction sites predate the effort to restore the Chesapeake Bay; during the 20th century such efforts have significantly reduced sediment loadings from rivers and streams.[11] The *Chesapeake 2000* agreement contains a goal of reducing sediment loadings (parallel to that for nutrients) sufficient to remove the impairment of water quality in all Bay waters. Determining numbers for these loading goals, however, proved more challenging than for nutrients. First, much of the sediment enters the Bay through shoreline erosion, which lies outside the domain of conventional nonpoint-source controls. Second, driven by storms and floods, sediment loads are highly episodic and largely beyond human control. Third, large quantities of eroded sediments now reside in river- and streambeds and behind dams. With each sizeable storm, this sediment can remobilize and move downstream—a process that can persist for decades. Finally, fine sediment deposited on the floor of the Bay and its tributaries remains subject to resuspension by currents, waves, and vessels for many years until the particles ultimately find their resting home in deep channels. Even then, shipping and dredging can remobilize this sediment.


Photo courtesy of NOAA

Erosion such as this on a Wye Island creek continue to add sediment to the Bay's tributaries.

Under the Recent Trends scenario, recent progress in reducing sediment loads to the Bay is expected to reverse as soil disturbances from the high rate of land development, increased sediment bypassing of the Susquehanna dams, and accelerated shoreline erosion due to more rapid sea level rise all contribute new sources. The effects of increased sediment loading would be most serious in smaller tributary creeks that receive streams from developing lands but also should be significant in areas of lowland and marsh erosion, such as the northern Tangier Sound region. Under the Current Objectives scenario, it is assumed that efforts in restoring 2,010 miles of riparian forest buffers and significantly constraining development will produce substantially lower sediment loadings than under Recent Trends, but only modest reductions from present levels. Under the Feasible Alternatives scenario, significant reductions in sediment loading from the watershed would presumably be achieved from reforestation of large parts of the watershed, tightly constrained development of new lands, more effective controls of sediment losses from construction sites, aggressive retrofitting and maintenance of stormwater management infrastructure in developed areas, stream and riparian zone restoration, and removal of sediments from the Susquehanna reservoirs. Additionally, adaptive strategies for managing shoreline erosion, tidal wetlands, and inundation will limit the supply of sediments to the Bay from shoreline erosion to recent levels, even with accelerated sea level rise.

Wetlands

The shores of the Chesapeake Bay were once lined with much greater expanses of tidal and freshwater wetlands—shallow-water areas with luxuriant plant growth and thick substrates of peat that developed over thousands of years. These wetlands, linking the land and water environments of the Bay, provide critical habitat for juvenile fish and crabs, birds, terrapins, and other organisms. They also perform important physical and chemical functions in the ecosystem, filtering contaminants and nutrients from the water, trapping sediment, and stabilizing shorelines. Many of the wetlands once present in the Chesapeake have been lost and their numbers continue to decline each year.

The program for restoration, mitigation, and substitution of freshwater wetlands has involved only a small fraction of the wetland area lost over the

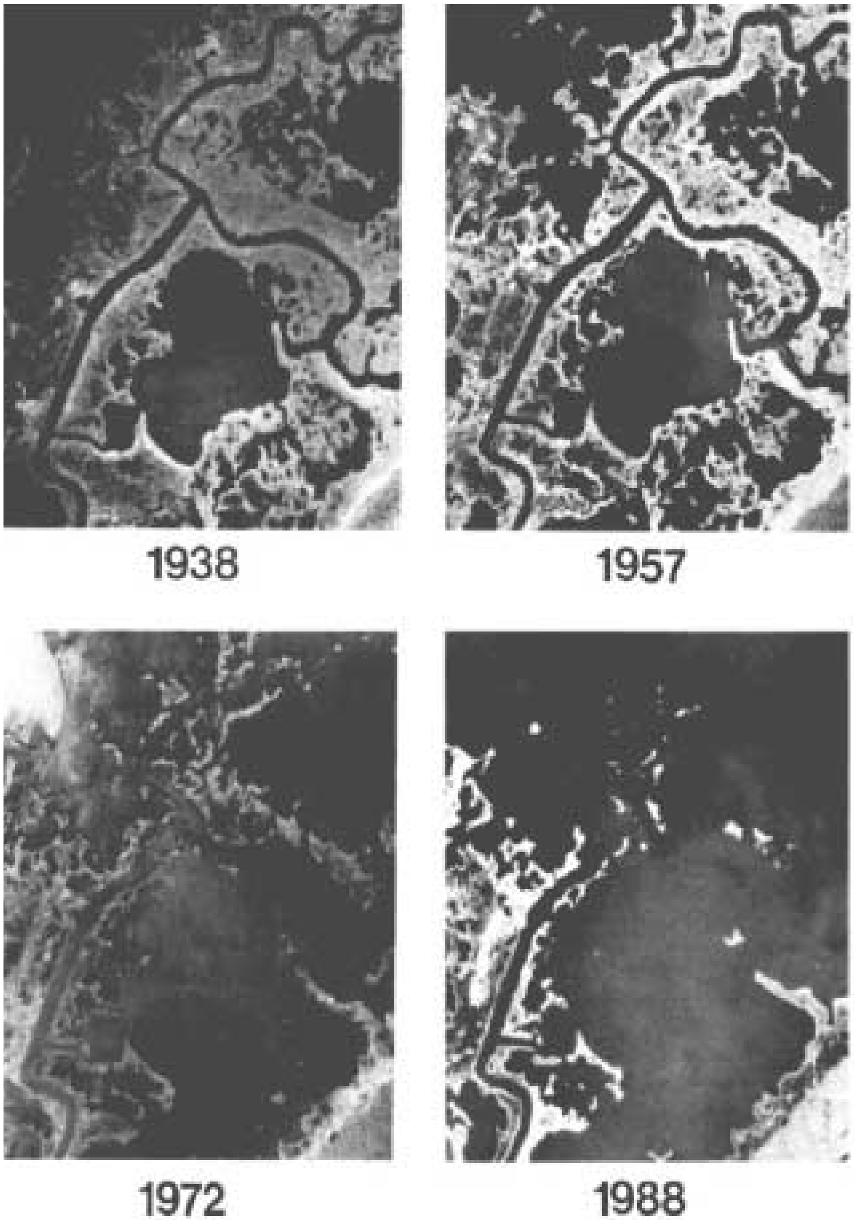

Photo courtesy of NOAA

The inexorable rise of sea level in the Chesapeake Bay is reflected in this time series of the Blackwater National Wildlife Refuge in Maryland. The dark areas represent open water; lighter areas represent vegetation.

century within the Chesapeake Bay watershed. From the 1780s through the 1980s, Maryland lost an estimated 73 percent and Pennsylvania an estimated 56 percent of their wetlands; nontidal wetlands make up most of these losses.[12] Wetland permitting has tightened significantly and mitigation requirements have increased during the last fifteen years, yet losses continue. Freshwater wetlands disappeared at basin-wide rates of about 3,000 acres per year during the 1980s. Reservoir and pond construction emerged as the most significant cause of these losses (~63 percent), with development and agricultural practices placing a close second (~37 percent).

Reservoirs differ considerably from wetlands, but they also remove nutrients from the water. Reservoirs also store peak flows and provide a consistent reducing (deoxygenating) environment compared to wetlands, which are subject to greater variations in water level. Migratory waterfowl use both environments as well. On the other hand, reducing environments near the bottom of reservoirs might lack some of the catalytic capacity derived from humic and fulvic acids (brownish and yellowish residues from the decomposition of plants) usually found in wetlands. So, the question arises: Are we losing 3,000 acres of freshwater wetlands per year (through the 1980s), or "losing" 1,000 and "transforming" 2,000 acres to features that are similar to wetlands (i.e., ponds and reservoirs)? Moreover, without maintenance, these reservoirs and ponds eventually could return to wetlands.

While nontidal wetlands are important to the Bay in their modulation of water fluxes, sediment, nutrients, and toxicants to the estuary, they do not have the two-way exchange of materials and organisms with the estuary like tidal wetlands. Until recently, however, the state of tidal wetlands in the Chesapeake was even more poorly understood than the status of nontidal wetlands. Through the analysis of historical aerial photography, researchers have documented the dramatic losses of large marsh systems along the Eastern Shore of the Bay since the 1930s.[13,14] But only within in the last several years, with the advent of models using satellite data, has the extent of tidal wetland decline become clear. These models indicate that over one-half the tidal wetlands in the Bay are now degraded, with perhaps one-fifth of previous acreage completely degraded and no longer functioning effectively.[15] Although human intervention has been largely responsible for localized losses of tidal wetlands, and certainly has accelerated losses elsewhere (e.g., the Blackwater National Wildlife Refuge), the predominant cause of tidal wetland loss in the Bay is sea level rise. Mounting evidence[16] documents the inability of many Bay tidal wetlands to persist in the face of rising sea level. In recent decades, the rate of sea level rise has been twice as fast as the ability of many marshes to elevate themselves.[17] The result of this prolonged imbalance has been the formation of large open-water areas (interior ponds) in the rapidly deteriorating marshes, with the prospect of their complete disappearance within a few decades.

One of the greatest problems facing those who wish to forecast wetland trends in the Chesapeake Bay drainage is the lack of long-term data on wetland coverage. The National Wetland Inventory (NWI), completed in the 1980s and just now being published, is already in danger of becoming obsolete. Even if a new inventory were initiated under a faster production schedule (not an unrealistic possibility, given recent developments in remote sensing technology), a 15-year record would still hardly be sufficiently extensive to determine trends accurately, especially if the definitions of wetlands types are still evolving.


Keith Weller, USDA NRCS

Given uncertainties in the current status of wetland accounts, current management actions will likely result in continued loss of both nontidal and tidal wetlands (Recent Trends). For nontidal wetlands, this downward trend can be a decelerating one, given enhanced monitoring, regulatory supervision, and active mitigation and restoration. The ultimate status, of course, depends on how flood-prone areas are used, because some uses are likely never to revert to wetland environments. The elusive goal of "no net loss" might actually be attainable (Current Objectives) for nontidal wetlands within the 30-year time span, but meeting the more ambitious Chesapeake Bay Program goal of significant net gains will be challenging without greatly expanded restoration efforts.

For tidal wetlands, the picture is more ambiguous and bleak; significant losses are anticipated even under Current Objectives. As long as sea level continues to rise at present rates (and, indeed, it is expected to accelerate), losses of wetlands will continue. The conversion of newly drowned uplands will replace some of the lost wetlands, but only on a small scale as this process is slow and the pace of estuarine wetland loss is many times faster.[18] It is unrealistic to expect that recently inundated uplands with their relatively sparse coverage of marsh plants will function as well as former marshes, which were thousands of years old and had accumulated meters of peat with complex subsurface hydrology and biogeochemistry. The prospect of a much different nearshore ecosystem for the Bay, therefore, looms large as these mature wetlands disappear.

