

Ecosystem services in Cecil County's Green Infrastructure

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ABSTRACT

This document examines a suite of 16 ecosystem services provided by forests and wetlands in Cecil County, Maryland, and attempts to estimate their economic value, primarily based on transfers from previous studies. Most of these services lack established markets, making value estimates difficult. We employed studies and data from Cecil County where possible, within Maryland as our second choice, and elsewhere in the U.S. as a third choice. We estimated total values per acre of upland forest, riparian forests and wetlands, non-riparian wetlands, and tidal marsh, finding a range between \$12,000-\$77,000/acre/year. These estimates contain several weaknesses; perhaps most importantly, lacking spatial explicitness.

Forests and wetlands in Cecil County provide \$2.1 billion in ecosystem services each year according to our estimates. This amount is two thirds that of the county's economic output (\$2.9 billion from all sectors in 2001; which is \$3.3 billion in 2006 dollars), and does not include ecosystem services from bodies of water, like the Chesapeake Bay. 80% of ecosystem service value was within the Green Infrastructure, which represents 37% of the county's land. Further, large contiguous blocks of forests and wetlands (i.e., Green Infrastructure hubs) are more likely to contain fully functioning ecosystems, and more likely to provide corresponding values to humans. Protection of these areas is therefore a vital investment.

KEYWORDS: Cecil County, Maryland, Green Infrastructure, ecosystem services, ecosystem valuation, hubs

OVERVIEW

Cecil County's undeveloped lands and waterways provide the bulk of the county's natural support system. Ecosystem services, such as cleaning the air, filtering and cooling water, storing and cycling nutrients, conserving and generating soils, pollinating crops and other plants, regulating climate, sequestering carbon, protecting areas against storm and flood damage, and maintaining hydrologic regimes, are all provided by the existing expanses of forests, wetlands, and other natural lands (Costanza et al. 1997, Conservation Fund 2000). These ecologically valuable lands also provide marketable goods and services, like forest products, fish and wildlife, and recreation. They serve as vital habitat for wild species, maintain a vast genetic library, provide scenery, and contribute in many ways to human health and quality of life.

When wetlands and forest are taken for development, there are costs incurred that are typically not accounted for in the marketplace. The losses in ecosystem services are hidden costs to society. These services, such as cleansing the air and filtering water, meet fundamental needs for humans and other species, but in the past, the resources providing them have been so plentiful and resilient that they have been largely taken for granted. In the face of a tremendous rise in both population and land consumption,

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we now realize that these natural or ecosystem services must be afforded greater consideration. The breakdown in ecosystem functions causes damages that are difficult and costly to repair, as well as taking a toll on the health of plant, animal, and human populations (Moore, 2002).

Costanza et al. (1997) estimated that ecosystem services contribute at least as much as to the global economy as do marketplace processes, and probably much more. Using over 200 case studies from around the world, De Groot et al. (2006) reported average economic values of wetland services around \$4000 per hectare per year (adjusted to 2006 \$). Because not all services were assessed, the authors considered this an underestimate. In Maryland, Pimentel (1998) estimated the value of biodiversity as about \$2.3 billion (adjusted to 2006 dollars) annually. Biosphere 2, an artificially closed ecological system built to house eight humans for two years, had operational and annualized construction costs on the order of \$10 million per year (Marino and Odum 1999), and was not particularly successful (oxygen levels dropped, pollinating had to be done by hand, and the inhabitants lost an average of 25 pounds apiece). If one extrapolated from this experiment, Earth's support of 6.6 billion people in 2006 (U.S. Central Intelligence Agency 2006) was worth \$11 quadrillion, or 170 times the global Gross Domestic Product. This does not include solar energy or legacy geologic, soil building, or evolutionary processes. Balmford et al. (2002) found that if the values of ecological services are considered, the benefits from conserving natural land gives a return on investment of at least 100 to 1. Odum (1970) estimated that managing 40 percent of the state of Georgia as natural, 10 percent as urban-industrial, 30 percent in food production, and 20 percent in fiber production would maximize ecological services while maintaining the current standard of living.

Below, we look at a comprehensive (but not complete) suite of ecosystem services provided by forests and wetlands in Cecil County, and attempt to estimate their economic value. Most of these services do not have established markets, making such estimates difficult. We used studies and figures from Cecil County where possible, within Maryland as our second choice, and elsewhere in the U.S. as a third choice. In cases where there was a range of values for a given service, we usually chose the conservative route and picked the lowest number. All dollar figures were transformed to 2006 equivalents, using an on-line inflation calculator (<http://www.westegg.com/inflation/>), which employs the Consumer Price Index from the annual *Statistical Abstracts of the United States*.

Finally, we summed these values per acre of upland forest, riparian forests and wetlands, non-riparian wetlands, and tidal marsh. These numbers are estimates only, and have several weaknesses. Perhaps most importantly, they are not spatially explicit. Some services, like pollination, depend on proximity to crops, yet not all forest in the county is within pollinator range of cropland. The value of flood protection, groundwater recharge, and other services also depends on human demand relative to supply. This ratio tends to be higher in urban areas than rural.

Further, large contiguous blocks of forest and wetland are more likely to contain fully functioning ecosystems (e.g., MacArthur and Wilson, 1967; Forman and Godron, 1986; Weber, 2007), and provide corresponding benefits to humans. Smaller, fragmented ecosystems are more likely to be impaired (Weber et al., 2004, p.59; Weber, 2007). Retaining connectivity, as appropriately sited and configured corridors can accomplish, can help to offset some of the functional losses caused by fragmentation (e.g., Anderson and Danielson 1997, Beier and Noss 1998, Bennett 1998, Söndgerath and Schröder 2002).

Similarly, not all forest and wetland types provide services equally. For example, more productive soils facilitate faster plant growth, and faster uptake of carbon. Some tree species are better at carbon uptake than others. Finally, using some services may impair other services. For example, timber extraction can hinder other forest functions like providing erosion control, soil formation, wildlife habitat, etc. Constructing trails for recreation can create vectors for invasive species. Proper management is therefore necessary to prevent long-term ecological degradation.

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ECOSYSTEM SERVICES

Carbon sequestration

Scientists are in agreement that global temperatures are rising due to human activities (Solomon et al., 2007), and the prognosis is grim if we do not act soon. We are already seeing the first effects of climate change, like hotter temperatures, devastating hurricanes, and the disappearance of islands and marshes in the Chesapeake Bay. By the end of the century, according even to conservative projections, our planet could be a radically different place.

With 4,360 miles of coastline (Johnson, 2000), Maryland is particularly vulnerable to global warming. The U.S. Environmental Protection Agency (1998) projects that Maryland could experience up to one meter of sea level rise, causing erosion along the coast, major property damage, and massive loss of wetlands throughout the Chesapeake Bay. Dr. James E. Hansen, director of NASA's Goddard Institute of Space Studies, recently warned (2006) that the Greenland ice sheet is melting twice as fast as it was five years ago, and could melt completely, increasing sea level by 6 meters.

Higher temperatures will also increase the spread of infectious diseases and exacerbate air pollution problems such as smog. Stream flows, lake levels, and groundwater levels will be lower in the summer and fall (U.S. Environmental Protection Agency, 1998). The composition of entire ecosystems is changing, forcing wildlife to shift their ranges, adapt, or go extinct. Agriculture yields could decline; forests will be stressed by fire, pests, and diseases; and many plant species will disappear (U.S. Environmental Protection Agency, 1998).

Carbon dioxide (CO₂) is the leading "greenhouse gas", trapping some of the sun's energy, and warming the Earth (Solomon et al., 2007). Human activities, especially the burning of fossil fuels, have greatly increased atmospheric concentrations of CO₂ and other greenhouse gases, which is warming our climate and changing our weather systems (Solomon et al., 2007).

Forests

Forests help remove large amounts of CO₂ from the air. During photosynthesis, trees convert CO₂ into oxygen; carbon is also stored in the body of the tree, in the soil surrounding its roots, and in debris that falls to the ground. Barford et al. (2001) found a mean sequestration rate around 2.0 MgC/ha/yr for a mature northern red oak stand. Wetlands with long periods of inundation are especially effective at storing carbon, in the form of peat.

