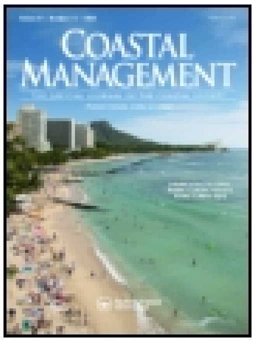

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Ecosystem Service Benefits of a Cleaner Chesapeake Bay

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ABSTRACT
Information on the economic benefits of natural resource improvement is an important, yet often overlooked, consideration in environmental decision-making. In 2010, the Environmental Protection Agency established the Chesapeake Bay Total Maximum Daily Load (TMDL) that set regulatory limits for nitrogen, phosphorus, and sediment needed to restore the Chesapeake Bay. Meanwhile, the Bay jurisdictions developed implementation plans to achieve these limits. Environmental benefits of achieving the TMDL would accrue due to on-the-ground changes in land use and land management that improve the health, and therefore productivity, of land and water in the watershed. These changes occur both due to the outcomes of achieving the TMDL (i.e., cleaner water) and as a result of the measures taken to achieve those outcomes. This study quantified these changes, then translated them into dollar values for various ecosystem services, including water supply, food production, recreation, and aesthetics. We estimate the total economic benefit of implementing the TMDL at $22.5 billion per year (in 2013 dollars), as measured as the improvement over current conditions, or at $28.2 billion per year (in 2013 dollars), as measured as the difference between the TMDL and a business-as-usual scenario. These considerable benefits should be considered alongside the costs of restoring the Chesapeake Bay.

KEYWORDS
benefit-transfer; Chesapeake Bay; economics; ecosystem services; water quality

Background

The Chesapeake Bay is the largest estuary in the United States, with a 64,000-square-mile watershed that includes parts of six states and the District of Columbia. Home to more than 17 million people and 3,600 species of plants and animals, the Chesapeake Bay watershed is truly an extraordinary natural system marked by its rich history and astounding beauty. These natural resources provide valuable and quantifiable economic goods and services, e.g., beautiful scenery that promotes recreation, tourism, and some of the country's highest property values; food like fish, crabs, clams, and oysters; and flood protection and erosion control. Like many estuarine and coastal systems, however, the Chesapeake Bay is degraded.

Every summer, the main stem of the Bay and several of its tributaries are plagued by dead zones, where not enough dissolved oxygen (DO) exists to sustain many forms of aquatic life.

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Color versions of one or more of the figures in the article can be found online at www.tandfonline.com/ucmg.

On average about 60% of the Bay and its tidal rivers have insufficient levels of oxygen (Chesapeake Bay Program 2012). In addition, water clarity in the Chesapeake Bay has declined so that underwater grasses, critically important as fish and crab habitat, have decreased to roughly 20% of historic levels.

In response to these water-quality problems the Environmental Protection Agency (EPA) promulgated a Total Maximum Daily Load (or TMDL) for the Chesapeake Bay, in December 2010 (USEPA 2010). The Bay TMDL set pollution limits for nitrogen, phosphorus, and sediment in the Chesapeake Bay needed to restore healthy levels of DO and water clarity. Meanwhile, the six Bay states and the District of Columbia released Watershed Implementation Plans (WIPs) describing the actions they would take to meet those limits by 2025.

Together, the TMDL and the states' implementation plans comprise a Clean Water Blueprint for the Chesapeake Bay, its rivers and streams. (We refer to the TMDL and plans collectively as the "Blueprint" throughout.) It will provide watershed-wide ecological benefits as well as economic benefits, since ecosystems that become more productive will supply more goods and services that have value to people. Some of those benefits are direct, such as the crabs, fish, and crops that have traditionally been enjoyed in abundance. Others are less obvious, such as trees that filter pollution out of our air and water, lands that slow or stop floods, and wetlands that reduce the impacts of storm surges created by increasingly frequent extreme weather events. No matter how easy or difficult to see or measure, all of these economic benefits provided by ecosystem services are relevant to consider as part of the value secured by the Blueprint.

With this study, we aim to provide three critical pieces of ecosystem services information. First, we estimate the dollar value of eight ecosystem services originating—and largely enjoyed—in the Chesapeake Bay watershed region, prior to the Blueprint (i.e., in 2009). Second, we estimate of the value of the same services, but for two future scenarios. In the "Blueprint" scenario, the Blueprint is fully implemented, land conversion (to urban uses) slows, forest areas expand, wetland loss slows, and land management changes reduce pollution loading. All of this leads to improvements in water quality and more ecologically and economically productive ecosystems. In the "Business as Usual" (BAU) scenario, the Blueprint is not fully implemented. Land development and pollution loading continue according to current forecasts, the result is lower water quality and poorer ecosystem service productivity. Third, we calculate the differences between the ecosystem service values under the Baseline and Blueprint scenarios, and between the values under the BAU and Blueprint scenarios.