Key to protecting many wetland areas will be the use of best management practices (BMPs) for both agriculture and stormwater management. These practices, along with emerging technologies, offer the best hope for reducing the channelization and excess sedimentation that can alter wetland hydrology. Beyond these practices and technologies, regulatory protection by itself will not be sufficient to ensure the viability of many tidal wetlands even through the first half of this century. Active management and restoration efforts will be necessary. Such efforts might include the building of oyster reefs or other offshore structures that can reduce scouring and encourage sediment deposition in nearshore areas. Moreover, tidal wetlands are not simply physical environments; they are biophysical habitats in which the plants themselves play a key role in creating and sustaining the habitat. Given adequate conditions of mineral sediment supply and tolerable water level fluctuations, wetland vegetation can create soil and root structures that enable the wetlands to keep pace with sea level rise. Under the Feasible Alternatives scenario, it is assumed that active management of at-risk tidal wetlands—through appropriate hydrological controls, sediment subsidies (e.g., spray placement of thin layers of dredged sediment on the marsh surface), and controls of biological pests (such as nutria)—coupled with the reconstruction of new tidal wetlands from dredged materials, would reduce but not eliminate the net loss of tidal wetlands over the next 30 years.

Courtesy of USDA

Toxic Contamination

Chemical contaminants, although not as pervasive a problem as nutrient pollution, can pose considerable threats to the living resources of the region and to human health. Contamination can result from a suite of human activities. These contaminants have the potential to pollute the air, surface water, or even groundwater, and ultimately end up in the Bay. Such contaminants include all manner of herbicides, pesticides, chemical solvents, petroleum products, and byproducts of combustion.

Like nutrients, chemical contaminants are introduced to the Bay both through point sources, such as industry outflow pipes, and nonpoint sources, such as runoff from storm water or agricultural fields. In addition, toxic compounds are often stored in bottom sediments, and can be reintroduced to the system when disturbed through dredging or by storms. Even years after the use of a chemical has been banned, therefore, its presence is still measurable in contaminated waters. For example, the pesticide DDT, although no longer in use, remains on the Chesapeake Bay Program's list of Toxics of Concern because scientists continue to find measurable levels during monitoring efforts.[19]

Of primary concern is the introduction of oil and other hydrocarbons into the Bay. Although some of these introductions occur through highly publicized "oil spills" and leakages from ship yards, most hydrocarbon introduction to the watershed occurs from urban runoff. Table 9-3 summarizes some estimates for hydrocarbon (gas, oil, etc.) inputs to the Bay along with their respective sources. Though admittedly rough, these data indicate that oil pollution from urban runoff (of all kinds) exceeds that from normal shipping operations by an order of magnitude. This information is consistent with the recent findings of the National Research Council that 80 percent of the inputs of petroleum into the marine environment comes from runoff and other chronic sources rather than the accidental oil spills so much in the public eye.[20]

Automobiles compose a significant source of hydrocarbons reaching the Bay. In addition to the other contaminants associated with vehicle exhaust (including nutrients from nitrous oxides and ammonia), automotive sources of contaminants include metals and other particulate matter from brake and tire wear.

Contaminants in many parts of the Bay are sufficiently diluted that immediate toxic effects are not a concern (although the long-term effects of chronic, low-level exposure to toxics remains largely unknown). Several regions within the Bay, termed Regions of Concern, have been identified as having a high probability for chemical contaminant-related problems. Focused clean-up efforts in these regions (Baltimore Harbor, the Elizabeth River, and the Anacostia River) are underway, but often the contamination problems are so severe that effective restoration is time-consuming and costly. In addition to the Regions of Concern, the Chesapeake Bay Program has designated ten Areas of Emphasis,[23] where a significant potential for chemical contaminant-related problems exists based on contaminant levels directly measured in the environment or on sediment bioassay results. Not yet severely compromised, these areas offer a focus for future efforts to control the release of chemical contaminants.

Most of the known impacts of toxic contaminants on Bay organisms have been identified experimentally or in the heavily contaminated Regions of Concern, although indicators of toxic impacts have been found within the much more extensive Areas of Emphasis as well. Furthermore, some contaminants in the tissues of fish throughout the Bay reach levels that could pose human health risks with heavy consumption of fish. Recent fish consumption advisories have been issued for mercury in several species of fish. In addition, contaminants such as trace metals and chlorinated hydrocarbons can persist in the environment for long periods of time, during which they can be remobilized from depositories in bottom sediments. In short, although the effects of toxic contaminants on the Chesapeake ecosystem are much less obvious and dramatic than the effects of nutrient overenrichment, there is ample reason to remain concerned about toxic effects and to reduce toxicant inputs to the Bay. This concern is especially well-founded since toxic chemicals and nutrient stressors can interact, compounding problems.[24]

	Shipping and Boating	Urban Runoff
Baltimore City (mgy)	0.024	1.8
Chesapeake Bay Basin Toxics Loading and Release Inventory 1994 (mgy)	1.8	33.0[21]
Chesapeake Bay Basin Toxics Loading and Release Inventory 1998 (mgy)	0.7	5.0[22]

Table 9-3. Hydrocarbon input estimates and sources. While oil tanker spills may be highly publicized, urban runoff of hydrocarbons poses a chronic threat.

Loadings of toxic contaminants to inland and coastal waters of the United States have dramatically declined over the past 30 years due to improved waste minimization, wastewater treatment, and prohibitions of certain persistent organic pollutants, such as DDT and PCBs.[25] This reduction ranks as a major accomplishment in environmental protection. Lingering problems remain, however, and new challenges are emerging. Although newly manufactured DDT and PCB are not entering the environment, these and other banned persistent organic contaminants remain in the ecosystem as part of a toxic legacy. We have learned that such persistent contaminants in watershed soils continue to wash into the estuary. In addition, new compounds of concern—such as the brominated diphenyl ethers (BDEs) commonly used as flame retardants in fabrics—appear as persistent contaminants around the world. While we have reduced the use of tributyltin—an antifoulant that causes reproductive impairment in mollusks at very low concentrations—on most vessels in the Bay, the compound is still used on some ocean-going military and cargo ships that call on Chesapeake Bay ports. Meanwhile, scientists continue to uncover reproductive and genetic effects of toxic contaminants at lower and lower levels.

Despite a growing regional population and increasing resource consumption, loadings of toxic contaminants to the Bay should continue to decline even under the Recent Trends scenario. Continued tightening of regulatory controls will reduce point-source effluents and atmospheric emissions from power plants. On the other hand, reductions in nonpoint-source inputs of toxic contaminants will be more limited because of legacy contaminants within the watershed and limited success in improving stormwater management. At the same time, reservoirs of contaminated Bay sediments will continue to reintroduce potentially toxic compounds to the water column whenever these sediments are disturbed by dredging, other human activities, or natural events, such as storms. The use of dredged materials for island restoration, rather than overboard placement, may actually result in a greater release of some contaminants, such as trace metals.

Assuming continued progress toward achieving Current Objectives—especially through improved management of urban stormwater runoff—loadings of toxic contaminants to the Bay would further decline. New requirements for power plant emissions will reduce inputs of mercury and the polynuclear aromatic hydrocarbons (PAHs) that result from fossil fuel combustion.

Although cleaner auto emissions will also be achieved, the continued increase in vehicle miles driven will undermine any net gains for automotive sources of toxic contaminants. Continued reliance on liquid petroleum products may actually result in increases of petroleum hydrocarbons into the environment. The growing numbers of boats on the Bay and the continued use of inefficient engines will make chronic oily marine emissions a lingering concern. Net improvements will depend on continuing regulation and compliance by the industry. At the same time, development of products that use fewer toxic ingredients will slow the introduction of contaminants at the source. Meanwhile, continued fish advisories for PCBs and other contaminants point to the continuing problem of relatively low-level toxicants moving through the system, many of which likely originate from historical, rather than new, sources.

The Feasible Alternatives path would lead to the cultural practice of a zero-emission (or nearly so) ethic. This likelihood is not as farfetched as it may seem—several international corporations are strategically moving in that direction for economic, as well as for environmental, reasons. Perhaps most problematic in reaching that ideal is not only industry with its powerful marketing tools, but a consumer public that often demands wasteful materials (e.g., excessive packaging) and disposes of them carelessly (e.g., dumping materials down the drain or burning plastics). Significant change will require altering personal behaviors that affect consumption, recycling, and transportation.

Despite best efforts, however, the notion of the "toxics-free" Bay—one into which society no longer places any substances that could produce toxic effects—will be more an inspirational goal than a certifiable reality. At a minimum, difficulties in managing stormwater runoff and the legacy contaminants it carries will keep us short of that goal. Agriculture will encounter some difficulties without the use of certain pesticides and, in particular, those herbicides required in some nutrient management strategies (e.g., cover crops). Nonetheless, significant reductions in toxic contaminants are possible under the Feasible Alternatives scenario and the zero-emissions concept on which it is based.

Trophic Status

Eutrophication, or the increase of organic matter to the estuarine ecosystem resulting from increased nutrient supplies, is widely regarded as the most pervasive and consequential cause of the degradation of the Chesapeake Bay ecosystem. The focus of previous chapters on changes in forests, agriculture, and land development has already laid the groundwork for describing how these changes affect the Bay's trophic status—the quality and quantity of the food supply and the future character of the estuary's food web. The nutrient supply, in particular, will affect dissolved oxygen levels and water clarity in the estuary, as well as its biological production.

Nutrient Loadings

Total nutrient loading estimates for an "average" year around 2030 were estimated in the chapter

Technological Solutions for all three scenarios (Recent Trends, Current Objectives, and Feasible Alternatives). These projections used year 2000 loadings from various sources as estimated by the Chesapeake Bay Program's Watershed Model. Increases or reductions of those loadings were projected based on the percentage changes developed in Technological Solutions and did not entail recomputation with spatially explicit changes in sources as in the Watershed Model. After completing the scenario estimates, the Chesapeake Bay Program then produced a new set of model projections for various nutrient reduction scenarios (referred to as tiers) as part of an attainment analysis for the setting of new nutrient reduction goals under the *Chesapeake 2000* agreement.[26] It is worthwhile, then, to compare the loadings of the *Chesapeake Futures* scenarios and the Chesapeake Bay Program tiers—two independent approaches using the same starting point, but with different source reduction assumptions and differing quantitative and qualitative approaches.