According to Strebel (2002), Maryland's vegetation absorbs about 55 million metric tonnes (MMT) of CO₂ from the atmosphere annually through photosynthesis. About 20% of this net primary productivity (NPP), or 10.6 MMT, is permanently sequestered by wetlands or forests, with little to no sequestration by other land uses. Unmanaged forest stores about 24% of its NPP in large, long-term soil reservoirs. Disturbing mature forests frees this carbon. However, frequent harvesting in degraded areas, if good soil management practices are followed, can result in carbon sequestration both in the soil and in wood products.

Wetlands

Wetlands are the most highly productive terrestrial ecosystems, and do not turn over organic matter quickly, accumulating it in the soil or as peat. Thus, if undisturbed, they may sequester CO₂ better than any other ecosystem type (Strebel estimated 50% of NPP), although this depends on hydroperiod and other parameters. While reforesting abandoned land, restoring wetlands, and preserving natural areas help to reduce and maintain CO₂ levels, developing these lands produces the opposite effect and increases CO₂ by releasing previously stored carbon into the atmosphere (Strebel, 2002).

There is growing interest in the monetary value of forests for carbon sequestration. Industries and governments throughout the world are increasingly concerned about rising greenhouse gases, and there are initiatives to substantially reduce or mitigate emissions. The European Union Emissions Trading Scheme traded carbon emission credits averaging \$22 per ton of carbon in 2006 (Kapoor and Ambrosi,

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2007). The market tripled in trading volume between 2005 and 2006, and additional markets are developing in Australia and Chicago (Kapoor and Ambrosi, 2007). Carbon reduction projects averaged \$11 per ton of carbon removed (Kapoor and Ambrosi, 2007). Thus, the 10.6 MMT of CO₂ sequestered annually by Maryland vegetation was worth around \$117 million in 2006, or \$31/ac for upland forests and \$65/ac for wetlands.

Clean air

Air quality affects the health of everyone, and is a major factor in illnesses ranging from cardiovascular disease to cancer and respiratory ailments (Moore, 2002). According to the State of the Air 2004 report issued by the American Lung Association (2004), all monitored Maryland counties, including Cecil County, received an air quality grade of "F" for the number of days with high ground ozone levels. This is of critical concern to those with respiratory problems. Ozone forms in chemical reactions in the atmosphere when nitrogen oxides and volatile organic compounds, primarily from burning fossil fuels, come into contact with sunlight and heat (American Lung Association, 2007). It attacks lung tissue and causes numerous health problems, including asthma attacks (American Lung Association, 2007).

Maryland has one of the highest asthma rates in the country (Moore, 2002). Of a population around 90,000, Cecil County has an estimated 2,000 children and 5,419 adults with asthma, 2,929 people with chronic bronchitis, and 976 with emphysema (American Lung Association, 2004). Nationally, asthma accounts for an estimated three million lost work days annually, and the annual direct health care cost of asthma is estimated at \$8.1 billion (American Lung Association, 2001; Moore, 2002).

Forests

Trees provide air quality benefits by absorbing sulfur dioxide and nitrogen oxide, two major components of acid rain (American Forests, 1999). In addition, trees can trap ozone, carbon monoxide, and particles in the air, all of which can be harmful to humans (American Forests, 1999). According to a study by American Forests (1999), trees in the Baltimore-Washington urban corridor removed 34 million pounds of air pollutants in 1997, at a value of \$106 million per year (adjusted to 2006 \$). With 555,090 ac of trees in the study area, this translates to a benefit of \$191/acre of trees.

Soil and peat formation

Forests

Fertile soil is a necessity for most plants, and in turn the animals and people who depend on them. NRCS (2007) estimated Maryland's annual soil loss to erosion at 3.6 tons/acre, almost entirely due to rainfall and runoff. This was one of the highest rates in the country (NRCS, 2007). Yet soil formation is a slow process, taking up to 1000 years to form 25mm (1 inch) of soil (Pimentel, 1998).

Organisms in the soil enrich it by breaking down litter and other organic matter, transforming nutrients into forms plants can use, and circulating the soil through burrowing and other movement. Pimentel (1998) wrote,

"One hectare of high-quality soil contains an average of 1300 kg of earthworms, 1000 kg of arthropods, 3000 kg of bacteria, 4000 kg of fungi, and many other plants and animals. These soil biota enhance crop productivity because they recycle the basic nutrients required for all ecosystems, including nitrogen, phosphorus, potassium, and calcium. The movement of earthworms and other biota through the soil further enhance the productivity of the soil by increasing water infiltration... Other activities of soil biota – mixing the soil components, enhancing aggregate stability, and preventing soil crusting – improve soil productivity as well. Earthworms bring between 10 and 500 t/ha of soil to the surface each year, and insects can also bring up between 1 and 10 t/ha of subsurface soil... These activities redistribute nutrients, aerate the soil, facilitate topsoil formation, and increase infiltration rates, thereby enhancing the quality of the soil and plant productivity."

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Sullivan (2004) wrote that earthworm digestion and soil mixing increases the content of carbon, nitrogen, phosphorus, and potassium. Worms are killed by tilling the soil, with populations reduced by up to 90% (Sullivan, 2004). Sullivan (2004) reported that a healthy population of earthworms can process 10 tons/ac/year of topsoil. Pimentel (1998) reported that this creates about 1 ton/ha/year of topsoil. With a mean price of \$1.89/ft³ (Home Depot, personal communication, June 7, 2007), or \$42/ton (approximately 90 lbs/ft³), this implies a soil formation value of \$17/ac/year.

Forested wetlands

Many seasonally flooded wetlands contain Sphagnum moss. Peat moss, which is *Sphagnum spp.* detritus, retails at \$3.16/ft³ (Home Depot, personal communication, June 7, 2007). Data on peat moss accumulation in mid-Atlantic wetlands was unavailable; however, an average of 1 mm/year in forested wetlands would equate to \$450/ac/year.

Tidal marsh

Studies in Delaware (Kana et al., 1988) showed sedimentation and peat formation of 5-6 mm/year in coastal marshes, corresponding to 715 ft³/ac/year (much higher than soil formation in forest). Using the same price for topsoil, this implies a soil formation value of \$1351/ac/year.

Floodplain forests

Studies in Tennessee, South Carolina, and Arkansas showed rates of sediment deposition in floodplain forests between 0.2 and 7.5 mm/year (Cavalcanti and Lockaby, 2005). Taking the average, this translates to a value of \$946/ac/year.

Flood protection and stormwater management

Conserving forests and wetlands can help local governments and other public agencies reduce costs from flooding and other natural hazards (McQueen, 2000). Nationwide, floods cause over \$4 billion in damages in an average year (Salzman et al, 2001). In 1999, a single flood resulted in damages to government properties estimated at \$6,408,180 (Moore, 2002). Floods also impact agriculture, when crops and livestock are destroyed and soil is washed away (Klapproth and Johnson, 2001).

Forests and wetlands can absorb stormwater and recycle it through the hydrologic system, with the potential to control runoff and flooding. Floodplains and wetlands can absorb and store stream and river overflows, and also reduce flow velocity through friction. Heavy vegetation can slow the runoff of precipitation into waterways, permitting some of the runoff to seep into groundwater aquifers and reducing peak flows. In contrast to natural land, developed land has little ability for absorption, and instead creates a large volume of fast moving (and more polluted) runoff.

Forests

American Forests (1999) estimated that between 1973 and 1997, tree losses in the Baltimore-Washington area resulted in a 19% increase in stormwater runoff - an estimated 540 million cubic feet of extra water. Replacing the lost stormwater retention capacity with engineered systems, at \$2/ft³ of storage, would have cost \$1.08 billion (American Forests, 1999), or \$679 per acre of forest lost (2006 \$).

Wetlands

Any topographic depression in the landscape has the potential to store water, and thereby play a role in flood control. Wetland basins not already filled to capacity can mitigate flooding by storage, slowing flood waters, and reducing peaks and increasing the duration of flow (Sather and Smith, 1984). The value of flood control by wetlands increases with: (1) size (the larger the wetland, the more area for flood storage and velocity reduction), (2) proximity of the wetland to flood waters, (3) location of the wetland (e.g., along a river, lake, or stream), (4) the amount of flooding that would occur without wetlands present, and, (5) the lack of other upstream storage areas such as ponds, lakes, and reservoirs (Mitsch and Gosselink 1993). Location within the drainage basin, texture of the substrate, and type of vegetation are also factors (Sather and Smith, 1984). Groups of wetlands in a watershed are more effective at flood control than isolated wetlands (Sather and Smith, 1984).