Ecosystem services framework

The idea that people receive benefits from nature is not new, but "ecosystem services" as a term of art describing the phenomenon is more recent, having emerged in the 1960s (Reid et al. 2005). Of several available definitions, Gary Johnson of the University of Vermont provides a definition that emphasizes that ecosystem services are not necessarily things—tangible bits of nature like a cup of water, a bushel of crabs, or a sunset—but rather the impacts on people of those bits of nature. To wit: Ecosystem services are the effects on human well-being of the flow of benefits from an ecosystem endpoint to a human endpoint at a given extent of space and time (Johnson 2010).

This flow, applied in this article, is illustrated in Figure 1, which shows the ecosystem services cascade in the form of a "concept map" of propositions, such as "Core Ecosystem Processes produce Beneficial Ecosystem Processes," and "Beneficial Ecosystem Processes

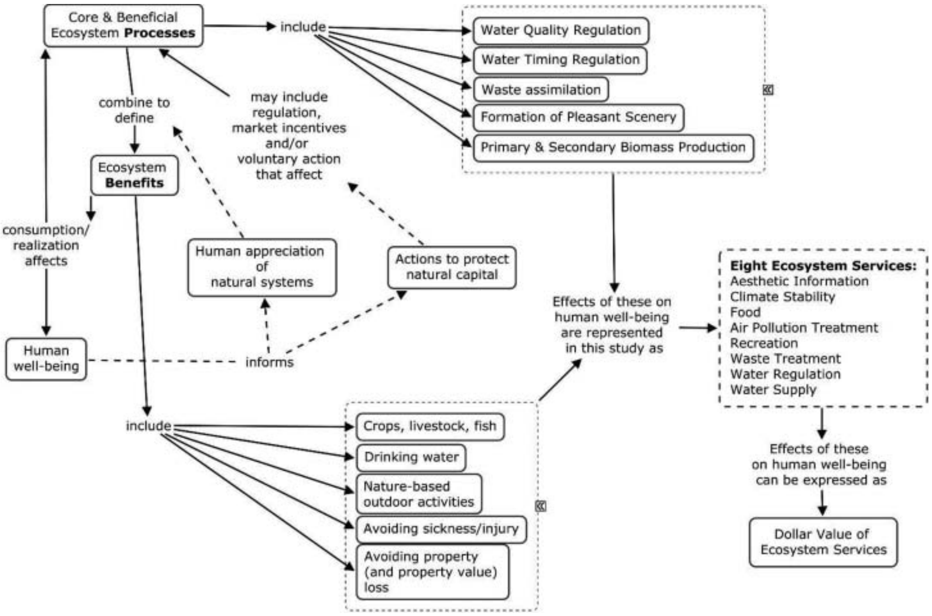

Figure 1. Generation of ecosystem services and estimation of their value in the Chesapeake Bay watershed.

combine (with human appreciation of natural systems) to define Ecosystem Benefits." The concept map also illustrates what happens after the ecosystem creates benefits. Namely, people consume or use ecosystem benefits and that, in turn, both enhances human well-being and affects core and beneficial ecosystem processes.

For example, human well-being informs both our appreciation of natural systems (drinking a glass of water makes us appreciate clean water, for example) and our actions to conserve or enhance the underlying conditions (often called "natural capital") that sustain ecosystem processes (Farley 2012). The Clean Water Blueprint and other remedial actions sit squarely within this system. They are elements in the positive feedback loop from ecosystem benefits through actions all the way back to a better chance for the ecosystem benefits to continue.

Select ecosystem services: Relation to the Blueprint

Studies focused on valuing natural capital often include 20 or more different ecosystem service categories, for example, Costanza et al. (1997, 2014), Esposito et al. (2011), Swedeen and Pittman (2007) and Flores et al. (2013). In the context of the Blueprint and Chesapeake Bay water quality, however, we focus on eight ecosystem services that we believed would be the most affected by implementing the Blueprint: food production (crops, livestock, and fish), climate stability, air pollution treatment, water supply, water regulation, waste treatment, aesthetics, and recreation. These ecosystem services play out in the Chesapeake region in the following ways.

Food production

In 1940, H. L. Mencken called the Chesapeake Bay an "immense protein factory," highlighting the food production capacity of the Bay and its tidal waters. Although some species, such as oysters, have declined markedly since then, the Chesapeake's fisheries industry, including both shellfish and finfish, is still significant. Agricultural lands account for approximately 22% of the Chesapeake watershed (USEPA 2010) and the value of Chesapeake Bay region agricultural sales in 2007 was about $9.5 billion (Conservation Effects Assessment Project 2011). In addition, the rivers, streams, and wetlands throughout the watershed provide food to residents of the Bay watershed primarily through opportunities for fishing and hunting.

In the tidal areas of the Chesapeake Bay, improvements in DO and underwater grasses mean cleaner water that is more conducive to finfish and shellfish production. For example, DO concentrations have been associated with higher blue crab harvests (Strand and Mistiaen 2003), disease resistance in oysters (Anderson et al. 1998), and more recently with the number and catch rates of demersal fish species in the Chesapeake Bay (Buchheister et al. 2013). Increases in DO will also lead to greater benthic biomass production which in turn provides food for upper trophic level species like crabs and fish (Diaz, Rabalais, and Breitburg 2012). Underwater grasses are critical to protect blue crabs and larval finfish from predation (Beck et al. 2001; Heck, Hays, and Orth 2003).