The Chesapeake Bay Program model projections used three levels of nutrient loading reductions:

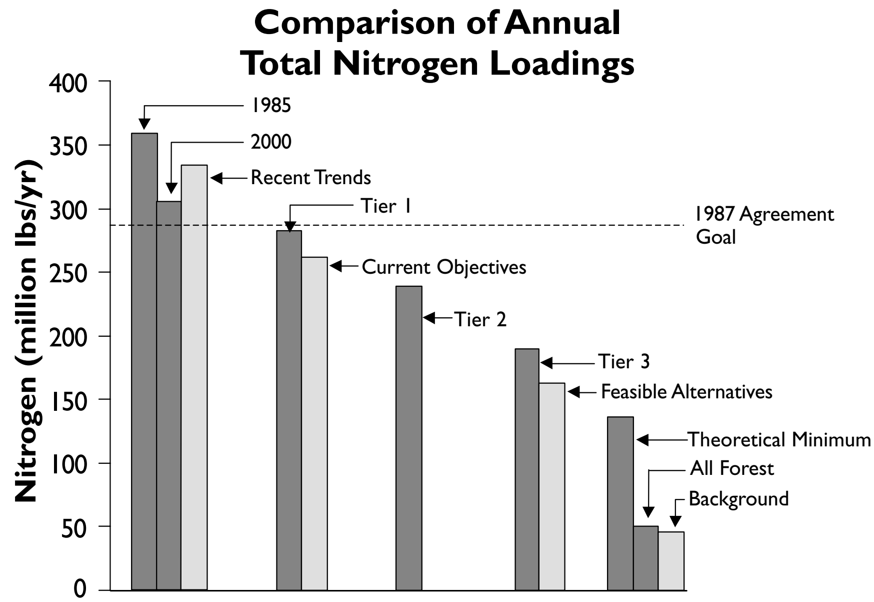

Figure 9-1. Comparison of annual total nitrogen loadings for Chesapeake Bay Program Watershed model projections (dark bars) and Chesapeake Futures scenarios (light bars).

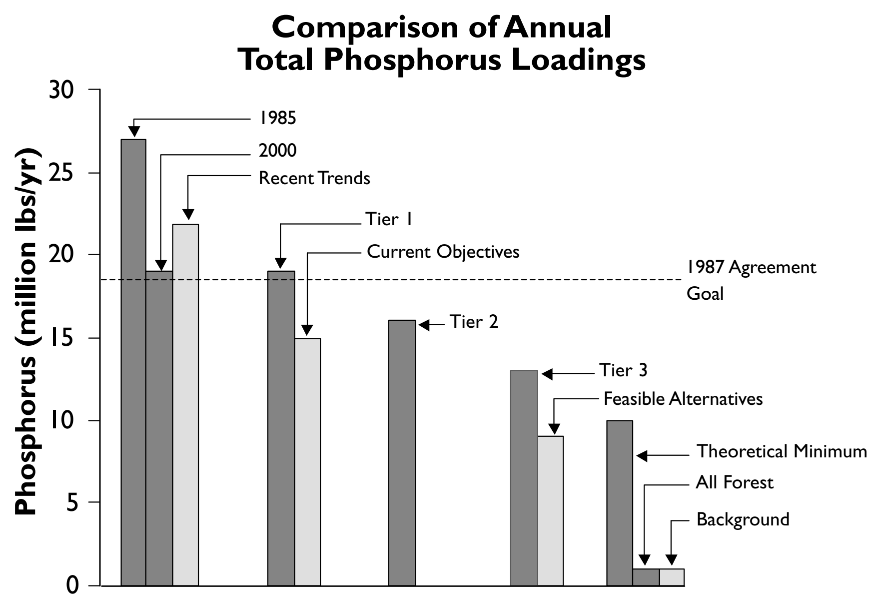

Figure 9-2. Comparison of annual total phosphorus loadings for Chesapeake Bay Program Watershed model projections (dark bars) and Chesapeake Futures scenarios (light bars).

- *Tier 1*. Uses status quo assumptions that the current level of effort is maintained in nutrient control programs and that programs and regulations scheduled to go into effect before 2010 are implemented.
- *Tier 2*. Assumes that levels of BMP implementation on all major point and nonpoint sources increase over Tier 1 and are technically possible.
- *Tier 3*. Assumes that BMP implementation levels on all major point and nonpoint sources increase over Tier 2 and are technically possible while technologies to reduce loads are introduced.

How Does the Chesapeake Compare?

Coastal systems are among the most heavily fertilized of ecosystems due to the inflow of nutrients such as nitrogen and phosphorus. In this company of highly enriched coastal systems, how does the Chesapeake Bay compare?

Compared to other estuarine systems (Figure 9-3), loading rates to Chesapeake Bay are moderate to high for total nitrogen (TN) and low to moderate for total phosphorus (TP). A ten-fold difference exists between the highest and lowest TN and TP loading rates for the Chesapeake subsystems, with an 80-fold range for TN and a 30-fold range for TP among all ecosystems shown. In these subsystems (except the Patuxent River), the nutrient input ratio (TN:TP) is well above the Redfield Ratio (the ratio between nitrogen and phosphorus in normal phytoplankton), indicating that excessive nitrogen is available to fuel phytoplankton production. In fact, this nitrogen ratio is higher than in most other systems surveyed. These differences apparently relate to the types of nutrient sources entering the system. Systems dominated by diffuse sources tend to have high TN:TP ratios, while those in which point sources dominate have lower ratios. In the Chesapeake systems, only the Patuxent has significant point-source nutrient inputs and a relatively low TN:TP input ratio. The pre- and post-sewage diversion input rates for Kaneohe Bay (points 3 and 5) also indicate the importance of diffuse versus point sources in determining TN:TP input ratios.

Also clear, however, is that comparable nutrient loading rates in different systems do not produce the same responses as those observed in the Chesapeake. For example, nitrogen loading rates for the Potomac River and Narragansett Bay are quite similar, but poor water quality conditions extend throughout the mesohaline (moderately salty) portion of the Potomac, whereas the analogous location is limited to a restricted reach of the well-flushed Narragansett Bay. On the other hand, loading rates to the Baltic Sea are much lower compared to most of the Chesapeake systems, but hypoxic (low-oxygen) and anoxic (no measurable oxygen) conditions currently characterize both. Estuarine morphology, circulation, and regional climate conditions undoubtedly have strong influences on the relative impact of nutrient loading rates.

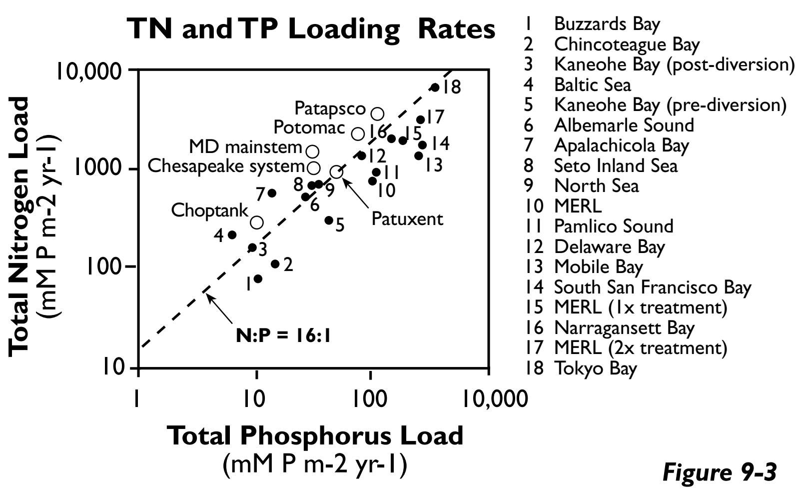

Figure 9-3

The Chesapeake Bay Program has also projected a theoretical minimum nutrient loading to the Bay, which assumes maximum levels of BMP implementation on all major point and nonpoint sources without considerations of physical limitations, participation levels, and costs. Also in this "everything-by-everyone-everywhere" scenario, new technologies (or those not currently addressed within the Chesapeake Bay Program Watershed Model) are included at implementation levels beyond Tier 3. In addition to the tiers, the model estimated nutrient loadings under a pristine condition in which the Bay watershed is essentially covered entirely by forest.

In Figure 9-1 and Figure 9-2, we compare the *Chesapeake Futures* scenarios (light bars) with Chesapeake Bay Program projections (dark bars) for tiers 1 to 3: annual average nutrient loadings estimated for 1985 and 2000, a theoretical minimum, and an all-forest condition. For nitrogen, the estimated atmospheric deposition directly onto tidal waters of the Bay[27] was added to the Chesapeake Bay Program projections developed for allocating reductions from the watershed and point sources.[28]

Before comparing the model projections and scenarios, it is important to emphasize that the Chesapeake Bay Program model projections are for 2010 and the *Chesapeake Futures* scenarios are for 2030. For example, loadings under the Recent Trends scenario are higher than those estimated by the Bay Program for 2000 because (absent supplementary efforts to control nutrients) additional population growth through 2030 would result in greater nutrient loadings. Similarly, reductions in nutrient loadings under the three tiers accomplished by 2010 might erode by 2030 without efforts to offset the population growth and development-related increases in nutrient loadings.

The assumptions under the Current Objectives scenario are actually somewhere between those of Tier 1 and Tier 2 for nitrogen. The assumptions under the Feasible Alternatives scenario are more aggressive than those of Tier 3, in part because of the longer time horizon. Some technological applications that are feasible in the 30-year timeframe are less so in the ten-year timeframe. In particular, a significant portion of the potential reductions in atmospheric deposition of nitrogen would be realized after 2010 as regulatory-influenced emission controls are implemented and transportation fleets convert to lower emission technologies (hybrid and natural gas-powered vehicles and, ultimately, fuel cells).

With these differences in mind, the comparison of results is reassuring from at least two perspectives. First, the generalized methodology used in *Chesapeake Futures* to estimate reductions of sources delivered to the Bay produced results that approximate those generated by sophisticated computer models. Second, somewhat different approaches to identifying feasible means of reducing nutrient loadings produced roughly similar results, lending validation to the claim that such load reductions are achievable. Only in the case of phosphorus does the Feasible Alternatives loading estimate approximate the Theoretical Minimum nutrient loading as projected by the Bay Program model.

These similarities extend even to comparisons in the *Chesapeake Futures* scenarios and the model's projections for specific source categories. The Current Objectives scenario for agriculture sources estimates 92 million pounds of nitrogen per year, falling between Tier 1 and Tier 2 estimates of 101 and 76 million pounds, respectively. The Feasible Alternatives scenario assumes 48 million pounds of nitrogen from agriculture, compared to 56 million pounds for Tier 3, but this is for 2030 when less land is expected to be agricultural and nutrient control strategies have become more advanced. For urban lands, the Current Objectives level is roughly comparable to Tier 1 projections (26 versus 29 million pounds), but this is after 20 additional years of urban/suburban development. The Feasible Alternatives estimate for nitrogen from urban land in 2030 is, however, lower (17 million pounds) than the Tier 3 projection (23 million pounds) for 2010, because of the more restrictive land development assumptions under this *Chesapeake Futures* scenario.