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In Wisconsin, watersheds with 30% wetland or lake area had flood peaks 60-80% lower than watersheds with no wetland or lake area (Sather and Smith, 1984). The reduction was 60-65% if the watershed was 15% wetland or lake (Sather and Smith, 1984). A study by the Massachusetts Water Resources Commission on the Neponset River indicated that the loss of 10% of the wetlands along that river would result in flood stage increases of 1.5 feet, and the loss of half the wetlands would increase the flood stage by 3 feet (California Dept. of Water Resources, 2005). Wetlands within and upstream of urban areas are particularly valuable for flood protection (Osmond et al., 1995). The impervious surface in urban areas greatly increases the rate and volume of runoff, thereby increasing the risk of flood damage (Osmond et al., 1995).

The drainage of wetlands, diversion of the Mississippi and Missouri rivers from their original floodplains, and development in the floodplains were partly responsible for the billions of dollars in damage to businesses, homes, and crops during the Midwest flood of 1993 (Osmond et al., 1995). The cost of replacing the natural flood control function of 5000 acres of drained wetlands in Minnesota was \$1.5 million annually, or \$300/acre (U.S. Environmental Protection Agency, 2006; Sipple, 2007). This was the lowest of available estimates. Thibodeau and Ostro (1981) estimated that the loss of 8,442 acres of wetlands within the Charles River system in Massachusetts would result in annual flood damages of over \$17 million (1976 \$; \$7,400/ac/yr in 2006 dollars). Because of this, the Army Corps of Engineers preserved the wetlands rather than constructing extensive flood control structures (Leschine et al., 1997). Three wetland systems studied by Leschine et al. (1997) provided \$36,000-\$51,000/ac of flood protection. According to the U.S. Environmental Protection Agency (2001, 2006), an acre of wetlands can typically store 1-1.5 million gallons of floodwater. At the lower amount, and given a replacement cost of \$0.27/gallon (American Forests, 1999), this translates to \$267,000 per acre, which was the highest of available estimates.

Wossink and Hunt (2003) compared the annualized construction, land opportunity, and maintenance costs of restored wetlands to stormwater ponds. We used data and best-fit curves from Wossink and Hunt (2003) to estimate the cost of a stormwater pond that could capture the same amount of runoff as a 1 acre Coastal Plain wetland. According to their data¹, a 1 acre wetland could treat runoff from a 100 ac watershed. The equivalent constructed pond would be $0.0075(100) = 0.75$ ac, and have a construction cost of $\$13909(100)^{0.672} = \$307,111$. The 20 year maintenance cost would be $\$9202(100)^{0.269} = \$31,760$ (present value), giving a total present value of \$338,871. Annualized² over 20 years, with a 7% interest rate, this is \$31,987/year. We did not include land opportunity costs, which would increase this value, especially in urban areas.

Riparian buffers

Riparian forest buffers play an important role in flood control. As flood waters move into riparian floodplains, vegetation slows the water's movement, reducing its erosive potential and capturing materials carried by the floodwaters (Klapproth and Johnson, 2001). The porous forest floor acts as a sponge, quickly absorbing and storing floodwaters, then releasing them slowly back into the stream and groundwater (Klapproth and Johnson, 2001). Severe floods in Virginia in 1994-95 caused more than \$10 million in damage (Klapproth and Johnson, 2001). In areas where forested buffers existed, the damage to river banks and adjacent farmlands was reduced (Klapproth and Johnson, 2001).

From the studies cited above, the value of forests and wetlands in controlling flood waters is greater along streams and rivers. However, we lacked data to quantify this greater value.

Tidal marsh

The role of coastal wetlands, such as tidal marshes, as storm buffers that protect inland areas from winds and ocean waves has been well established (see Ramsar Convention on Wetlands, 2000b). Coastal wetlands provide natural "horizontal levees" that are far more cost-effective than constructed levees (Costanza et al., 2007). They are also able to recover quickly from storms. Coastal and inland wetlands

¹ Tables 2 and 4 in Wossink and Hunt (2003).

² Formula for computing annualized cost: $A = PV / (((1+i)^n - 1) / (i(1+i)^n))$, where PV = present value, i = interest rate, and n = number of years.

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also reduce flooding, storing rain water and releasing it gradually into receiving surface waters or recharging groundwater. Wetlands in South Carolina, Florida, and Louisiana bore much of the brunt of Hurricanes Hugo (1989) and Andrew (1992).

Conversely, the loss of coastal wetlands produces higher storm damage than otherwise would be the case. A recent example was supplied by Hurricane Katrina in 2005. That storm's 29-foot storm surge is a reminder of what can occur when coastal wetlands are lost. It has been estimated that for every 2.7 miles of wetlands, storm surges are reduced by about a foot (U.S. Army Corps of Engineers, 1961). Hurricane Isabel in 2003 caused \$915 million in damages to Maryland (2006 \$), most of this from storm surge (Wikipedia). Retaining coastal wetlands rather than building along the shore would have reduced this figure considerably.

Prior to Hurricane Katrina, a \$14 billion project had been proposed for restoring Louisiana wetlands. While this amount would constitute a significant public investment, it represents only a fraction of the more than \$81 billion in storm damage incurred and nearly 2,000 human lives lost from this single hurricane. Costanza and Farber (1995) used a willingness to pay approach to value the Terrebone wetlands in Louisiana at \$258/ac/year for storm protection (converted to 2006 \$), not including values to fisheries, trapping, and recreation. In a recent study, Costanza et al. (2007) found that the mean value of coastal wetlands for reducing hurricane damage in the U.S. was \$1,430/ac/year (converted to 2006 \$).

Water supply and hydrologic regulation

Clean water from forested watersheds is important to all Marylanders. Both surface and ground water are important sources of drinking water in the state. Almost two million people get their water from the three reservoirs in Baltimore County, and much of the Washington metropolitan area depends upon reservoirs as well (Moore, 2002). In rural areas, ground water is often more important. Cecil County withdraws 3.66 million gallons of fresh water per day for public drinking water; 44% from ground water, and 56% from surface water (City-data.com, 2007). In addition, the Maryland Dept. of the Environment (MDE) reports that about half of all stream flow in Maryland originates as ground water (Moore, 2002). Ground water is especially important to stream flow when rainfall is low.

The ultimate source of drinking water in Maryland is rainfall. Forests and wetlands slow surface runoff during rainfalls, and catch some of this water. Some of the trapped rainfall is absorbed by plant roots, some is stored in depressions or soil, and some percolates into surficial, intermediate, or deep aquifers. The rate of infiltration depends on a number of factors, including land use, geology, soils, and precipitation (Moore, 2002). Water stored on the surface or below ground keeps plants alive, provides drinking water for humans and wildlife, and helps maintain stream base flow in dry periods. Evaporation of surface water in wetlands, streams, and ponds also contributes to the hydrologic cycle.

A well-functioning hydrologic cycle is not only important for proper ecosystem function and drinking water supplies, it is important for the hydroelectric industry in Maryland. Maryland has eight hydroelectric projects, with two stations (Conowingo and Deep Creek) that provide almost \$123 billion worth of hydroelectricity each year. Stable stream flow helps hydroelectric managers predict and manage the water used for power generation. In contrast, highly fluctuating flows, such as those found in urban areas, can result in potential losses from dam spillovers (Moore, 2002).

Forests

In the process of transpiration, trees take in groundwater through their roots and release it to the atmosphere through their leaves. From there, water vapor can be carried by air currents over large distances, and then returned to the ground through precipitation. A large tree can return 10 gallons of water a day to the atmosphere (Moore, 2002). Water evaporates more slowly from shaded forest soil than bare soil exposed to the sun.