Implementing the Best Management Practices (BMPs) called for in the Blueprint means more fertile and productive agricultural land. For example, increased implementation of practices like conservation tillage and cover crops will lead to better soil water retention, making cropland more productive and less susceptible to damage from droughts. A study in Pennsylvania found that under severe drought conditions, crops grown with these practices out-yielded conventionally grown crops by 70–90% (Lotter, Seidel, and Liebhardt 2003). To the contrary, moderately eroded soils are capable of absorbing only 7–44% of the total rain that falls on a field. As a result, eroded soils exhibit significant reductions in crop productivity (Pimentel et al. 1995). Many conservation practices also build soil organic matter, which has a significant positive effect on crop yields (Pimentel et al. 2003). Finally, healthier streams and wetlands also add to food production benefits.

Water supply

Various habitats within the Chesapeake watershed help filter, retain, and store freshwater, contributing to both the quantity and the quality of our water supply. Forests and other vegetation filter rain into ground water and surface waterways from which residents of the Chesapeake watershed receive water for drinking, agriculture, and industry. Approximately 75% of the people living in the Bay watershed rely on surface water supplies for their drinking water (Sprague et al. 2006).

The Blueprint will result in more land retained in land uses in which water retention, filtering, and aquifer recharge are effective (forests, urban open space). Implementation of BMPs on urban and agricultural lands will increase infiltration and groundwater recharge and reduce sediment load. Less sediment and other pollutants reaching water supplies means cleaner drinking and processed water and reduced water treatment costs for residential and industrial users, including breweries and soft drink and water bottlers.

Water flow regulation

The amount and timing of water flow in the rivers and streams that feed the Chesapeake Bay depends, in large part, on the storage capacity of the watershed. Impervious surfaces like roads, rooftops, and sidewalks stop precipitation from infiltrating into the soil. Instead, the rainwater washes rapidly into storm drains and stream channels. These high peak flows contribute to flooding and erosion of stream banks, which add additional pollution to the region's waterways. In addition, the same process that causes flooding during rain events leaves the stream dry during other times of the year. In the Bay region, groundwater contributes a high percentage of stream flow (Lindsey et al. 2003). Thus, if rain is not allowed to percolate into the soil to recharge groundwater, stream flows will be lower, especially during dry times. For example, a study of the Gwynns Falls watershed in Baltimore indicated that heavily forested areas reduced total runoff by as much as 26% and increased the low-flow volume of streams by up to 13% (Neville, 1996).

Increases in forest cover, streamside grasses, and forests, and the implementation of urban practices focused on infiltration and retaining natural hydrology will mean the landscape will have greater capacity to absorb and then slowly release water into streams and rivers and the Chesapeake Bay. This increase in water regulation capacity will mean reduced flood damage and more natural stream flows.

Waste treatment

In the tidal portions of the Chesapeake Bay, wetlands, underwater grasses, oysters, and other sedentary biota play a crucial role in removing nitrogen, sediment, and/or phosphorus from the water. For example, marshes of the tidal fresh portions of the Patuxent River remove about 46% and 74% of the total nitrogen and phosphorus inputs, respectively (Boynton et al. 2008). The pollution removal capacity of oysters is widely acknowledged. Oysters indirectly remove nitrogen and phosphorus by consuming particulate organic matter and algae from the water column (Newell et al. 2005). In addition, some of the nutrients are deposited by the oysters on the surface of sediments and under the right conditions, the nitrogen can be transformed via microbial-mediated processes into nitrogen gas that is no longer available for algae growth (Higgins, Stephenson, and Brown 2011). In addition, microorganisms in sediments and mudflats can also breakdown human and animal wastes and even detoxify chemicals, such as petroleum products.

In the non-tidal portions of the Bay regions, forests, and wetlands are particularly effective at capturing and transforming nitrogen and other pollutants into less harmful forms. In addition, not only do forest buffers filter and prevent pollutants from entering small streams, they also enhance the in-stream processing of pollutants, thereby reducing their impact on downstream rivers and estuaries (Sweeney et al. 2004).

Increased dissolved oxygen and underwater grasses result in more effective nutrient cycling and regulation in the tidal parts of the Bay. For example, Kemp et al. (2005) estimate that if underwater grasses in the upper Bay were restored to historic levels, they would remove roughly 45% of the current nitrogen inputs to that area. Indirect benefits of increased oyster production also will contribute to enhanced processing and removal of particulates and nitrogen. Maintaining and improving the health of forests, wetlands, and streams throughout the watershed will increase their ability to process and transform nitrogen and other pollutants. Furthermore, increases in streamside grasses and forests and the implementation of urban practices like green roofs and rain gardens will mean greater pollutant removal and processing, not just for nutrients and sediments but also for other contaminants like agricultural pesticides, petroleum products, and bacteria.

Air pollution treatment

Air pollution treatment refers to the role that ecosystems play in absorbing and processing air pollutants, such as nitrogen oxides, sulfur dioxide, particulates, and carbon dioxide. Trees are particularly effective at removing airborne pollutants. For example, the urban tree canopy in Washington, D.C., covers less than a third of the city, yet removes an amount of particulate matter each year equal to more than 300,000 automobiles (Novak et al. 2006). Scientists estimate that the 1.2 million acres of urban forest in the Chesapeake region collectively remove approximately 42,700 metric tons of pollutants annually (Sprague et al. 2006).