Before considering the consequences of these predicted changes in nutrient loadings, we must emphasize that all of these estimates are, in a sense, abstract. They are all based on a year of average freshwater inflow (the Chesapeake Bay Program for 1985–1994). In reality, the annual streamflow into the Chesapeake Bay has varied by a factor of nearly three during the last 64 years (Figure 4-5); such variability greatly affects the delivery of nutrients to the Bay from nonpoint sources. The 1950s and 1960s generally experienced average to below-average freshwater inflows, while the subsequent period experienced much greater interannual variability and record high flows. Nitrogen loading from a river like the Susquehanna is generally proportional to freshwater flow, at

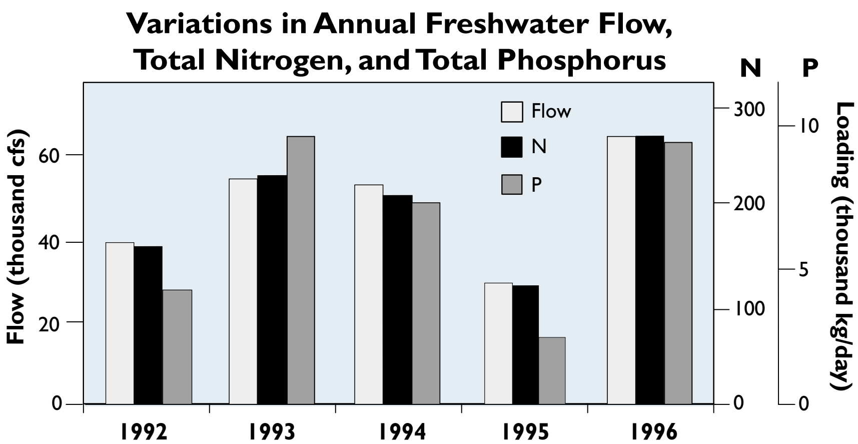

Figure 9-4. Variation in annual freshwater flows and loadings of total nitrogen and total phosphorus during the mid 1990s. Total nitrogen loadings closely follow flows, while total phosphorus loadings are disproportionately lower during low flows.

specific times throughout the year and into the future. In addition to this and other models, *Chesapeake Futures*, used more-generalized reviews of the literature, historical comparisons, and the professional judgment of participating scientists to surmise what conditions would be like under the three scenarios; this report does not specify the distribution of low oxygen, algal blooms, and other parameters in space and time.

Scenarios for dissolved oxygen and other indicators of the trophic condition of the estuary borrow heavily from recent analyses of a historic database on dissolved oxygen in the mainstem Bay.[29] During the 1980s, the scientific community vigorously debated whether hypoxia (harmfully low dissolved oxygen concentrations) had become widespread due to human-induced nutrient enrichment[30] or whether the apparent expansion was merely a function of increased freshwater discharges that produce strong density stratification and oxygen depletion of the Bay's deep waters.[31]

The analysis cited above finally clarified this controversy; both factors are involved. The extent of summertime hypoxia in the Bay varies greatly with the amount of freshwater inflow from January through May. Higher flows not only deliver more nutrients, stimulating the production of organic matter that depletes oxygen reserves, but also increase the density stratification (lighter, fresher water at the surface and denser, saltier water near the bottom) of the water mass, isolating hypoxic bottom water from surface oxygen supplies. Even accounting for the effects of variations in freshwater flows, however, the extent of moderate hypoxia (defined as dissolved oxygen concentrations less than 2 mg/L) increased three-fold from 1950 to the 1990s. Severe hypoxia (less than 0.2 mg/L), evident only during high flow years in the 1950s, has become an annual phenomenon since 1968. Empirical, statistical models can depict increases in the extent of summertime

least over a span of a few years (Figure 9-4). Phosphorus loading, on the other hand, tends to increase disproportionately with flow because increased runoff mobilizes phosphorus associated with soils and sediments. Consequently, the interannual range in nutrient loading is greater than the range of reductions included in the forecasts.

On the other hand, while the Bay clearly responds to these interannual variations, its degradation has occurred over the long term. Normalizing nutrient loading scenarios and projections to average flow conditions allows us to evaluate the prospects of recovery over the same long-term time scale. These projections, however, do not mean that these numbers will be the loadings actually received in 2010 or 2030. Actual loadings will depend on the freshwater discharges at those times. More appropriately, the scenarios and projections reflect the average conditions during these decadal time periods.

Dissolved Oxygen

The Chesapeake Bay Program uses a complex three-dimensional, hydrodynamic model to project the effects of reductions in nutrient loading on dissolved oxygen and other water quality and ecological properties. The model is able to predict water quality conditions throughout the Bay as a function of nutrient inputs at specific locations at hypoxia and anoxia (the nearly complete absence of dissolved oxygen) for the "average year," measured by the volumes of water fitting the definitions (Figure 9-5).

While this 50-year trend in increasing hypoxia is surely due to increased nutrient loading, we lack comprehensive data on nutrient loadings to the Chesapeake Bay prior to 1978, preventing us from statistically relating nutrient loading to the extent of hypoxia. Several lines of evidence, however, suggest that loadings of nitrogen (the nutrient most responsible for overenrichment in marine and estuarine waters) may have doubled between the 1950s and the late 1980s. Nitrate concentrations in the tidal freshwater Chesapeake Bay increased two- to three-fold between 1965 and 1980.[32] Nitrate concentrations of Potomac River discharge increased from about 1 mg/L during the 1950s to about 2 mg/L in the mid to late 1980s.[33] Use of nitrogen fertilizers and atmospheric NOx emissions in the United States more than doubled during that same time period.[34]

The Feasible Alternatives scenario for nitrogen loading is a 55 percent reduction of average annual loading from the 1985 base-case level (the Chesapeake Bay Program's Tier 3 projection is for a 45 percent reduction). For a first approximation, we assume that the dissolved oxygen conditions and trophic status of the Bay proper will return to conditions simlar to the 1950s: substantial reduction in the volume and area of Bay bottom covered by hypoxic

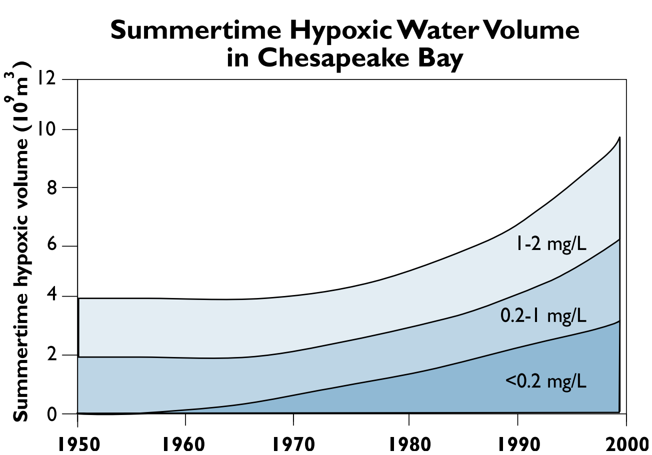

Figure 9-5. Regression predictions of summertime hypoxic volumes for Chesapeake Bay under average flow conditions (after Hagy, 2002).

waters and the elimination of anoxia (<2 mg/L) except during high-flow years. Nitrogen loadings under the Current Objectives scenario are 73 percent of the 1985 loadings (normalized to the average-flow year). Based on Potomac River nitrate concentration data and national fertilizer and atmospheric emission trends, this situation approximates the hypothetical average conditions around 1975. Figure 9-5 indicates that this would result in considerable improvement in dissolved oxygen conditions with the volume of hypoxic waters decreasing by about one-half. Anoxia, however, would still occur, except during years with substantially below-average flows, but would be about one-half as extensive. The good news is that considerable improvements in dissolved oxygen conditions in the deeper parts of the Bay should be attainable even under the Current Objectives scenarios.

If we have made progress in reducing nutrient loadings to the Chesapeake Bay following the 1987 Agreement such that nitrogen loadings declined 15 percent by 2000, why haven't we seen improvements in dissolved oxygen conditions during the late 1990s? Several possible reasons are plausible. First, the 2000 loading estimates based on the Watershed Model are just that—estimates. They assume that certain management practices to control nonpoint nutrient pollution have been implemented and have certain effectiveness. While flow-adjusted nitrogen loadings from many of the gauged Chesapeake rivers have declined since 1985, the actual effectiveness of the credited management practices remains unverified. Second, the model assumes immediate effectiveness of the management practices once they are implemented. In fact, lag times in soil systems and water passage through groundwater means that several years may pass before nonpoint-source reductions are manifest in reduced loadings to the Bay. Third, the Bay itself may take a few years to recover and burn off accumulated organic matter. Based on these considerations and experience with time lags under conditions of increasing nutrient loadings in the Mississippi River basin and decreasing nutrient loadings in the Danube River basin,[35] an overall five- to seven-year lag effect would not be surprising.

Finally, freshwater inflows were higher than the long-term average during the 1990s, which included four much higher-than-normal flow years (Figure 4-5) and more extensive hypoxia.

This last point reemphasizes that freshwater inflows, and thus nutrient loadings, to the Bay are and will remain highly variable. Floods and droughts will cause dissolved oxygen and other trophic conditions to vary from year to year. Furthermore, scientists are beginning to uncover the importance of multi-year climatic cycles related to such phenomena as the El Niño-Southern Oscillation and the North Atlantic Oscillation on not only freshwater inflows but also temperature and ocean-Bay exchange. Moreover, significant climate changes are expected during the 21st century due to global warming (Changing Times chapter). While accelerated sea level rise will probably not affect the volume of the Bay sufficiently to influence circulation and stratification (and thus hypoxia), changes in the amount of precipitation and runoff and earlier seasonal warming of Bay waters would have a profound effect on hypoxia. Although climate models differ in their projections of precipitation in the Mid-Atlantic region, most predict greater precipitation, particularly during the winter and spring.[36] On the other hand, greater evapotranspiration may result in drier soils and decreased runoff during the warmer months. Increases in winter-spring runoff beyond the assumed average would increase nutrient loading under all scenarios and, coupled with earlier warming, increase stratification, which would exacerbate hypoxia significantly. While most of these climate changes are expected later in the 21st century, beyond the scope of *Chesapeake Futures*, they may make the climb toward restoration of adequate dissolved oxygen levels in the Bay that much steeper. Therefore, an anticipatory, long-term strategy would be to "go long" rather than "stop short" on nutrient reduction targets.