The natural hydrologic cycle contrasts with what happens when impervious developed areas prevent water infiltration. In fact, the U.S. Department of Agriculture, Natural Resources Conservation Service (NRCS) estimated that water runoff develops ten times faster on developed land as compared to

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unaltered landscape (Moore, 2002). Rain water that falls on developed land is therefore not recycled. NRCS stated that the management of precipitation is a major factor in whether or not there is sufficient quantity and quality of drinking water (Moore, 2002).

Studies of desertification have shown that vegetation is a controlling factor in the exchange of water and energy between the land and the atmosphere, and that large-scale deforestation dries up an area's climate (Moore, 2002). For example, a study in Brazil showed that forests returned three-fourths of rainfall to the atmosphere, with only one-fourth running into streams and rivers. When land is deforested, however, the ratio is roughly reversed, with a quarter of the rainfall returned to the atmosphere and three quarters running quickly off the land (cited in Bacon, 2002).

Wetlands

Wetlands act as reservoirs for the watershed, retaining water from precipitation, surface water, and ground water (Osmond et al., 1995). Most wetlands release this water into connected surface water and ground water. The effect of wetlands on ground water recharge and discharge is variable. Some wetlands recharge ground water, but most wetlands occur where water is discharging to the surface (Sather and Smith, 1984). Wetlands may recharge less than upland forest because of greater evapotranspiration and less permeable soils. Temporary or seasonal wetlands seem more likely to recharge than permanent or semi-permanent wetlands (Sather and Smith, 1984). Wetland features affecting groundwater recharge include hydroperiod, substrate, presence of surface outlets, amount of edge, and type and amount of vegetation.

Mitsch and Gosselink (1993) reported that stream discharge during the spring from watersheds with 40% wetlands and lakes was 140% greater than watersheds without wetlands or lakes. Forested wetlands overlying permeable soil may release up to 100,000 gallons/acre/day into the ground water (Osmond et al., 1995). Ground water can be adversely affected by activities that alter wetland hydrology (Osmond et al., 1995). Drainage of wetlands lowers the water table and reduces the hydraulic head providing the force for ground water discharge. If a recharge wetland is drained, this can change the hydrology of the watershed. For example, researchers at the University of Florida calculated that if 80% of a 5-acre cypress swamp were drained, available ground water would be reduced by an estimated 45% (Osmond et al., 1995). A 1975 Massachusetts study concluded that an average acre of wetlands could supply water at a savings of \$2,800 per year compared to other water sources (2006 equivalent: \$11,000) (California Dept. of Water Resources, 2005). A 1992 study estimated that an average acre of wetlands could provide 100,000 gallons per day at a rate of \$16.56 per day less than water procured elsewhere (California Dept. of Water Resources, 2005). This savings translates to \$8,630 in annual water supply per wetland acre (2006 \$) (California Dept. of Water Resources, 2005).

Clean water

Forests and wetlands protect water bodies from pollutants and sedimentation by absorbing and filtering water. Compared to these natural ecosystems, urban landscapes add seven times as much nitrogen and ten times as much phosphorus to surface waters (Moore, 2002), and impervious surfaces like roads and parking lots carry pollutants such as oils, grease, heavy metals, and salts to streams. Agricultural runoff also contributes to heightened nutrient loads.

Excess nutrients are a key water quality concern in Maryland, for drinking water, for stream health, and for aquatic life, particularly in estuarine areas. Excess nitrogen and phosphorus can cause fish kills and algal blooms, and promote growth of invasive aquatic plants. The Maryland Dept. of Natural Resources (DNR) found that 57% of the state's non-tidal stream miles had unnaturally elevated nutrient concentrations, and these concentrations were generally higher in watersheds with more agricultural land use (Boward et al., 1999). The study reported that some sites with greater than 50% agricultural land use upstream contained nitrate concentrations as high as 24 mg/L (Boward et al., 1999; Moore, 2002).

In Maryland, much drinking water is obtained from reservoirs, streams and rivers (Moore, 2002). National Drinking Water Regulations set maximum allowable concentrations for microorganisms, turbidity, and chemicals (U.S. Environmental Protection Agency, 2002). In spite of high standards and government

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oversight, each year almost a million Americans still become sick as a result of drinking contaminated water, and many people die (Salzman et al, 2001). When contamination levels are of concern, local governments have been forced to pump water from deeper aquifers or to create expensive water treatment facilities (Moore, 2002).

Klapproth and Johnson (2001) noted,

"...communities across the nation spend millions of dollars each year to treat contaminated waters. As nutrients, sediments, and other contaminants move off the land and into streams, the costs of treating municipal water supplies increase. Sediment basins must be built, filters cleaned more frequently, and chemical coagulants and disinfectants must be added to the water. Turbid water may also have serious taste and odor problems. In 1991, the costs of treating contaminated water were estimated to be \$10 to \$15 per month for a family of three."

Klapproth and Johnson (2001) listed several studies from the early 1990's demonstrating public interest in maintaining clean water supplies and willingness to pay for programs to improve water quality (dollar figures unadjusted):

- A nationwide survey found that individuals were willing to pay on average \$275 to \$366 per household per year to improve water quality to a "swimmable" level.
- Residents of Georgia expressed a willingness to pay \$5.49 to \$7.38 per month to improve the quality of drinking water in their state, even though most rated their water quality currently as very safe, safe, or fair.
- Another survey of Georgia residents found they were willing to pay \$641 per household annually for a program that would protect groundwater supplies.
- Citizens of Dover, N.H., were willing to pay \$40 per household annually for a groundwater protection plan.
- A survey of citizens from Indiana, Nebraska, Pennsylvania, and Washington indicated a willingness to pay nearly \$55 per month to remove all nitrates from their water supplies.

Contaminated water can also increase industrial expenses as it causes steam electric power plants to operate less efficiently, clogs cooling equipment, corrodes pipes, and increases the rate at which pumps and other equipment wear out (Klapproth and Johnson, 2001). In one study, suspended sediment and algae cost steam electric power plants and other water cooling facilities \$24 million annually (1983 dollars) in maintenance costs (Klapproth and Johnson, 2001).

Forests

By slowing surface runoff and providing opportunities for settling and infiltration, forests help remove nutrients, sediments and other pollutants. Infiltration rates 10-15 times higher than grass turf and 40 times higher than a plowed field are common in forests (Chesapeake Bay Program, 2000; Casey, 2004). Tree roots remove nutrients from settled runoff and groundwater, and store them in leaves and wood. Through the process of denitrification, bacteria in the forest floor convert harmful nitrate to nitrogen gas, which is released into the air (Chesapeake Bay Program, 2000). In stream and river floodplains, vegetation traps and removes water-borne particulates during storms.

Many studies have shown a relationship between water quality and the amount of forest cover in the watershed. Baltimore County (2005) found that the more forest cover a watershed had, the lower the concentrations of nitrate in the streams. For sites sampled statewide by the Maryland Biological Stream Survey (MBSS) between 1995 and 1997, Benthic Index of Biotic Integrity (IBI) scores increased with increasing forest cover in the catchment (Roth et al., 1999). The Hilsenhoff Biotic Index, a macroinvertebrate indicator of organic pollution tolerance, was also significantly correlated with catchment forest cover (Roth et al., 1999). Fewer pollution-tolerant organisms were found in catchments with more forest cover, indicating less stream degradation (Roth et al., 1999). Aquatic salamander richness was also higher in catchments with higher amounts of forest cover (Roth et al., 1999). As indicated by the benthic macroinvertebrate community, watersheds in Baltimore County with >50% forest cover generally had the best stream conditions, followed by watersheds with 40-50% forest (Allen and Weber, 2007).

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In some parts of the U.S. attention has focused on the benefits of protecting natural watersheds to assure safe and plentiful drinking water supplies, rather than on building expensive filtration plants to purify water from degraded watersheds (World Resources Institute, 1998). Ernst (2004) cited a study of 27 water suppliers that found that the more forest cover in a watershed, the lower the water treatment costs. According to the study, 55% of variation in treatment costs can be explained by the percent of forest cover in the source area (Ernst, 2004). Further, for every 10% increase in forest cover in the watershed, treatment and chemical costs decreased about 20%, up to about 60% forest cover (Ernst, 2004). The study had insufficient data for watersheds with more than 65% forest cover (Ernst, 2004).