Sequestration of carbon dioxide is also an important function of the region's habitats. It is estimated that Chesapeake forests are currently storing a net 17 million metric tons of carbon annually (Sprague et al. 2006). In addition, agricultural practices like conservation tillage, cover crops, and riparian buffers are all effective at removing carbon dioxide from the atmosphere. Agriculture as a whole, however, is a net emitter of many gases, so there are no values for agricultural air pollution treatment ecosystem services counted in this study. A recent study has also documented the significant carbon sequestration benefits of tidal wetlands (Needelman et al. 2012).

Healthier forests and wetlands are able to better absorb and process airborne pollutants and increase carbon sequestration rates (Bytnerowicz et al. 2013). Increased tree canopy, particularly in urban areas, will lead to improved air quality, increased public health benefits, and reduced health care costs. For example, the estimated value to Lancaster City, Pennsylvania and its citizens of reduced air pollutant-related impacts is more than $1 million per year from implementing practices in their Green Infrastructure Plan (USEPA 2014).

Climate stability

Climate stability refers to the influence land cover and biologically mediated processes have on maintaining a stable environment. In urban areas, trees and other vegetation reduce the "heat island" effect. In Baltimore, the difference in summer temperatures between the inner city and a rural wooded area is commonly 7°C (12°F) or more (Heisler 1986). In addition, trees in both urban and suburban areas provide shade and act as wind breaks to surrounding dwellings, reduce indoor temperatures in the summer, and increase them in the winter, and in doing so reduce energy use and costs. Shaded houses can have 20–25% lower annual energy costs than the same houses without trees.

Implementation of the Blueprint will increase and improve habitats that can absorb and more slowly release solar radiation and increase evapotranspiration that helps with cooling. In urban and suburban areas, more tree canopy, open spaces, and green roofs will reduce the heat island effect and lower air temperatures, resulting in lower energy use associated with space cooling and human health benefits, such as reductions in the number of heat-related illnesses and associated health care costs (Philadelphia Water Department 2009).

Aesthetic value

Aesthetic value derives from our appreciation of and attraction to natural, scenic land and waterways (de Groot, Wilson, and Boumans 2002). The existence and popularity of state parks, state forests, and officially designated scenic roads and pullouts in the Chesapeake

Bay watershed attest to the social importance of this service. From an economic perspective, beautiful scenery and healthy natural features areas attract people to live, work, and recreate in a region and convey quantifiable aesthetic benefits to individuals and communities. A study in Baltimore, Maryland, for example, revealed that as tree cover increases, residents become more satisfied with their community. The study also showed that when neighborhood forest cover is below 15%, more than half of the residents consider moving away (Grove 2004). Other studies substantiate the idea that degraded landscapes are associated with economic decline (Power 1996).

Reduced sedimentation, increased dissolved oxygen, and increased underwater grasses and water clarity indicate enhanced habitat health and aesthetics in tidal areas and are likely to lead to greater enjoyment of scenic amenities by residents and visitors. These would translate into higher property values, more future visits, and other positive outcomes. In Delaware, for example, property values within 1,000 feet of the shore have been projected to increase by eight percent due to improved water quality in the Chesapeake Bay watershed (Kauffman et al. 2011b). Farther inland, urban green space creates more pleasant scenery and a more desirable living environment, along with higher economic value (reviewed in McConnell and Walls 2005).

Recreation

The Chesapeake Bay region's residents and visitors experience the quality of the environment through sport fishing, swimming, hunting, boating, birding, hiking, and other activities. In 2009, tourists spent $58 billion in Maryland, Pennsylvania, Virginia, and Washington, DC, and these dollars supported some 600,000 jobs and contributed $14.9 billion in labor income and $9.4 billion in taxes (Stynes 2012). Similarly, in 2001 more than 15 million people fished, hunted, or viewed wildlife in the Chesapeake region's forests and contributed approximately $3 billion to the regional economy (Sprague et al. 2006). In Virginia alone, it is estimated that 642,297 people use the Virginia Birding and Wildlife Trail annually and the total economic effect of the trail in 2008 was $8.6 million (Rosenberger and Convery 2008).

Improvements to water quality in the tidal portions of the Chesapeake will result in greater enjoyment of and participation in water-based recreational activities (Bockstael, McConnell, and Strand 1988). Lipton and Hicks (2003) found that an increase in dissolved oxygen will dramatically increase striped bass catch rates, resulting in more pleasurable fishing experiences. A Virginia study found that "water quality, fishing quality, and other environmental factors" ranked among the most important criteria that influence boaters' decisions on where to keep their boats (Lipton, Murray, and Kirkley 2009).

BMP implementation on land and improved water quality would indicate more biologically productive natural areas, and cleaner, more productive landscapes provide a higher quality recreational experience. Riparian buffers and wetlands contribute to recreational fishing services by providing improved aquatic habitat and healthier aquatic communities that lead to increased fishing opportunities for gamefish popular among the region's anglers (Hairston-Strang 2010; "The restoration of Lititz Run: Despite black marks, waterway benefits from groundbreaking inroads by a local coalition" 2008). Maintaining and improving forest health will also increase opportunities for hunting and bird-watching (Sprague et al. 2006).