Tim McCabe, USDA NRCS

Water Clarity

Nutrient enrichment reduces the clarity of Bay water as phytoplankton growth decreases light penetration. Again using an empirical, historical analysis, researchers can evaluate the consequences of reducing nutrient concentrations to 1950s levels.[37] One study concentrated on the middle reaches of the Bay, where impairment due to eutrophication has been most dramatic. The study assumed that light penetration would be sufficient to allow submerged aquatic vegetation to grow to the 2-meter depth contour as it once did. Further assuming current average light attenuation coefficients of 0.8/ m (with 80 percent of the light lost in the first meter and only 1 percent of light penetrating to 5 meters depth), the restored light attenuation in open waters would be 0.4/m (1 percent light level at about 10 meters) and 0.8/m in shallow-water environments that experience frequent sediment resuspension. We accept these values as the average condition under Feasible Alternatives. As a general approximation, an open-water light attenuation coefficient of 0.6/m is used for the Current Objectives scenario.

Water clarity in the upper portion of the Bay and the upper reaches of its tidal tributaries is unlikely to change greatly under these scenarios because water clarity in these regions is more a function of mineral particles in suspension rather than bioseston (suspended particles produced by organisms). On the other hand, water clarity in the lower reaches of the Bay, while less impaired, should improve from nutrient load reductions. In the middle reaches of the Chesapeake Bay, summer phytoplankton biomass—measured as chlorophyll—has doubled since the 1950s (consistent with the halving of light penetration). In the lower Bay, phytoplankton biomass has

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Volunteers plant oysters in the Choptank River. Such proactive measures assist the Bay restoration effort.

increased by even greater percentages although from significantly lower levels in this less-rich part of the Bay.[38] The large-scale restoration of oyster reefs could further reduce the bioseston and light attenuation, but given the constraints discussed below this effect is likely to be modest, except in some tidal tributaries where enhanced filtration from achievable reef restoration may contribute significantly to water clarity.

With light availability increased to a level that allows SAV to grow to 2-meter depth, 10 percent of the mid-Bay bottom area would become suitable for establishment of SAV—seven times more area than currently covered by these plants. Not all of this habitat would be colonized, however, because waves and currents make some bottom areas too dynamic for the establishment of SAV. Still, allowing enough time for colonization and establishment of beds, SAV coverage under the Feasible Alternatives Scenario should reach up to five times the present coverage. Perhaps even more importantly in terms of the trophic status of the Bay, increased water clarity (reduced light attenuation) would illuminate a significantly greater area of bottom habitat in the mid-Bay that would allow for 91 percent greater production of benthic microalgae according to one estimate (Figure 9-6).[39] For the Current Objectives scenario, we roughly assume a doubling of SAV coverage and a 40 percent increase in the production of benthic microalgae.

Biological Production

The Feasible Alternatives mid-Bay would have much more extensive SAV beds and approximately 50 percent less planktonic primary production, but nearly twice the benthic microalgal production. Overall, estimates indicate that the total primary production would be 37 percent less than in the 1990s.[40] Of course, humans are concerned more with the trophic status of fish and shellfish than microalgae. Would not this reduction of primary production cause a reduction in production higher up the food chain? Indeed, various runs of the Chesapeake Bay Program's Water Quality Model for

Increase in Habitat Available for SAV and Other Species Under the Feasible Alternatives Scenario

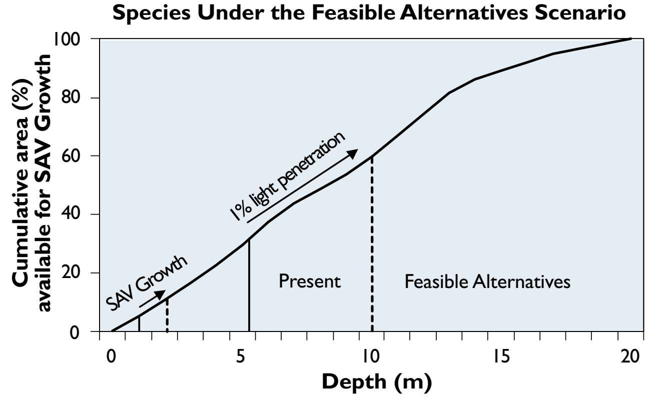

Figure 9-6. Cumulative area of shallow bottom habitat (0 to 20 meters) for the middle portion of the Bay. The graph shows projected increases in SAV growth from the present (solid line) to 2030 (dotted line), given the implementation of Feasible Alternatives. An increase of light availability (1 percent penetration) results in a shift from the present (solid line) to 2030 (dotted line), with more light reaching benthic diatoms and other bottom-dwelling species.

the Bay have shown benthic animals and fish actually starving under assumptions of severely reduced nutrient loading.

Certainly, estuaries such as the Chesapeake Bay and other coastal waters have high fisheries production because they receive relatively high influxes of nutrients.[41] Furthermore, human-induced nutrient enrichment of coastal waters in other parts of the world has led to increases in fisheries production from the fertilization effect.[42] Such increases are usually manifest in greater production of fish species that feed directly on the plankton, but some examples suggest that production of benthic feeders and even shellfish can be increased. The worldwide experience has also shown, however, that when eutrophication proceeds to the extent that regular and extensive hypoxia occurs, those fish species that depend on benthic resources rapidly decline.

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This proposition for the present and "restored" Bay has been scrutinized using a type of analysis that examines the food chain as a network of relationships among species.[43] This groundbreakeing study concluded that with realistic shifts in food webs from bacterial production to species that directly support fish production, it is possible to support upper trophic levels in the mid-Bay even with a significant decrease in primary production due to nutrient loading abatement. Furthermore, because stress and mortality from hypoxia and anoxia would also decline, the biomass and production of benthic animals would dramatically increase, along with a rise in benthic microalgal production. Together with an increase in the SAV nursery habitats, a Feasible Alternatives Bay should allow increased production of bottom-feeding species such as blue crabs, spot, and croaker, as well as prey species consumed by freely swimming species such as striped bass. All in all, the trophic efficiency of the Bay would increase as more of the available primary production goes into fish, crabs, and the like and less goes to bacteria. For example, while an estimated 0.125 percent of net phytoplankton production currently passes to striped bass in the mid-Bay, this number could increase to 0.237 percent in a restored Bay.[44]

The food webs of the Chesapeake Bay are obviously complex and analyses necessarily speculative—too much so to be able to develop specific quantitative outcomes for the Current Objectives and Feasible Alternatives scenarios. Nevertheless, a sufficiently strong scientific basis exists to conclude that production of higher-trophic-level animals of direct value to humans (with the possible exception of plankton-feeding menhaden) would not decrease by reducing nitrogen loadings to about half the 1990s levels. Furthermore, production of some species that rely on benthic production should actually increase.

Life in the Bay

Health of the Ecosystem

The Chesapeake Bay is home to creatures of every shape and size. The public's image of the Bay's inhabitants often focuses on the beautiful or the functional: the great blue heron, the oyster, the striped bass, and, of course, the blue crab. But in addition to these important members of the Bay's community are many lesser known, but just as important, organisms: polychaete worms that rework bottom sediments and feed fish; underwater grasses that provide important habitat to many animals; microscopic algae at the base of the food chain and the minute crustaceans that graze on them; and menhaden and anchovy—small fish that provide food to the larger fish in the Bay. Each organism in the Chesapeake Bay plays an important role in the functioning of the ecosystem, and they all interact with one another. A change in any one piece of the ecosystem can have ramifications that spread throughout the other components by removing a food source, increasing competition for a resource, reducing the amount of light available for photosynthesis, and so forth. Although "health" is a vernacular metaphor, scientists also use the concept of ecosystem health more formally for describing the efficient and productive performance of an ecosystem.[45]

All of the analyses conducted in the other sections of *Chesapeake Futures*—calculating changes in land use, innovations in technology, fluctuations in the physical and chemical parameters of the Bay—are ultimately designed to address the question: How will our actions and decisions affect the living Chesapeake Bay—the health of this ecosystem and its living resources? What are the possible outcomes during this century? These outcomes will be determined to a significant degree by how nutrient reduction efforts affect the trophic status of the Bay, as discussed above, but also by the degree to which habitats are restored, how living resources are utilized, and through external changes (such as climate change) that are beyond the direct control of society within the region.

To address this question, one can take a "bottom-up" view of the Chesapeake food web as in the section on Trophic Status and focus on the single-celled phytoplankton, bacteria, and zooplankton through which energy flows to higher consumers. Because the plankton play such an important role in oxygen generation and depletion in the Bay, projections about plankton abundance provide important information about the health of the Bay's ecosystem and the quality of its habitats. Alternately, one can take a "top-down" perspective on the health of the ecosystem. If fish populations are healthy, their status suggests that food is plentiful and good habitat remains available. Populations in decline or showing signs of stress may indicate a problem somewhere in the ecosystem. Commercial fish species, in particular, may serve as bellwethers since we often have reasonable fishing industry information about the status of these populations. Ideally, one should assess the health of an ecosystem from both bottom-up and top-down perspectives.

The assessment outlined in Trophic Status suggests that under the Recent Trends scenario, the health of the Chesapeake Bay would worsen as we approach 2030 and become comparable to the nadir years of the late 1980s and early 1990s. Overall primary production would be high, but the distribution of that production among phytoplankton, benthic microalgae, and SAV would be greatly uneven, with planktonic production dominating. Widespread and severe hypoxia would continue to stress benthic organisms and swimming animals that otherwise use deep-water habitats. Restoration of the oyster reefs—which played such an important role in filtering

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Fisheries Management: Multiple Jurisdictions, Multiple Species


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Three management jurisdictions—Maryland, Virginia, and the Potomac River Fisheries Commission—are responsible for managing fisheries in the waters of Chesapeake Bay. While each jurisdiction exercises these rights independently, the Chesapeake Bay Program coordinates their actions. Development of Chesapeake Bay-specific fishery management plans (FMP) has encouraged this coordination. The 1987 Chesapeake Bay Agreement mandated the development of such FMPs for commercially, recreationally, and ecologically valuable aquatic species. These FMPs must consider biological, economic, and social factors of each resource in setting management practices. Recent FMPs emphasize identifying and protecting essential fish habitats; many of these plans now include Chesapeake Bay-specific habitat requirements for important species. Over 15 FMPs currently provide guidance to the Bay states for coordinated, baywide management of fisheries. In addition to these local jurisdictions, several fish of importance fall under federal jurisdiction, since their populations migrate across state boundaries. The Atlantic States Marine Fisheries Commission (ASMFC) manages these migratory species as interjurisdictional fisheries. Like the Bay Program, ASMFC coordinates its management actions through regularly revised FMPs.