New York City recently avoided spending \$6-8 billion in constructing new water treatment plants by protecting the upstate watersheds that have accomplished these purification services for free (World Resources Institute, 1998). The annualized construction cost would have been around \$500 million/year (\$6 billion in 1997, 5% interest rate, 20 years). In addition, Ernst (2004) reported that annual operating expenses would have been \$300 million/year. Based on this economic assessment, the city invested \$1.5 billion in buying land around its reservoirs and instituting other protective measures, actions that will not only keep its water pure at a bargain price but also enhance recreation, wildlife habitat, and other ecological benefits (World Resources Institute, 1998). The Catskill/Delaware watersheds that supply 90% of New York City's drinking water cover 1,583 mi² (1 million ac), and are primarily (89%) forested (Mehaffey et al., 2001). In 2006 dollars, their supply of clean drinking water is \$1100 per acre of forest per year.

Riparian buffers

Riparian forest buffers have proven to be effective at reducing nutrient loads in areas that have largely been deforested. In Baltimore County, Allen and Weber (2007) found that watersheds with more than about 70% riparian forest had the best stream conditions, followed by watersheds between 40-70%. It appeared that riparian forest was most important in largely deforested watersheds. Riparian forest had a more noticeable impact along perennial streams and shorelines than along intermittent streams. Forested buffers (which are more effective than grass over the long term) can remove up to 21 pounds of nitrogen and 4 pounds of phosphorus per acre per year from upland runoff (Klapproth and Johnson, 2001). Studies have demonstrated reductions of 30 to 98 percent for nitrogen, phosphorus, sediments, pesticides, and other pollutants in surface and groundwater after passing through a riparian forest (Osmond et al., 1995; Chesapeake Bay Program, 2000; Casey, 2004).

Retaining and restoring buffers is one of the least expensive strategies for reducing nitrogen loads, costing approximately \$5 per pound of nitrogen removed (Moore, 2002). Stream buffers are most effective when they are continuous and sufficiently wide. The Chesapeake Bay Commission (2004) reported that feasible upgrades of wastewater treatment plants to clean their effluent to the Chesapeake Bay would cost an annualized \$8.56/lb. of nitrogen and \$74.00/lb. of phosphorus (2004 \$). Using numbers from Klapproth and Johnson (2001), an acre of riparian forest would correspondingly have a nutrient reduction value of \$825/year (2006 \$).

Wetlands

General agreement exists that wetlands change water quality through retention and/or modification of sediments, toxins, and nutrients in the water (Sather and Smith, 1984). As water passes through wetlands, its velocity is reduced, large populations of microbes decompose organic substances, and particles are bound to sediments (Sather and Smith, 1984). Submerged and emergent plants help purify water both directly (by absorbing nutrients and other chemicals through their roots) and indirectly (by supplying substrates for bacterial growth, providing a medium for physical filtration and absorption, and restricting algal growth and wave action). Restored wetlands have been shown to be effective at trapping significant amounts of nutrients and sediments (Jordan, 2002). Both natural and restored wetlands have been effective at treating wastewater (Sather and Smith, 1984). Wetlands are most effective at nutrient transformation and uptake when there are seasonal fluctuations in water levels (Maryland Department of the Environment, 2006).

Tidal wetlands are highly effective nutrient sinks; for example, through denitrification (Maryland Department of the Environment, 2006). However, nutrient uptake and transformation occurs on a

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seasonal basis during the growing season; at the end of the growing season, as plants die and decompose, nutrients are released back into the water (Maryland Department of the Environment, 2006).

Scientists have estimated that wetlands can remove between 70% and 90% of entering nitrogen. The estimated mean retention of phosphorus by wetlands is 45%, although wetlands with high soil concentrations of aluminum can remove up to 80% of total phosphorus. Biological oxygen demand (BOD) removal by wetlands can approach 100%. BOD is a measure of the oxygen required for the decomposition of organic matter and oxidation of inorganics such as sulfide, and is introduced into surface water through inputs of organic matter such as sewage effluent, surface runoff, and natural biotic processes. If BOD is high, low dissolved oxygen levels result, which can kill aquatic life. Wetlands remove BOD from surface water through decomposition of organic matter or oxidation of inorganics (Osmond et al., 1995).

Wetlands have also been shown to change some toxic substances (e.g., heavy metals and pesticides) to harmless states. Other substances may be temporarily buried in sediments in wetland areas. Heavy metals are removed from wastewater by ion exchange and adsorption to sediment clays and organic compounds; by precipitation as oxides, hydroxides, carbonates, phosphates and sulfides; and by plant uptake (Sather and Smith, 1984). Heavy metal removal varies 20-100% depending on the metal and the wetland (Osmond et al., 1995). Forested wetlands can play a critical role in removing metals downstream of urbanized areas (Osmond et al., 1995). Lead leaking from a hazardous waste site in Florida was retained at high levels by a downstream wetland. The majority of the lead (75-80%) was bound to soil and sediments through adsorption, chelation, and precipitation (Osmond et al., 1995). The rest was bioavailable, absorbed primarily by eel grass (Osmond et al., 1995). In another study, researchers found that wetland vegetation and organic substrate retained 98% of lead entering the wetland (Osmond et al., 1995).

The fate of pesticides and other toxins is similar to heavy metals. Some are temporarily buried in sediments, some changed to harmless forms and some may enter the food web (Sather and Smith, 1984). The longer the duration that water and transported materials remain in the wetland, the greater the likelihood that the materials will be retained (Maryland Department of the Environment, 2006). Wetlands are also able to remove pathogens from surface water (Osmond et al., 1995).

Landers (2006) examined side-by-side comparisons of 11 types of best management practices (BMPs), and found that constructed wetlands were the most effective. The wetland in the study removed 100% of suspended solids, 99% of nitrate, 100% of zinc, and 100% of petroleum byproducts, and reduced peak flows by 85% (Landers, 2006). This greatly exceeded the performance of standard retention ponds, as well as expensive manufactured devices (Landers, 2006). Langland and Cronin (2003) reported that wetland restoration and tree planting were the most effective BMPs at reducing sediment runoff from agricultural fields (96% from high-till fields).

Studies of wetland water quality benefits, cited by the California Dept. of Water Resources (2005) and Sipple (2007), include the following:

- Tidal wetlands in Louisiana provided \$11,000 (2006 \$) worth of water treatment benefits per acre per year (1974 study).
- Wetlands along the shores of the Great Lakes in Michigan provided \$15,700 (2006 \$) worth of water quality improvement per acre per year (1978 study).
- Natural waste assimilation by marsh in the Charles River Basin of Massachusetts substituted, per acre, for annual capital costs of \$200 plus \$3,480 in maintenance and operation costs of a tertiary waste treatment plant (2006\$; 1981 study).
- The Congaree Bottomland Hardwood Swamp in South Carolina removes a quantity of pollutants equivalent to a \$5 million waste water treatment plant (1990 study).
- A 2,500 acre wetland in Georgia saved \$1 million in water pollution abatement costs annually, or \$400/ac/year (study date unknown).

Hey et al. (2005) found that the cost of restoring and operating wetlands to remove nitrogen and phosphorus was 50-70% less than the cost of constructing and operating engineered wastewater

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treatment systems. To achieve the standards of 3.0 mg/L of nitrogen and 1.0 mg/L of phosphorus that 189,000 ac of wetlands could achieve, \$184 million/year of annualized costs would be required to build and operate treatment systems. In 2006 dollars, this translates to a wetland value of \$1000/ac/year.

Erosion control and sediment retention

Forests

Standing vegetation stabilizes soils, especially along stream banks, on steep slopes, and where soils are highly erodible. Forests and forest buffers help protect streams by sheltering and anchoring their banks. Trees and vegetation also intercept driving rain and slow the flow of water over the ground, thereby reducing scouring and preventing soil from eroding into water bodies and roads. Increased sediment loads in streams and lakes can impact fish and invertebrate populations and habitats, alter stream channels, and reduce water quality. Erosion also leads to poor soil productivity (Moore, 2002). Dreher and Price (1995) reported sediment delivery from developed land as 8 to 28 times greater than that from woodlands and wetlands.