Ecosystem service benefit estimation

Our estimation of the economic benefits of the Blueprint are rooted in anticipated changes in the underlying health of that natural capital, and changes in the mix of forest, wetlands, and other land uses natural habitats that will result from implementing the Blueprint. Attainment of the goals of the Blueprint will directly produce benefits associated with cleaner water, including more productive fisheries and an improved source of aesthetic and recreational value. In addition, because the Blueprint will be achieved through a variety of actions to protect and restore critical natural capital—such as expanded forest coverage, improved streetscapes, restored wetlands, and more input-efficient agriculture—the Blueprint will also generate "co-benefits" like improved air quality, reduced flooding, and increased food production that also have economic benefits.

One widely used method for estimating the dollar value of ecosystem services is the "benefits transfer method" or "BTM." Called "the bedrock of practical policy analysis" when primary data collection is impractical (OECD 2006), BTM takes a benefit estimate calculated for one set of circumstances and transfers that benefit to another set of reasonably similar circumstances. As Batker et al. (2010) put it, the method is very much like a real estate appraiser using comparable properties to estimate the market value of the subject property. The key is to select "comps" that match the circumstances of the subject area as closely as possible.

Typically, comps are drawn from studies of the value of various ecosystem services from similar land cover types. So, for example, if the source study includes the value of wetlands for recreation, one might apply per-acre values from the source wetlands to the number of acres of wetlands in the subject area. Furthermore, it is important to use source studies that are from regions with underlying economic, social, and other conditions that are similar to the subject area.

Careful as one may be to select appropriate comps, estimates coming from the benefits transfer method must be understood to be an approximation of the true value of ecosystem services in the subject region. Thus, the estimates of ecosystem service value presented below are certainly different from what the actual values would be if we could observe and measure them directly. However, we submit that the enhanced BTM-based estimates developed here are useful as a first approximation of the magnitude of those benefits.

Full implementation of the Blueprint will be challenging. It will require significant additional investments in pollution reduction measures, enforcement of existing laws and regulations, innovation, and more. Hence, garnering support of elected officials and the public for clean-up efforts is key. This study will provide an idea of the value provided by the Chesapeake watershed and of the change to that value from implementing the Blueprint that we hope will inform future policy decisions.

Methods specific to this study

Following Esposito et al. (2011) and Esposito (2009), we employ a four-step process to evaluate the ecosystem service value of the Chesapeake Bay Watershed and the benefits (increment to value) associated with the Blueprint. Details can be found in Phillips and McGee (2014).

Assign land and water in the Chesapeake Bay watershed to one of seven land uses (forest, wetlands, open water, urban open space, other urban land, agriculture, and other) based on the Chesapeake Bay Land Change Model (CBLCM) (P. Claggett, personal communication, phone and email, December 23, 2013 re: NLCD and Chesapeake Bay land cover adjustments; Johnston 2014a, 2014b) and remotely sensed land cover data (Fry et al. 2011). Acreage is taken from spatial tabular data covering the seven land uses in 2,862 “land-river segments” (portions of sub-watersheds lying in different counties).

Land use is estimated for each of three scenarios defined as follows:

Baseline: Land use as it was estimated in 2009, with various best management practices (BMPs) then in place.

Blueprint: Land use projections to 2025, based on historic trends and with the same 2009-era BMPs still in place plus full implementation of the Phase II Watershed Implementation Plans developed by the States pursuant to the Blueprint.

Business as Usual (BAU): Land use projections to 2025, based on historic trends and with practices expected to be implemented with or without the Blueprint due to state or federal regulations.

Table 2 shows acreage by land use for each scenario.

- Establish indicators of baseline ecosystem health/productivity for each river segment in the watershed to estimate the current value of the Chesapeake Bay watershed ecosystem prior to implementing the Blueprint. For the non-tidal portion of the watershed, our proxy for ecosystem health is derived from an existing index of “wildness” that reflects the relative lack of pollution and other human disturbance for each location in the Chesapeake Bay watershed (Aplet 1999; Aplet, Thomson, and Wilbert 2000; Aplet, Wilbert, and Morton 2005; Wilbert 2013). We compute this proxy at the river segment level of geographic detail. For the tidal waters of the Bay itself, the proxy is the degree to which the river segment has attained the DO standard.
- To account for the effect of actions taken (or not taken) under the states’ WIPs that would likely improve ecosystem service health/productivity in the Blueprint and

Table 1. Summary of land use and health indicators for Baseline, Blueprint, and Business as Usual scenarios.

	Scenario		
Model Inputs	Baseline (2009)	Blueprint	Business as Usual
Land Use area Tidal Segments Open Water	Estimated from GIS and National Land Cover Database	No change	No change
Health Tidal Segments Open Water	2009 modeled estimates of DO attainment	Improvement to 100% attainment of DO criteria	No change from Baseline
Land Use Area Non-tidal Segments All Land Uses	2009 estimates of land use	Projected changes in land use by 2025 due to Blueprint implementation (i.e., with Phase II WIPs)	Projected changes in land use by 2025 without Phase II WIPs.
Health Non-Tidal Segments All Land Uses	Adjusted for the Index of Wildness.	Baseline habitat condition adjusted by the modeled percent change in projected N, P and sediment loads delivered to the Bay from each segment, assuming Blueprint is fully implemented.	Baseline habitat condition adjusted by the modeled percent change in projected N, P, and sediment loads delivered to the Bay from each segment, assuming no Phase II WIPs.