For years, we have attempted to manage exploited species, one by one. Although there have been some success stories, overall the track record is not good. In part, this failure comes from neglecting to account for the interactions among the species. For example, some fish species may depend on oysters to provide suitable habitat while other species, such as striped bass, prey on menhaden and—perhaps if there are not enough menhaden—on blue crabs. Now the daunting challenge taken up by the *Chesapeake 2000* agreement is to manage the interconnected diversity of fish and shellfish species in the Bay within the more far-reaching context of ecosystem health.

excess plankton and providing habitat for fish, crabs, and their prey—would show only spotty progress. Significant tidal wetlands that provide additional habitat and buffer the estuary from extreme events would have been lost. As a result, the biological diversity of the Bay and its resiliency[46] in responding to extreme events such as floods would remain seriously impaired and possibly decline. The ecosystem could be more prone to population outbreaks of a few species, including harmful algae.

If we continue implementation of Current Objectives, including nutrient control, contaminant loading reductions, and important habitat restoration, some improvements in the Bay's health are likely through 2030. As light infiltrates deeper into Bay waters, dissolved oxygen conditions improve, SAV returns, toxic bottom sediment contracts to smaller zones. As some—albeit limited—progress is made in restoring oyster reefs, food resources and habitat dimensions will diversify. Furthermore, the ecosystem would regain some capacity to resist stresses and recover from severe events. One example of this capacity is the increase of denitrification mechanisms. In addition, as previously discussed analyses suggest, the production of fish, crabs, and other higher consumers would not decline.

The Feasible Alternatives scenario describes even greater opportunities for the recovery of the Chesapeake ecosystem. Expansion of suitable benthic habitats and SAV beds would be much more dramatic than those achieved through Current Objectives. Substantial commitments to the restoration of oyster reefs, using management approaches that account for the threat of disease, would be successful in restoring 10 percent of the historic oyster biomass in the Bay. Going much beyond that is unlikely not only because of disease mortality but also because of the huge costs of rebuilding the physical structures that the oysters took millennia to produce. The result would not be the Bay at which Captain John Smith marveled, but more akin to the one that Bernie Fowler knew as a young man. The ecosystem would be substantially more diverse and resilient. It would produce less phytoplankton and bacteria but more fish and crabs that depend on bottom habitats.

There are at least two caveats to this relatively rosy scenario. One is that biological surprises lie ahead. Such surprises may come in the form of invasive species, perhaps introduced unintentionally by ballast waters from ships or by working their way up the coast due to warming conditions or maybe even via the introduction of non-native oysters. The mix and relationships of the Bay's biota may change in ways that surpass speculation. The second we now appreciate in hindsight; human impacts to the very top consumers can have a cascading effect on the ecosystem as a whole.[47] This brings us to the role of living resource use in future Bay outcomes.

Living Resources

Clearly, the principal symbols of the Chesapeake Bay are its fish and shellfish. Blue crabs on license plates, rockfish on restaurant menus, and a common social inheritance in communities that grew out of their dependence on oysters. In large part, the success of our stewardship of the Chesapeake Bay will be measured by the number of crabs harvested, rockfish hooked, or oysters shucked. The extent to which we can meet societal expectations for the Bay's fisheries depends upon changes in the overall productivity of the system and in the regimes to manage exploited populations. These two areas are linked, but are not necessarily interdependent. While the abundance of exploited fish and shellfish populations reflects biological productivity and exploitation rates, the patterns of exploitation reflect not only underlying biology but also economics and other social factors.

While some species, such as the striped bass, have returned to the Bay in large numbers, others, such as oysters, have experienced major, and even catastrophic, decline. Still others, such as the blue crab, face intense fishing pressure that jeopardizes their sustainable harvest. Attempting to learn from past mistakes and better incorporate scientific information and analysis, the management of Bay fishery resources is becoming more comprehensive, with management plans in development for most species among responsible states. These plans often set precautionary harvest limits with some margin of safety to prevent the collapse or reduction of stocks. Whether these plans will prove successful remains to be seen—their implementation is within a charged political environment that must account for a variety of economic and cultural concerns, and they are based, by necessity, on imperfect scientific understanding. Furthermore, the scientific, management, and user communities will have to learn to adapt as they apply multi-species management called for in the *Chesapeake 2000* agreement.

Following Recent Trends, we can expect the recurrence of more fishery "crises" that track from one resource species to the next—from horseshoe crabs to blue crabs, from menhaden to striped bass—as we apply, at best, reactive management. The degraded health of the ecosystem would limit the production of valued species and cause wild variations in abundance. Largely unsustainable fisheries would thwart the full, long-term potential for the economic and social well-being of Bay communities. Fewer and fewer people would be able to make a living on what was Mencken's immense protein factory, and fewer consumers would enjoy the traditional cultural benefits of eating fresh Chesapeake Bay seafood.

Courtesy of NOAA

Through determined pursuit of Current Objectives, the situation would improve but only modestly. The production and carrying capacity of the Bay for living resources would increase, while better informed and committed management would allow for greater economic and social benefits by modulating boom-or-bust cycles and allowing more predicable and rational use of the resources.

The Feasible Alternatives scenario provides the opportunity for even greater significant improvement. At its base, improved fisheries conditions would result from greater ecological efficiency in the protein factory, even though the input of raw materials (primary production) would actually decline. Furthermore, through informed, forward-looking, and precautionary management, the use of living resources would become more sustainable and profitable. Of special significance would be a deepening understanding of multi-species interactions and new management regimes based on that knowledge—especially important, for example, in the relation between signature species such as striped bass and blue crab. Still, the resource base remains finite, and researchers and managers will have to allocate fisheries resources that provide the greatest economic and social benefit.

Scenario 1: Recent Trends

Primary Expectations:

- *In addition to continued contributions from agricultural and legacy sediment, additional sediment will enter the Bay and its tidal tributaries from land development, bypassing of the Susquehanna dams, and erosion of shorelines due to accelerated sea level rise. Coupled with the stimulation of plankton growth from increased nutrient loading, water clarity in much of the Bay is likely to decrease.*
- *Significant areas of tidal wetlands—their landward migration restricted—will be lost to sea level rise.*
- *Loadings of toxic contaminants will continue to decline slowly, but seafood consumption advisories will continue as a result of a legacy of contamination.*
- *As average nitrogen loadings creep back toward 1985 levels due to population growth and development, excessive phytoplankton production will continue. Anoxia and severe hypoxia will occur annually and be worse in high-discharge years.*
- *Submerged aquatic vegetation will contract, except in those tributaries remote from increased sources of sediments and nutrients.*
- *Bacteria and small phytoplankton will continue to dominate biological production while food chains supporting fish and crabs remain relatively inefficient.*
- *The biological diversity and resiliency of the Bay ecosystem will remain compromised and outbreaks of harmful algal blooms could increase.*
- *Fisheries crises will continue due to management operating in a reactive mode and the limited capacity of the ecosystem to produce valued resources.*

Scenario 2: Current Objectives

Primary Expectations:

- *More limited land development, improved stormwater management, and riparian buffer restoration will hold the line in sediment inputs from the watershed, but* *sediments mobilized from shoreline erosion will increase. Water clarity in some regions of the Bay and its tidal tributaries will increase as a result of decreased nutrient loadings, but not in areas near rapidly eroding shorelines.*

- *Significant areas of tidal wetlands will still succumb to sea level rise and restrictions to their landward migration.*
- *Loadings of contaminants will continue to decline a bit more rapidly, but impairments due to legacy contamination will also continue.*
- *Average nitrogen loadings will decline, eventually resulting in demonstrable reductions in excessive phytoplankton growth and severe hypoxia equivalent to levels seen in the mid-1970s. Except in the driest years, some anoxia will still occur.*
- *Submerged aquatic vegetation will expand in selected tributaries and approximately double in extent throughout the Bay.*
- *Benthic microalgae will play a greater role in the Bay's biological productivity, while bacteria and small phytoplankton will contribute less. Production of fish relying on these bottom resources will increase as food chain efficiency increases and preferred habitats expand.*
- *The biological diversity and resiliency of the Bay ecosystem will increase, buffering the Bay from extreme events and reducing the frequency and severity of harmful algal blooms.*
- *The socioeconomic value of the Bay's fisheries will increase modestly as the productive capacity of the Bay ecosystem increases and harvests are managed in a more sustainable manner.*

Scenario 3: Feasible Alternatives

Primary Expectations:

- *Highly restricted land development, substantial retrofitting of stormwater infrastructure, and removal of sediment from behind Susquehanna dams will result in real reductions of sediment loads from the rivers. Adaptive shoreline management strategies will target protection efforts and sustain the longevity of tidal wetlands, resulting in no net increase in the quantity of sediment mobilized by erosion. Water clarity in most regions of the Bay and its tidal tributaries will increase substantially due to decreased nutrient loadings.*
- *Tidal wetlands will remain close to present total acreage levels due to barriers to their landward migration along with active management to enhance soil accretion in deteriorating marshes.*
- *Practical applications of a zero-discharge ethic in industry, government, and society in general will lead to dramatically reduced loadings of many contaminants. Nevertheless, localized toxic effects will still occur despite our best efforts to manage inputs of legacy contaminants, contaminated sediments, and a continuing reliance on herbicides in agriculture.*
- *Average nitrogen loadings will decline to nearly one-half of those experienced toward the end of the 20th century, approximating levels not seen since the 1950s. This decrease will result in approximately proportional reductions in plankton productivity and substantial reductions in the extent of hypoxia, again back to levels typical of the 1950s. Significant anoxia will occur only during flood years.*
- *Submerged aquatic vegetation will expand in extent some four- or five-fold.*
- *Even though primary production in the Bay would decrease by one-third or more from reduced nutrient loading, production of many fish and crabs will actually increase due to expanded habitat availability and a doubling of the efficiency of food chains leading to higher consumers such as striped bass.*
- *The health of the Bay ecosystem—its useful production, diversity, and resilience—will improve even more. The biology of the Bay will be different from what it ever was—more like Bernie Fowler recollects than it is today, but still very different from the Bay that Captain John Smith experienced.*
- *Although supplies will perpetually fall short of growing demands, the living resources of the Bay will provide more sustained and profitable benefits to society from the improved health of the Bay as well as informed, forward-looking, and precautionary management of fishery resources.*

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Chesapeake Choices

Following European colonization and with the advent of the Industrial Age, the Chesapeake Bay became an estuary under intense and growing pressure. As American society moves further into the Information Age, new questions arise about just how much we will be able to shape the world of the future, and how much will be shaped by forces that remain beyond our control.