The increased impervious surface associated with development has major impacts on stream biota. Loss of forest leads to fluctuating water levels, higher peak velocities, unstable stream banks and beds, increased sedimentation, loss of deep pools and coarse woody debris, and decreased water quality. According to Boward et al. (1999), when watershed imperviousness exceeds 25%, only hardy, pollution-tolerant organisms can thrive. Other species decline or become extinct. Above 15% impervious cover in a watershed, fish and benthic macroinvertebrate community condition, as measured by the indices of biotic integrity, is fair to poor (i.e., never good). Even very low levels of imperviousness can have detrimental effects. When upstream impervious land cover is above 2%, pollution-sensitive brook trout are never found (Boward et al., 1999).

As mentioned earlier, NRCS (2007) estimated Maryland's annual soil loss to erosion at 3.6 tons/acre. With soil retailing at \$42/ton (discussed previously), the value of forest in preventing soil erosion is thus \$151/ac. Avoiding the cost of dredging could be added, but this is a service best performed by riparian buffers.

Riparian buffers

Riparian vegetation is especially important for sediment retention. During flood events, streams and rivers overtop their banks, and water flows through the adjacent floodplains and wetlands. Flood waters often carry large volumes of suspended sediment, mostly fine sand, silt and clay. Because dense vegetation, microtopography, and woody debris in floodplains and wetlands provide resistance, the flow of water is slowed and sediment is deposited and stored there (Maryland Department of the Environment, 2006).

Riparian forest buffers reduce flood damage as they reduce water velocities and capture sediments. The sedimentation of streams contributes to flood damage by filling in streambeds and increasing the frequency and depth of flooding and by increasing the volume of flood waters, as well as by causing additional damage itself (Klapproth and Johnson, 2001). In Delaware, Weber (2007) found that streams were likely to be in better physical condition if their upstream catchment had >45% riparian forest or wetland (within 30m of the stream bank). Streams were rated according to their sediment load, bank stability, and eutrophication.

Once a stream is degraded by erosion, it is very expensive to restore. According to DNR's Watershed Restoration Division and Baltimore County's Department of Environmental Protection and Resource Management, the unit cost for stream restoration, design, and construction averages \$1.2 million per mile in urban and suburban watersheds (Moore, 2002). DNR estimates that stream restoration in non-urban watersheds costs approximately \$0.6 million per mile (Moore, 2002), or around \$130 per foot in 2006 dollars. This figure does not include monitoring costs.

Maryland's State Highway Administration (SHA) estimates the following construction costs for stream restoration (Sandy Hertz, SHA, personal communication, July 24, 2007):

- Full stream restoration (new channel): \$300 - \$500 per linear foot

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- Bank armoring only/spot restoration: \$100 - \$300 per linear foot
- Vegetative stream restoration (biologs/fascines etc.): \$50 - \$100 per linear foot
- Riparian buffer planting only: \$5 - \$50 per linear foot

Design costs are typically 30% of the construction costs, and the monitoring budget over 5 years is around \$30 per linear foot (Sandy Hertz, SHA, personal communication, July 24, 2007). Using a construction cost of \$100 per linear foot, adding design and monitoring costs, and annualizing over 20 years with a 7% interest rate³, this totals \$15/ft/year. These costs are equivalent to DNR's estimate for rural stream restoration.

The Maryland Dept. of Natural Resources Stream ReLeaf program recommends a buffer width of 100 feet on each side. In Cecil County, which is still primarily rural, the value of riparian forest (usually recommended for restoration purposes to be 100 ft from either bank) is correspondingly \$15/year * 43,560 ft²/ac / 200 ft² = \$3,267/ac/year.

Klapproth and Johnson (2001) reported that sedimentation increases the rate at which lakes and reservoirs are filled, costing communities millions of dollars to create new facilities and to maintain existing ones. A 1985 study estimated that 1.4 to 1.5 million acre-feet of reservoir and lake capacity are permanently filled each year with sediment (Klapproth and Johnson, 2001). Nationwide, sedimentation of water storage facilities cost communities nearly \$1.1 billion in 1983 (Klapproth and Johnson, 2001). Nearly a million acre feet of additional storage capacity, at a cost of \$600 to \$1400 per acre-foot (2006 dollars), must be built to capture and store sediment (Klapproth and Johnson, 2001).

Another cost of increased sedimentation is the public dredging of channels. In fiscal year 2002, Congress appropriated over \$50 million for U.S. Army Corps of Engineers projects in Maryland, including the annual maintenance dredging of Baltimore shipping channels; the maintenance dredging of the Ocean City Harbor, Inlet and Sinepuxent Bay; the dredged material use at Poplar Island; and new dredging projects in Dorchester, Wicomico, Charles, and Anne Arundel counties. State and local sources spend significant amounts as well. In fiscal year 2001, DNR's Waterway Improvement Fund provided over \$1.4 million to applicants for dredging projects. Baltimore County reported spending about \$6 million on dredging projects between 1988 and 2001. Sedimentation also reduces the capacity of reservoirs to hold water, requiring expensive periodic dredging (Moore, 2002).

Wetlands

Wetland vegetation helps control erosion in coastal, lacustrine and riverine systems by binding and stabilizing substrates, dissipating wave and current energy and trapping sediments (Sather and Smith, 1984). Physical forces may prevent vegetation from establishing; wetland plants are usually found where waves, currents and wind are not too strong (Sather and Smith, 1984). Wetland erosion control effectiveness depends on the flood tolerance and resistance to undermining of plants, the width of the vegetated shoreline band, the efficiency of the shoreline band in trapping sediments, the soil composition of the bank or shore, the height or slope of the bank or shore, and the elevation of the bank toe with respect to mean storm high water (Sather and Smith, 1984; Osmond et al., 1995). Coastal and estuarine marshes retain sediment brought in by tides and residual suspended sediment from rivers (Maryland Department of the Environment, 2006).

The value of wetlands in trapping sediment is higher than that of upland forest, since wetlands can trap sediments from upslope, much as an engineered sediment basin does. Typically, wetland vegetation traps 80-90% of sediment from runoff (Osmond et al., 1995). The California Stormwater Quality Association (2003) reports the average annual costs for installing and maintaining a sediment basin as \$0.05/gallon (2006 \$). With an acre of wetlands typically able to store 1.0-1.5 million gallons of floodwater (U.S. Environmental Protection Agency, 2006), and multiplying by 0.8, this translates to \$40,000 per acre of wetland.

Tidal marsh

³ Annual cost parameters were chosen to be consistent with other engineering costs in this study.

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Shore erosion is a serious problem in the Chesapeake Bay. Maryland loses approximately 260 acres of tidal shoreline to erosion each year (Maryland Shore Erosion Task Force, 2000). In Cecil County, 44 miles of shoreline (22% of the total) are eroding (Maryland Shore Erosion Task Force, 2000). Not only are shorelines and islands disappearing, but shore erosion adds 11 million cubic yards of sediment, 5.7 million pounds of nitrogen, and 4.2 million pounds of phosphorus per year to the Chesapeake Bay, degrading water quality (Maryland Shore Erosion Task Force, 2000).

Tidal marsh offers considerable protection from shore erosion. A study in the Chesapeake Bay showed that 30m wide *Spartina alterniflora* marshes reduced wave energy by virtually 100% (Knutsen et al., 1990). Widths of 20m were nearly as effective, reducing wave energy by 98% (Knutsen et al., 1990). Marsh creation is the cheapest way to stabilize shorelines, costing \$34 per linear foot (2006 \$) (U.S. EPA, 1993). In contrast, structural stabilization averages around \$410/foot (2006 \$) (Maryland Shore Erosion Task Force, 2000). The Army Corps of Engineers estimated that for every dollar spent to control erosion, as much as \$1.75 is returned to the economy in the form of improvements to resources, including submerged aquatic vegetation, fish, benthic organisms, shellfish, and wetland habitat (Maryland Shore Erosion Task Force, 2000).

1,863 acres of tidal marsh were identified in Cecil County from DNR wetland data (see Appendix A for which classes were selected). 186.7 km of shorelines and 33.1 km of streams were within or adjacent to this tidal marsh⁴. Just looking at shorelines, tidal marsh performs the equivalent of 186.7 km * 3281 ft/km * \$410/ft = \$251 million of structural stabilization. Annualized over 20 years, with a 7% interest rate, this is \$23.7 million/year. Dividing by 1,863 acres gives \$12,700/acre/year.