BAU scenarios, we make one of the following adjustments, depending on the river segment in question.

- For the non-tidal river segments, adjust baseline health according to the average of modeled changes of nitrogen, phosphorus, and sediment loadings from each segment. Loading projections for the Blueprint and BAU scenarios are provided by the same model as the land use changes in step 1. Several studies have highlighted the ecological benefits of reducing nutrient and sediment loads. For example, productivity of cropland increases when sediment erosion is reduced (Pimentel et al. 2003) and less sediment in surface water means reduced water treatment costs (Groundwater Protection Council 2007). Deegan et al. (2012) found that excess amounts of nutrient loading contribute to coastal salt marsh loss. In addition, the management actions themselves—such as planting of cover crops, implementing no-till farming, and adding green infrastructure in urban areas—also have environmental benefits.
- For river segments covering the main stem of the Bay and tidal tributaries, apply each scenario's DO attainment, replacing the baseline health number. For the Blueprint scenario, attainment is expected to be 100%. For the BAU scenario, for which no DO projections are available, we make the conservative assumption that no further deterioration in DO will occur and use the same level of attainment / health as in the Baseline scenario.

See Table 2 for average health/productivity factors for each scenario and type of river segment.

- Finally, we reach the fourth step in which ecosystem service productivity per unit of land or water is converted to a value (i.e., dollars per year). Data for these calculations come from a custom dataset drawn from the Earth Economics' Ecosystem Valuation Toolkit (Briceno & Kochmer 2014). The toolkit includes an extensive database of ecosystem service valuation studies from which Earth Economics has extracted studies most applicable to the Chesapeake Bay region. These studies provide estimates of ecosystem service benefits for each habitat expressed as dollars per acre per year. Not all land use ecosystem services combinations were covered in the database, however, so to fill some of the gaps, we turned to other tools, including the "The Economics of Ecosystems and Biodiversity" (TEEB) project and studies of the value of natural systems in or near the Chesapeake Bay watershed (Kauffman, Homsey, Chatterson, McVey, & Mack 2011a; 2011b; Van der Ploeg et al. 2010; Weber 2007). Where a range of values for each land use was available, we elected to use the minimum value, which produced more conservative estimates of baseline value as well as of the benefit from implementing the Blueprint. In general, the value of eight ecosystem services in each scenario (Baseline, Blueprint, and BAU) was estimated by multiplying land area (acres) times the relevant proxy for health/productivity, times dollars-per-acre-per-year for those services.

Using the data described above, we can estimate the annual ecosystem service value for each scenario according to this general formula (see Table 2):

(1) where:

$$ESV = \sum\nolimits_{i,j,k} \left[\left(Acres_{j,k}\right) \times \left(Baseline\ Health_k\right) \times \left(Health\ Adjustment_k\right) \times \left(\$/acre/year\right)_{i,j} \right] \quad (1)$$

$Acres_{j,k}$ is the number of acres land use (j) in river segment (k)

Baseline Health$_k$ *is the initial health proxy for river segment (k)*

Health Adjustment$_k$ *is an adjustment to take into account changes to pollutant loading for non-tidal segments between the baseline and 2025 scenarios*

(This adjustment applies to non-tidal segments (k) only.)[1]

*($/acre/year)*$_{i,j}$ *is the minimum of the dollar value of each ecosystem service (i) provided from each land use (j) each year.*

The health adjustment for non-tidal segments is equal to one minus the average percent change in loading for the three pollutants (nitrogen, phosphorus, and total suspended solids).

$$\begin{aligned} &Health\ Adjustment\ (for\ non-tidal) \\ &= [1 - average(\%\Delta N\ loading, \%\Delta P\ loading, \%\Delta TSS\ loading)] \end{aligned} \tag{2}$$

Health in the Blueprint scenario, for example, becomes:

$$\begin{aligned} &Health\ in\ Blueprint\ for\ River\ Segment\ k = Baseline\ Health_k \\ &\times [1 - (Average\ \%\Delta\ in\ pollutant\ loading\ for\ Blueprint)_k] \end{aligned} \tag{3}$$ [2]

Table 2. Summary of acreage (by land use) and health indicator for tidal and non-tidal segments in three scenarios.

	Baseline (2009)	Blueprint	Business as Usual
Tidal Segments (Health Indicator, 0–1 scale)	0.709	1.000	0.709
Open Water (Acres)	2,902,290	2,902,290	2,902,290
Non-Tidal Segments (Health Indicator, 0–1 scale)	0.533	0.606	0.494
Agriculture (Acres)	9,115,604	8,508,590	8,937,770
Forest (Acres)	26,087,310	26,146,565	25,599,783
Open Water (Acres)	418,638	418,638	418,638
Urban Open (Acres)	1,827,581	2,138,186	2,157,705
Urban Other (Acres)	3,272,272	3,519,108	3,627,798
Wetland (Acres)	245,895	238,374	232,321
Other (Acres)	130,960	128,794	124,252

By comparing the Baseline to the Blueprint results we obtain an estimate of the value of natural capital that would be gained relative to current conditions. And by comparing the Blueprint to BAU results, we obtain an estimate of the value of Blueprint once implemented and effective, compared to what the value would be if nothing further is done.