This report has put forward three potential scenarios for the future of the Chesapeake Bay. Clearly, projected outcomes differ markedly: from the inertia of continuing along the path of recent trends to the conscious decision to implement a range of feasible alternatives. As articulated in the separate chapters, the Chesapeake region of 2030 will see very different futures, depending on the course chosen at the beginning of the 21st century. A quick summary reveals the following findings.

Land Use And Development

If recent trends continue, the area of additional developed land in the Chesapeake watershed will increase by more than 60 percent by 2030, resulting in the loss of more than two million acres of forests and agricultural land. At the same time, impervious surface areas will increase by more than 25 percent in many sub-watersheds, further degrading the quality of streams throughout the central part of the Chesapeake watershed.

Continuing recent trends will also mean that nitrogen loads to the Bay will grow by over 30 million pounds per year—more than 10 percent of current nitrogen loadings—due to land development and population growth causing increased nonpoint-source runoff, more sewage discharge, and greater numbers of septic systems. Phosphorus loads will grow by about 3 million pounds per year—about 15 percent of current total loadings. Meanwhile, air quality will deteriorate as the vehicle miles driven continue to grow faster than the population and outpace improvements in auto emission technology.

If, however, feasible alternatives are put in place, creative growth management and strategic land preservation efforts could reduce the development of resource lands to less than 400,000 acres. The amount of impervious surface would also increase at a much slower rate than in the Recent Trends scenario.

Given a Feasible Alternatives scenario, nitrogen loads to the Bay from new development and population growth drop by 143 million pounds a year, less than half the level projected under the Recent Trends scenario. Strategically preserved and restored riparian buffers would also further

Skip Brown

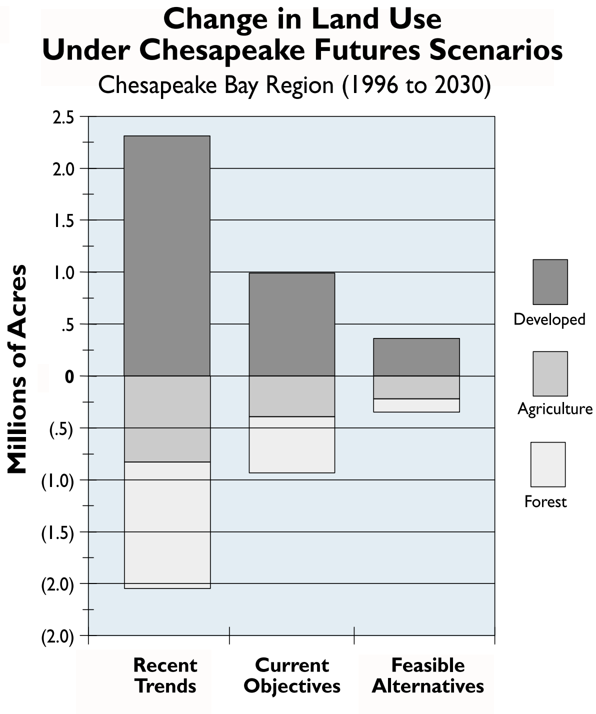

Figure 10-1.These bars illustrate how expanding development comes at the cost of farms and forests. The three scenarios represent significantly different choices when assessing future losses of such land.

ameliorate nonpoint inputs of nutrients from development. Loading rates from urban areas could decrease from an estimated 22 pounds per acre given recent trends to an estimated 19 pounds per acre with the use of feasible programs and technologies.

In addition, new and expanded public transportation networks would stabilize or reduce the use of automobiles. Improved emission control technologies, increased fuel efficiency, and alternative technologies (e.g., fuel cells) that reduce greenhouse gas emissions would all result in significantly improved air quality.

Forests

If recent trends continue, the increase in total Chesapeake basin forest cover witnessed during most of the 20th century will come to an end. Unfortunately, further wide-scale loss of forests will continue in or near metropolitan areas. In addition, forests will continue to become fragmented throughout the basin, with the most acute fragmentation near metropolitan areas and in the Coastal Plain and Piedmont provinces.

The conversion from farms to forest has driven the rebound in tree cover for several decades in portions of the Bay watershed. If recent trends continue, agriculture-to-forest conversion would likely decline, especially in the Ridge and Valley and Appalachian Plateau provinces, as fewer farms exist to go out of production.

While local riparian buffer restoration will continue to have positive impacts, their regional influence will remain marginal, given expected limited progress in reforesting a substantial portion of the more than 100,000 miles of streams and shoreline in the watershed. Current levels of restoration will likely be insufficient to offset increasing impacts of population growth and land development. With feasible alternatives, however, the region will likely see a greater increase in forest cover, including some stabilization within the basin's Coastal Plain and Piedmont. Some additions in riparian buffers and decreases in forest fragmentation would also occur.

Also important for the future of Bay watershed forests will be more active management of private forestland. Such management is essential since in the future private individuals will own many forest acres, either in large contiguous tracts, or (more likely) in small to mid-size parcels of several acres or more. Private forest landowners may not consider themselves forest owners or foresters; a concerted outreach effort focused on their needs and interests will help make them more responsible forest owners.

Along with improved management of privately owned forests, non-consumptive management of

Tim McCabe, USDA NRCS

public forests (e.g., uses other than timber harvesting) can ultimately help preserve these lands. Such uses include various forms of recreation and tourism that incorporate an appreciation of wildlife and the importance of wild lands for human relaxation and renewal.

These changes and improvements in forest management would increase the quality and quantity of forests through strong recognition of their environmental and economic importance. While this ethic may currently inform the management of some public lands, such as public parks or national forests, it has been less evident on private forestland.

The region should strengthen the economic infrastructure for forest products, including better product development and marketing, in addition to increased awareness and more active management. At present, too many trees leave the region to be made into value-added products, with a large share of the profits leaving the watershed.

With the development of more sophisticated social attitudes and improved management, including a willingness to receive immediate short-term instruction and assistance, the region will see an improvement in the function of forests and, therefore, in local and regional effects on nutrients and water quality. This change in forest management could have important long-term impacts on the watershed's forestlands and enable the region to respond to environmental change, such as shifts in climate and acid rain. In the end, the character and quality of forests in the watershed will help to determine the quality of waters entering the Chesapeake Bay.

Agriculture

If recent trends in land use continue, urban and suburban expansion will result in the loss of almost 700,000 acres of agricultural land. As noted above, with less farmland available to go out of production, agriculture-to-forest conversion could decline, particularly in the Ridge and Valley and Appalachian Plateau provinces. As already witnessed in many parts of the watershed, the demand for undeveloped land will raise prices, continuing to fragment existing farmland and alter the character of rural areas. Small farmers will find it difficult to make a living from traditional farming as global markets and other economic forces erode profits.


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Not all recent trends are bad, of course, and improvements in technology, as well as certain elements of globalization, will have some positive effects on agriculture. Given agriculture's present course, however, projected changes will push existing farms toward a greater dependence on intensive agriculture, with both positive and negative results (e.g., greater volume and efficiency, but also greater wastes and environmental impact). Without proper handling, increases in animal waste could cause significant problems for the current effort to reduce nitrogen and phosphorus inputs to local waterways.

If, though, feasible alternatives are put in place, land preservation efforts, combined with programs that support the economic sustainability of farming, would preserve open space and maintain viable rural communities. With the implementation of creative

Challenging the Will of the People

Bob Nichols, USDA NRCS

Transportation Habits

Americans are inextricably linked to their cars. Cars—and trucks and SUVs—are wonderful inventions, and allow remarkable freedom of movement. A dependence on cars and trucks carries with it a range of problems, however, including:

- Heavy use of resources, including finite fossil fuels.
- Release of harmful emissions, including not only poisonous gases (e.g., carbon monoxide) but also nitrogen oxides, which add a considerable burden to the Chesapeake system—estimated at about a quarter of total nitrogen loads.
- Increasing use of valuable land for more roads and highways, with concomitant noise pollution near those roadways.
- Rising rates of traffic-related accidents, injuries, and fatalities—as well as lost time, increased stress, and "road rage."

Technical solutions, such as fuel cells, may alleviate some of the resource-related problems associated with automobiles, as well as many of the harmful emissions. A more difficult problem may prove to be the development patterns that have evolved in concert with increased dependence on cars and trucks.

Development Patterns

In many parts of America, independent lifestyles form an integral part of the cultural fabric and often translate into large single-family homes on increasingly large lots. Such a lifestyle also fosters greater dependence on the automobile. Even apartment dwellers can experience a sense of freedom and autonomy when they hop in their cars and head for the open road. Unfortunately, they often find that open road clogged with traffic. One study estimated that Washington, D.C.-area motorists, for example, find themselves stuck in traffic jams an average of 76 hours each year.[1] Moving farther and farther from the aggravations of city life, the typical modern commuter spends hours in the car, and many dollars on gasoline and maintenance. While the populace may understand the economic and environmental benefits of cluster development and more centralized building patterns, they will not necessarily embrace such development. Key to changing the way we use the land will be the following:

- Departing from roadside strip development to the formation of small village centers for shopping and offices. Such development should take advantage of circular rather than linear designs, creating more appealing and walkable space.
- Making development more attractive. Shops and offices need not be ugly structures surrounded by a sea of asphalt. Parking garages integrated into developments and walkways linking buildings can de-emphasize the parking lot and re-emphasize walking and exercise.
- Bolstering designated growth areas. Rather than having growth areas serve as mere receptacles for increased density, planners can feature these areas as models, with improved infrastructure, design criteria, and protected parks and public spaces.
- Pursuing full-cost pricing for expensive far-flung infrastructure. Those who wish to have roads, electric lines, and other amenities carried out to previously undeveloped areas will have to bear a fair cost; otherwise, general tax revenues subsidize sprawl.

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Susquehanna River
The Susquehanna River is the largest river emptying into the Atlantic Ocean with its watershed fully contained within the borders of the United States. Originating in New York State, the Susquehanna slices through the center of Pennsylvania. Shallow and essentially non-navigable for most of its length, this massive waterway drains a primarily agricultural watershed, missing influential urban and industrial centers of both the east and the west but passing through coal and iron ore mining as well as timber harvesting areas. While this no doubt relieves the river of some contaminant burdens associated with big industry, it also means that it lies largely outside the traditional spheres of political clout.[2]

Because of its sheer size, the Susquehanna dominates the Chesapeake-area landscape from a hydrologic point of view. Comprising about 43 percent of the Bay's watershed, the Susquehanna contributes about 40 to 70 percent of the nitrogen entering the Bay depending on annual flow.[3] The nutrients coming down the Susquehanna flow primarily from farm fields.