Regulation of water temperature

Riparian buffers

Riparian vegetation shades adjacent streams, moderating water temperatures and protecting against rapid fluctuations that can harm many aquatic species. Elevated water temperatures and increased sunlight when riparian vegetation is lost can also accelerate algae growth and reduce dissolved oxygen. In a small stream, temperatures may rise 1.5 degrees in just 100 feet of exposure without trees (Casey, 2004). Many aquatic organisms cannot survive such stresses. Currently, very few Maryland streams are cool enough to support brook trout, particularly in the eastern half of the state. Loss of forests is a key factor in their population decline (Boward et al., 1999).

According to Long (2000), a 1987 survey of willingness to pay and travel costs for trout fishing in Maryland averaged \$39.31/person/day (1987 \$). There were an estimated 467,600 trips made for trout fishing in Maryland in 1987, and the mean number of days per trip was 1.54. This equates to approximately 720,104 trout fishing days in 1987 statewide. With 463 miles of trout streams in Maryland, the average value per mile was \$108,000 (2006 \$). Because trout require cold water to survive, the value of temperature moderation by riparian forest (within 100 feet of the bank on each side) would be $\$108,000/\text{mi} / ((200 \text{ ft} * 5280 \text{ ft}/\text{mi}) / (1 \text{ ac}/43,560 \text{ ft}^2)) = \$4,450/\text{ac}$.

Pest control

Worldwide, there are an estimated 9000 species of insect and mite pests, 50,000 species of plant pathogens, and 8000 species considered weeds, of which 5% are serious economic problems (Pimentel, 1998). Approximately 99% of pests are controlled by predators and host plant resistance (Pimentel, 1998). However, Pimentel (1998) estimated that pests destroy \$100 billion/year in potential food and fiber in the U.S.

Forests

Large blocks of forest, especially those containing interior habitat, can help control pests in nearby agricultural fields or residential areas. Bats and insectivorous birds, which roost or nest in forests, prey on

⁴ Tidal marshes from DNR wetlands were buffered 10m to account for spatial errors, then streams and shorelines from the county hydrology layer were clipped within this buffer.

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a large variety of invertebrates. Blankenship (2000) estimated the forest pest control value of birds at \$5,000/acre. Pimentel (1998) estimated the value of natural enemies to pests within forests at \$20 million/year, or \$8.50/acre (2006 \$), a relatively low number. The most common bat found in Maryland, the little brown bat (*Myotis lucifungus*), can consume up to 600 mosquitoes in just one hour (Chesapeake Wildlife Heritage, 2001).

Forest edge species consume insects on nearby crops. For example, the indigo bunting feeds on grasshoppers, beetles, cankerworms, flies, mosquitoes, cicadas, weevils and aphids (Chipper Woods Bird Observatory, 2001). In contrast, use of chemical pesticides to control insects is increasingly ineffective as pests evolve resistance to the pesticides. Pesticides can also poison groundwater and streams. Pimentel (1998) estimated that crop losses in Maryland would be at least \$120 million/year greater (2006 \$) without natural enemies, or \$41/acre of forest habitat.

Pollination

The recent population decline of domesticated European honeybees (Roach, 2004a), and its impact to farmers, shows what happens when we rely on a single species for a given need. Crop pollination shortages are becoming increasingly common (Greenleaf and Kremen, 2006). There are about 4,000 different species of wild bees native to North America (Roach, 2004b), not to mention other insects, bats, birds, etc., that can pollinate crops. In fact, prior to the advent of large-scale monoculture agriculture in the 1950's, the elimination of woodlots, hedgerows, wind breaks, etc., and mass use of chemical pesticides, wild bees and other species did all the pollinating (Roach, 2004b). Reliance on trucked beehives is a recent phenomenon.

Forests

Studies of watermelon farms in central California and coffee farms in Costa Rica showed that plants near forest stands were pollinated much more effectively, by a variety of native bee species, than plants further away and reliant on domestic bee hives (Ricketts et al., 2006). Furthermore, the high diversity of bees supported by these forested areas meant that when one species declined (insect populations fluctuate from year to year), there were many other species able to take over, making crop pollination reliable from year to year (Ricketts et al., 2006). Forests and other areas with high plant diversity have different flowers blooming throughout the spring and summer, and therefore can support pollinators year-round.

Even where domestic honeybees are used, Greenleaf and Kremen (2006) found that "behavioral interactions between wild and honey bees increase the pollination efficiency of honey bees on hybrid sunflower up to 5-fold, effectively doubling honey bee pollination services on the average field," and "both proximity to natural habitat and crop planting practices were significantly correlated with pollination services provided directly and indirectly by wild bees." Greenleaf and Kremen (2006) suggested conserving natural habitat to increase crop production (in the case of sunflowers) and protecting wild bee populations to ensure our food supply.

The standard stocking rate using domestic honeybees for pollination is 1.5 hives per acre (Greenleaf and Kremen, 2006). As of 2007, Michigan farmers were paying \$50-60 to rent each hive (Hair, 2007). California almond growers, where the demand is high, were paying \$125-150 per hive, and using 2 hives per acre (Hair, 2007). Using the lowest of these figures, we can infer a crop pollination value from nearby forest of \$75/ac/year. Pimentel (1998) reported a pollination value of \$195 million for Maryland (in 2006 \$), which also translates to \$75/year per acre of forest.

Wood products

Natural lands provide a direct source of wood, food, and other products. These provide a livelihood for those in the timber and fishing industries, as well as contribute to the larger economy as these employees both spend their money in the community and add value to natural products to create furniture, houses, frozen food dishes, etc.

Forests

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Forestry and wood products are the fifth largest industry in Maryland (Moore, 2002). The long-term profitability of this industry is directly linked to a sustainable forest resource base. In 2001, according to the economic model IMPLAN, the forestry and wood products industries in Maryland generated \$2.4 billion in income, and created over 16,000 jobs.

Cecil County generated \$9 million in wood products and 180 jobs in 2001 (IMPLAN data). According to FIA data, Cecil County had 72,000 acres of harvestable timber land in 1999. Most (81%) was oak/hickory forest. Dividing, each acre of forest generates \$142/year for the wood products industry (2006 \$), even though it takes decades for the trees to reach harvestable size.

Fish and wildlife habitat

Wetlands

Some species of wildlife rely on wetland habitats throughout their lives, while others only reside in wetlands seasonally. The size, nature of the surrounding landscape, substrate, and vegetation of a wetland influence the species found there. Many game species spawn in wetlands; however, this is dependent on their water depth and quality, vegetation, soils, and interspersions with other land types. Several commercially trapped mammal species are dependent on wetlands, including muskrats and beavers. Nearly a third of North American bird species require wetlands at some time in their lives for food, cover, breeding, molting, or resting grounds (Sather and Smith, 1984).

Tidal marsh

The U.S. commercial fisheries harvest is worth more than \$2 billion annually (Sipple, 2007), providing the basis for a \$26.8 billion fishery processing and sales industry (Sipple, 2007), and in 1988, employing over 274,000 fishermen and 90,000 shore workers (Stedman and Hanson). Overall, including both commercial and recreational endeavors, seafood is a \$50 billion industry (Sipple, 2007). Fish and shellfish that depend on wetlands for at least part of their life cycle (e.g., food sources, spawning grounds, or nurseries for young) constitute more than 75% of the commercial and 90% of the recreational harvest (Sipple, 2007). The coastal marshes of Louisiana alone produce a commercial fish and shellfish harvest amounting to 1.2 billion pounds annually, which was worth \$244 million in 1991 (Sipple, 2007). In this region, 96% of the commercial harvest and more than 50% of the recreational catch are wetland-dependent fish and shellfish (Sipple, 2007).

About 78% of the commercial fish and shellfish in the Chesapeake Bay are dependent on estuarine wetlands, including striped bass, menhaden, hard clam, and blue crab (Stedman and Hanson). Maryland's commercial fisheries are also 78% dependent on estuaries and their wetlands (Stedman and Hanson). In 1999, commercial landings of fish and shellfish in Maryland totaled 67 million pounds, worth \$64 million in sales (O'Bannon, 2001). Landings dropped by 27% in 2000 (O'Bannon, 2001). In 2002, the cumulative impact of commercial fish and shellfish landings in Maryland added \$182 million to Maryland's economy (2006 \$) (Ryan and Duberg). Dividing 78% of this by the area of marsh (almost all of which is coastal), emergent wetlands contributed \$617/ac in fish and shellfish production.