Benefit estimates

For the Baseline scenario, the total estimated natural capital value of the Chesapeake watershed, as represented by the eight selected ecosystem services, is $107.2 billion per year in 2013 dollars (see Tables 3 and 4). Forests generate the majority of the ecosystem value in the region. This is due, in part, to the fact that the region is heavily forested—roughly 59% of the watershed area is still in forest. In addition, forests are particularly good at producing high-value services, like filtering drinking water, reducing flooding, providing aesthetic benefits, and being excellent places for hunting, hiking, and other types of recreation.

Table 3. Summary of Ecosystem Service Values (ESV) for seven land uses, by scenario

	Baseline	Blueprint			Business as Usual	
Land Use	ESV (millions of 2013$)	ESV (millions of 2013$)	Change from Baseline (%)	Difference from BAU (%)	ESV (millions of 2013$)	Change from Baseline (%)
Agriculture	12,258	13,434	10%	23%	10,949	−11%
Forest	73,960	86,406	17%	24%	69,639	−6%
Open Water	16,721	24,301	45%	47%	16,549	−1%
Urban Open	3,403	4,706	38%	26%	3,727	10%
Urban Other	11	14	26%	18%	12	7%
Wetland	356	364	2%	34%	270	−24%
Other	467	508	9%	32%	386	−17%
Total	$107,176	$129,732	21%	28%	$101,531	−5%

These Baseline estimates are generally in line with other studies of the value of natural capital in comparable regions. In a study of the Delaware estuary, an area about one tenth the size of the Chesapeake Bay watershed, Kauffmann et al. (2011a) estimated a total of $12.8 billion (adjusted to 2013 dollars) in ecosystem service value. If the Delaware watershed were increased in size to match the Chesapeake watershed, that estimate would come to nearly $137 billion in annual value. Similarly, Mates (2007) finds that the ecosystem service value of New Jersey is about $9.7 billion (adjusted to 2013 dollars). With the Chesapeake Bay watershed being about 8.2 times the size of New Jersey, that assessment would suggest that the ecosystem service value of the Chesapeake Bay watershed would provide approximately $131 billion per year.

Knowing the Baseline value is important: it gives a sense of how much the natural systems of the Chesapeake Bay contribute to the region's economy on an annual basis. But the true purpose here is to see how much value implementing the Blueprint could add to the natural capital value of the region.

With full implementation of the WIPs and ultimate achievement of the pollutant loading and water-quality goals of the Clean Water Blueprint, the total value of the Chesapeake watershed is estimated at $129.7 billion annually (using these eight ecosystem services), which is an increase of more than $22.5 billion per year, or roughly 21%, over the Baseline. This increase is largely due to improved habitat health associated with lower pollutant loads

Table 4. Summary of Ecosystem Service Value (ESV) for eight ecosystem services, by scenario.

	Baseline	Blueprint			Business as Usual	
Ecosystem Service	ESV (millions of 2013$)	ESV (millions of 2013$)	Change from Baseline (%)	Difference from BAU (%)	ESV (millions of 2013$)	Change from Baseline (%)
Aesthetic Value	38,446	47,407	23%	29%	36,653	−5%
Climate Stability	5,498	6,508	18%	24%	5,237	−5%
Food Production	12,129	13,313	10%	23%	10,839	−11%
Air Pollution Treatment	3,471	4,061	17%	24%	3,271	−6%
Recreation	3,071	4,099	33%	27%	3,227	5%
Waste Treatment	12,155	16,470	35%	39%	11,827	−3%
Water Regulation	12,386	14,448	17%	24%	11,634	−6%
Water Supply	20,019	23,427	17%	24%	18,843	−6%
Total	$107,176	$129,732	21%	28%	$101,531	−5%

and higher water quality attainment. The remainder is due to some reallocation of land to uses (e.g., forests) that are relatively more productive from an ecosystem services standpoint. The majority of the benefits of implementing the Blueprint will accrue to "upstream" habitats rather than to the open water habitat that includes the Chesapeake Bay and its tidal rivers.