A key challenge in the restoration of the Chesapeake is reducing the flow of sediment and nutrients down the Susquehanna, without placing an unfair burden on the farmers trying to make a living there. While reducing sediment loads, experts will also have to solve the problem of dams, such as the Conowingo, that have trapped sediment for decades and will soon reach their capacity as sediment dikes. Not only will more sediment reach the Bay once this limit is reached, but subsequent large storms will likely scour some of the trapped sediment and send a slug of dirt and nutrients into the upper Bay. It will be difficult, if not impossible, to restore the Chesapeake Bay without a sustained focus on the Susquehanna River.


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Economics
Perhaps the greatest challenge of all will be money. What will be the health of U.S. and regional economies in the year 2030? What will the Gross Domestic Product be? Productivity? Unemployment rate? Will Americans feel that they can afford environmental programs and restoration efforts? Central to this question will be what Americans are willing to pay for. For example, some estimates suggest that in Maryland alone, upgrading aging waste treatment plants will cost some $4.3 billion in the next two decades or so.[4] Will citizens be willing to pay increased fees for advanced waste and stormwater treatments? Will they pay more for more environmentally friendly homes and automobiles? If consumers "vote with their dollars," will they opt for fancier cars, larger homes, more perfect lawns—or for cleaner air, healthier forests, a restored Bay? What will be their sense of community?

Clearly, we must continue finding ways to blend economics and environment, to couple healthy social systems with healthy ecosystems. If the experiences of some countries—in Eastern Europe, for example—are any indication, ignoring the environment for short-term economic gain will prove more costly in the long term. Whether or not Bay-area residents will agree as we approach the year 2030 remains to be seen, but legislation at the federal and state levels, especially since the 1970s, has indicated a powerful will on the part of the citizenry to protect the environment from despoliation, even as the country experienced some of the highest levels of production and prosperity in its history.

programs, fewer than 300,000 acres of agricultural land would be lost to new development. Technological advances and improved policies would resolve animal waste problems, improve efficiency, and provide financial planning and business management aid to farmers. Beyond this, various economic and environmental policies, along with behavioral changes, could further ensure the existence and success of agriculture in the watershed.

If farming can remain viable in the Bay's drainage basin, the region will retain some of its rural character, offering distinct areas for rural and urban living, while avoiding the threat of sprawling sameness across the watershed.

Kent Mountford

Chesapeake Bay and its Ecosystem

The choices that individuals and society at large make at the beginning of the 21st century will ultimately determine the condition of the Bay ecosystem—possibilites that range from worse than its low point in the 1990s to a state approximating that of the 1950s. Population growth and development could easily reverse recent gains. If, however, we decide to fully implement feasible alternatives, we could see a Bay with much clearer water, up to five times more submerged aquatic vegetation, little or no anoxia in bottom waters, sustainable production of valued fishery resources, and improved biological resilience to future shocks.

Even steadfast efforts to fully implement the commitments made during the 1980s and 1990s could well result in only modest improvements. To achieve the full benefits listed above will require application of improved technologies, active environmental restoration, and a societal commitment to spread more slowly and carefully across the land. The landmark *Chesapeake 2000* agreement sets us on that course by posting some ambitious goals, but many blanks remain on how to reach these goals. While it is difficult to imagine how many of the *Chesapeake 2000* goals can be met in less than ten years, we hope that *Chesapeake Futures* provides some inspiration through additional ideas founded on scientific understanding. Furthermore, the need for environmental management will not end, but continue into the future. By 2010, we will have learned more about the responses of the ecosystem to our efforts, unanticipated surprises will have emerged, and new technologies will have come online. We must fully account for all of these as we carry on toward 2030 and beyond.

Final Thoughts

The primary question, when considering the Bay's future, centers on whether or not those who live in the watershed will be able to reverse recent trends—of the past 50 years in particular—or whether growing population, unchecked resource consumption, and a casual disregard for the natural environment will overwhelm our attempts to restore the Bay and its fisheries and wildlife.

The choices faced by the region are far more than rhetorical. Consider, for example, the well-known examples of DDT and lead-treated gasoline. The effect of DDT on wildlife, including bald eagles and ospreys, is now well understood. The danger of even low levels of exposure to lead, especially for young developing minds, has also become evident. At the time that authorities threatened to ban DDT and lead-treated gasoline, however, some questioned the science behind these decisions and warned of dire economic consequences. Looking back, it appears clear that not only were such bans worth the economic cost, but that not outlawing these substances would have carried greater costs than our society would have wanted to bear.

When the landmark study of the Chesapeake Bay began in 1976, U.S. Senator Charles "Mac" Mathias—largely credited with gathering support to fund the study—wondered if large industries such as Bethlehem Steel would prove to be the primary cause of the Bay's decline.[5] After years of research, however, it became apparent that in addition to toxic compounds from business and industry, the Bay faced an onslaught from the watershed as a whole—from sediment and nutrients washed from farm fields and construction sites to nutrients finding their way to the Bay through waste treatment plants, septic systems, and groundwater.

With the exception of air pollution from the Ohio River Valley and other areas outside the region, most of the Bay's problems begin with those who live and work in the Chesapeake watershed. Although the diffuse nature of this pollution poses significant difficulties for its control, individuals can help in several ways. Waters entering the Bay can be much cleaner, for example, if individual farmers adopt more rigorous programs to limit overuse of fertilizers, herbicides, and pesticides and to control animal waste; if individual homeowners learn to use less fertilizer and pesticide on their lawns; and if urban and suburban dwellers pay a little extra for wastewater and stormwater treatment.

Ron Nichols, USDA NRCS

Choices for the Chesapeake

This report began with a look at the past, and at the evolution of change to the Bay since the Colonial period. It ends on a hopeful note, mindful of how improved technologies—despite their tarnished reputation—have also addressed difficult environmental problems. One thinks of the building of waste treatment systems, such as Baltimore's Back River plant in 1912, which not only reduced noxious odors but also helped to stop the spread of human pathogens that caused outbreaks of typhoid and other dangerous diseases. More recently, the adoption of advanced wastewater treatment technologies by waste treatment plants has reduced the input of nitrogen and phosphorus from municipal sewage. The Chesapeake Bay Program predicts that by 2005 almost 131 major municipal wastewater treatment facilities will have BNR or NRT, treating about 63 percent of the wastewater flow in the region.[6] The ultimate significance of this technology implementation will depend on the actual levels of nitrogen removal achieved.

Other technological advances have helped to scrub smoke stacks, filter water, and treat chemical wastes. Most of these extremely important advances have taken place in industry, or in large municipal systems, such as wastewater or drinking water plants. A key challenge for the coming decades will be whether public policies and private practices can take advantage of such technological advances, along with creative thinking and wise leadership, to further reduce the flow of nutrients, sediment, and toxic compounds into the Bay and its tributaries from the many diffuse nonpoint sources throughout the watershed.

Of the three scenarios in this report, only Feasible Alternatives appears to offer considerable promise for reversing the negative trends of the post-World War II period. A significantly cleaner Bay, with improved bottom habitat and increased oxygen levels, will likely result from more pronounced and creative efforts in several areas. For example:

- Implementing advanced nutrient removal at all major waste treatment plants.

- Putting progressive agricultural practices into effect, such as precision subsurface nutrient application, cover crops, and effective buffers.
- Designing new development—as well as retrofitting existing development—in ways that will save land area and decrease harmful runoff.
- Managing fisheries with a multi-species, ecosystem-based approach that accounts for the Bay's overall food web and the health of key habitats.
- Taking advantage of new technologies, from fuel cells to solar energy, to reduce the combustion of fossil fuels and the emissions that result.
- Improving mass transit in meaningful ways, reducing congestion on the region's highways. and decreasing demands on fossil fuels and other finite resources.
- Undertaking large-scale, proactive restoration efforts, such as building high-relief oyster reefs and, in concert, extensive underwater grass beds to improve bottom habitat and to create positive feedback loops in the Bay's nutrient and oxygen cycles.

In conclusion, moving forward with a range of innovative and creative techniques is necessary if we are to reach the fundamental goal of restoring the Chesapeake Bay's clarity and productivity. Anything less will result in incremental improvements that will likely be overwhelmed in the long term by the deleterious effects of unplanned or poorly managed land use development. The projected outcomes are fairly clear. The choices, while challenging, are ours alone to make.

Endnotes

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[2] Stranahan, S. 1993. *Susquehanna: River of Dreams*. Baltimore, MD: The Johns Hopkins University Press, p. 284ff. Stranahan notes that a statewide response to the river's problems has at times been difficult in Pennsylvania, with its 2,600 local governments.

[3] U.S. Geological Survey. 1995. Fact Sheet FS-055-95.

[4] Recent estimates by the Chesapeake Bay Commission hold that improving Bay water quality will cost some $11.5 billion watershed-wide, an effort necessary to remove the Bay from the federally imposed list of "Impaired Waters." Chesapeake Bay Commission. 2003. *The Cost of a Clean Bay: Assessing Fundings Needs Throughout the Watershed*. Annapolis, MD.

[5] Personal interview with Senator Mathias taped by the Maryland Sea Grant College, 1993.

[6] Chesapeake Bay Program website, *www.chesapeakebay.net*. As noted earlier in this report, Delaware, New York, and West Virginia have signed memoranda of understandings and the Chesapeake Bay Program now includes these states (in addition to data from facilities in Maryland, Pennsylvania, Virginia, and Washington, D.C.) in its calculations.

CHESAPEAKE FUTURES
Choices for the 21st Century

The changing history of land use in the watershed has already had observable impacts on the Bay, and how the landscape of the Chesapeake evolves over the next 30 years will in large measure determine the Bay's future. There are four key drivers that will paint the landscape portraits of the 21st Century: climate, discussed in the previous section, development, agriculture and forestry, and land conservation. In order to understand changes in agriculture and forestry, it is first necessary to examine patterns of development and effects of growth throughout the watershed.

As seen in the previous section [changing times], the coastal regions of the United States are experiencing some of the fastest population growth rates in the country, and the Mid-Atlantic is no exception. In the Chesapeake, an average of 334 new people move into the 64,000 square mile watershed each day (CBP). According to the Natural Resources Inventory, 128,000 acres of "natural" land are converted to urban and suburban uses every year. (NRI, 2001)

Of greater concern, however, are changes in the way people live. Many metropolitan areas throughout the United States have witnessed an exodus of tax-paying residents, as people move out of urban areas into the suburbs. Baltimore, Washington, and Richmond have experienced population losses for decades (ref-Census), as their surrounding, traditionally rural counties swell with new residents. Out-migration from the urban core to the suburban fringe, conversion of natural lands into low-density unplanned development, increased reliance on automobiles, and strains on public infrastructure as a result of expansion all have led to the phenomenon known as sprawl.

The Sierra Club rated Washington, D.C. as the 3rd most sprawl-threatened large city in the U.S. (SC) Over the past 16 years, the number of houses has increased more than twice as much as the population.

Chesapeake Bay Program

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