Under the Business as Usual scenario, by contrast, ecosystem service value could drop as land continues to be converted from more productive to less productive habitats (from forests to developed urban land, for example), and as land health and water quality continue to deteriorate. Based on the Chesapeake Bay Program's projections of land use change and of pollution loads, we estimate that total ecosystem service

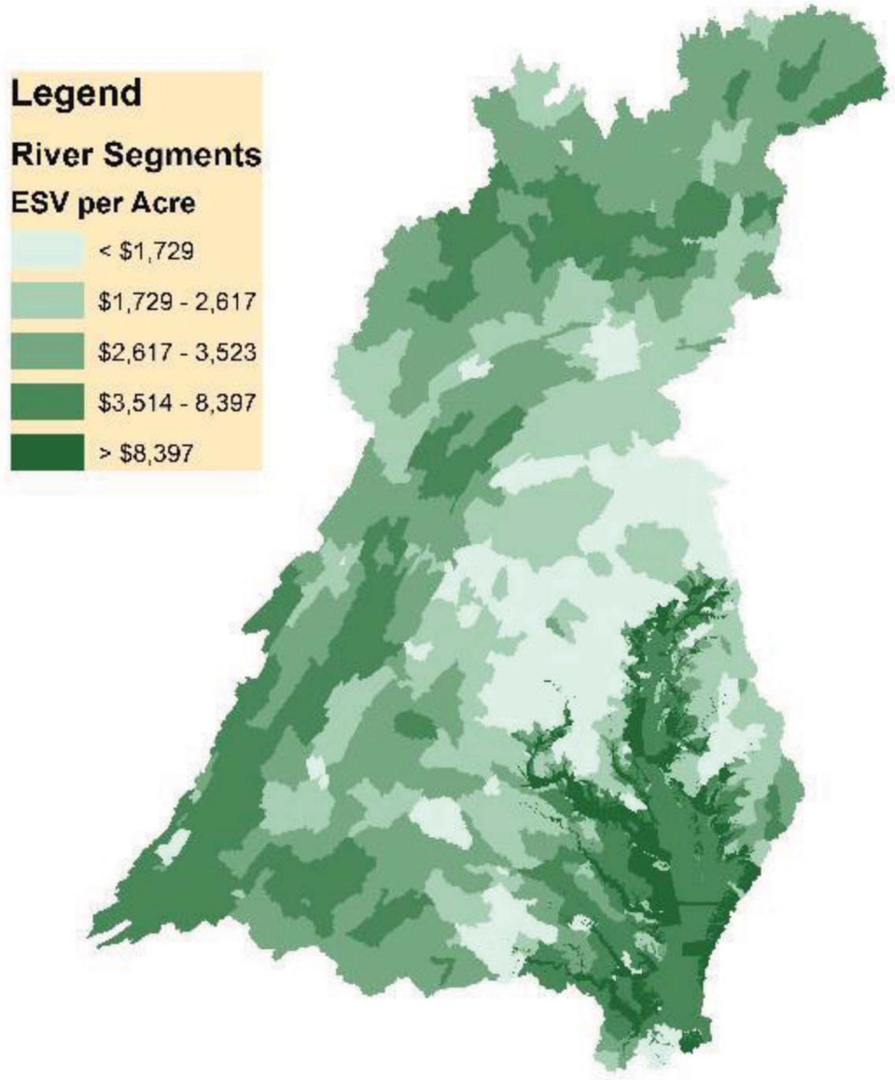

Figure 2. Total value of eight Ecosytem Services (averaged for river segments) under the Blueprint scenario (2013 dollars).

value could drop by $5.6 billion per year (in 2013 dollars) to $101.5 billion beginning in 2025.

Finally, comparing the Business as Usual result to the Blueprint projections, we estimate that the Blueprint would produce about $28.2 billion more each year in ecosystem service value than under the Business as Usual scenario.

Ecosystem service value can also be explored for states, counties, and smaller geographic units, such as depicted in the map in Figure 2. This map shows the average value per acre of all eight ecosystem services under the Blueprint scenario, by river segment. Lighter shades of gray indicate lower per-acre values. Being a function of the land use (land cover), health and per-acre values for different ecosystem services, total ecosystem service value does tend to be higher in river segments with more forest cover and those near the tidal Bay that, under the Blueprint scenario, is assumed to be functioning at full health. Other high-value river segments are in the main stem of the Bay, where the area is larger, and per-acre water supply, aesthetic, and recreational values are high.

Conclusion

Natural capital, as the basis for ecosystem service flows, is an important contributor to the Chesapeake Bay region's economy and quality of life. As this study result suggests, implementing the Chesapeake Clean Water Blueprint could result in important economic benefits relative to today's conditions and relative to conditions that would be expected to prevail if no further action is taken to reduce pollution to the Chesapeake Bay. These benefits accrue both due to changes in the pattern of land conversion in the region and due to adoption of best management practices that result in reductions of pollutant loads.

Full implementation of the Blueprint will be challenging and will require significant additional investments in pollution reduction measures across the watershed. Recognizing that economic benefits of these actions would also be distributed among diverse industries, individuals, and communities is important to garner and maintain the support needed to restore the Chesapeake Bay.

Notes

1. For tidal segments we do not adjust baseline health; rather we apply the ending health proxy for each of the two 2025 scenarios. Specifically, health of the tidal segments in the Blueprint scenario is assumed to be 1.00, given the 100 percent DO attainment goal of the TMDL. For the Business-as-Usual scenario, attainment, and therefore health, is assumed to remain unchanged from the baseline.
2. Sensitivity analysis regarding this assumption that a percentage change in pollution loading would result in the same percentage change in habitat quality revealed that our model results were fairly stable, even when the 1:1 relationship was changed to 0.5:1 and to 1:1.5. [The reason is likely that while the changes in nutrient and sediment loading required under the Blueprint are important, they do not represent large percentage changes for most river segments.

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