Genetic information and biological diversity

All ecosystems can be visualized as a web of materials and organisms, interconnected by flows and transformations of energy, matter, and information. Each native species is uniquely adapted to transform and channel energy in an ecosystem, and each plays a role in ecosystem functioning. Ecosystems with higher diversity are generally more efficient. For example, diverse communities are more likely to contain species able to utilize different amounts and combinations of limiting resources like nutrients or light; and more likely to have symbiotic relationships. As species are lost from an ecosystem, those that depend on them for food, pollination, or other needs, also begin to disappear. Many interconnections between species are not even known (witness the difficulty of multi-species fishery management, for example). Ecosystem resistance and resilience to stresses is dependent on species composition and diversity. Diverse communities are more likely to contain species tolerant to disturbances like flooding, drought, or pests. The spread of pests is quicker among spatially contiguous hosts. Monocultures like corn or wheat fields are more susceptible to disease or pest outbreaks than diverse systems, and have to be maintained

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with intense management. Ecosystems with low diversity, like islands or agricultural fields, are also more susceptible to invasion by exotic or weedy species, because of empty niches (Weber, 2003).

Top predators are especially important because they act as ecosystem regulators (Soule and Terbough, 1999). In their absence, trophic structures can become destabilized, with consumers and mesopredators becoming more abundant, and floral recruitment and diversity decreasing (Soule and Terbough, 1999). In Maryland, the loss of top carnivores like cougar and wolves, along with increased edge habitat, has led to an overpopulation of white-tailed deer in many areas. Exceeding the regional carrying capacity, deer over-browse tree seedlings and herbs. The native herbs are often replaced by exotic invasives like Japanese stiltgrass (*Microstegium vimineum*) or garlic mustard (*Alliaria petiolata*), which the deer tend to avoid. The decreased plant diversity in turn affects animals dependent on them for food or cover.

The loss of species impacts the functional capacity of the ecosystem to provide services valued by humans. For example, recruitment of oaks (a valuable timber tree) has suffered as uncontrolled populations of deer preferentially browse on oak seedlings. Many Maryland forests are dominated by maples, sweetgum, and tulip poplar, which also have less food value to wildlife than oaks and hickories. As illustrated by the bee study in Costa Rica, biodiversity provides protection from fluctuations, whereas reliance on a single species, domestic honeybees, has left farmers at risk of losing their crops. In another example, Madritch and Hunter (2002) found that intraspecific tree diversity, as expressed in varying leaf litter chemistry, can affect the ecosystem processes of carbon and nitrogen cycling. Our knowledge is far too limited to compensate with engineering for the millions of Earth's species that are each evolved to capture and process energy and materials as efficiently as possible.

One of the greatest values of biodiversity might be a capacity to adapt to change, such as global warming. Another value is the mostly untapped potential of species and genes to tailor crops, cure diseases, and provide other vital services. All of our food crops have their roots in wild species. Wild rice, which has a species native to Maryland, is an invaluable source of new genetic material for developing disease resistance in one of the world's most important crops.

Host-plant resistance (HPR) is widely used in agriculture to combat pests and diseases because it significantly reduces the need for pesticides, which are both expensive and environmentally destructive. In the wild, all plant species rely on HPR characteristics such as thorns, hairs, coatings, chemicals, and other repellants (Pimentel, 1998). A single tree may contain 1000 different chemicals (Pimentel, 1998). Such traits can be transferred to cultivated crops. In fact, the vast majority of crops contain some degree of HPR, increasing yields and economic returns (Pimentel, 1998). Pimentel (1998) reported that this saves \$80 million per year in potential losses to pests and pathogens in Maryland (2006 \$), and that the benefits of using HPR nationwide are about \$300 for every \$1 spent on research and development. The Ramsar Convention on Wetlands (2000a) reported that the value of wild plant traits on a global scale is in the billions of dollars globally.

Unfortunately, pests and diseases often evolve tolerance to crop resistance factors (Pimentel, 1998). A typical lifespan of a commercially-bred crop variety has been estimated at 5-10 years before new genetic material is required to combat pest and disease problems (Ramsar Convention on Wetlands, 2000a). This means new forms of genetic resistance must continue to be identified and obtained from plants in natural ecosystems (Pimentel, 1998).

Over 20,000 medicinal plant species are currently in use, and over 80% of the world's population depends on traditional medicine for their primary health care needs (Ramsar Convention on Wetlands, 2000a). Roughly half of all prescription medicines are derived from natural sources, not to mention vitamins and herbal supplements. In the U.S., prescription drugs linked to discoveries made in nature have an economic value of \$80 billion (Jenkins and Groombridge, 2002). Research on a South American clawed toad revealed that chemicals in its skin have potential as antibiotics, fungicides and anti-viral preparations (Ramsar Convention on Wetlands, 2000a). The blood of horseshoe crabs contains a compound used by the pharmaceutical industry to test the purity of drugs and medical equipment that holds human blood (Ramsar Convention on Wetlands, 2000a). However, only a small percentage of

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species have been examined for potential pharmaceutical applications: less than 1% of the world's 250,000 tropical plants have been screened, for example (Jenkins and Groombridge, 2002). And unfortunately, at current extinction rates of plants and animals, Earth is losing a major drug every two years (Jenkins and Groombridge, 2002). Fowler (2006) writes,

"Increased interest in plants as a source of novel pharmacophores recognizes their chemical diversity and versatility, not matched by synthetic chemistry libraries. In spite of the surge of activity in synthetic chemistry over the last 20 years or so, almost half the some 850 small molecules introduced as drugs were derived from plant sources. Over 100 small molecules derived either directly or indirectly from plants are currently at some point in the clinical trials process. It is argued that the present use of plant-derived drugs and remedies only scratches the surface of what is a major reservoir of untapped potential, the level of biological and chemical diversity possessed by plants having much to offer in the drive for novel therapeutic agents in the fight against disease."

Biological diversity and genetic information are not easy to translate into dollar terms. Aside from contributing to other ecosystem functions and values, species and genotypes found in Maryland have unknown potentials for agricultural, pharmaceutical, and biotechnology advances. Maryland supports globally rare species, which are a logical starting point for protecting such a legacy. Since species are irreplaceable once extinct, this should be a constraint on economic activity rather than something to trade off, and we should try to ensure their long-term survival as an investment for future generations. Just as we preserve scientific, engineering, and cultural knowledge in libraries, so should we preserve our world's genetic library.

Recreation

Natural areas not only provide a list of ecological services, they provide an array of recreational opportunities that contribute to our quality of life. These include hunting, fishing, hiking, bird watching, camping, rock climbing, canoeing, and many others. A study by Balmford et al (2002) reported that the economic value of retaining Canadian freshwater marshes for hunting, angling and trapping was 60% greater than the value derived from converting them to agriculture. This did not include other values such as nutrient cycling, water regulation, and peat accumulation.

The demand for outdoor recreation in the United States has greatly outpaced population growth. Nationally, more than half of all adults hunt, fish, bird watch or photograph wildlife, spending \$59.5 billion annually (Sipple, 2007). Nature-related recreation is the fastest growing sector of the tourism industry (Sipple, 2007). Visits to national parks jumped 134% between 1965 and 2000, to 284.1 million (McQueen, 2001). Visits to national forests and wildlife refuges have also increased dramatically. Bird watching is the fastest growing outdoor activity, tripling from 1982-83 (21 million participants) to 1997 (63 million) (Sipple, 2007). Nationally, 24.7 million people took trips away from home in 1991 to partake in birding, spending \$5.2 billion in goods and services, generating 191,000 jobs, and bringing governments more than \$895 million in sales and income tax revenues (Sipple, 2007).

Other fast-growing activities include hiking, backpacking, and camping. In 1993, the 273 million visitors to national parks created more than \$10 billion in direct and indirect expenditures, and generated more than 200,000 jobs (McQueen, 2001). The National Park Service's operating budget was \$1 billion in 1993, bringing taxpayers a 10 to 1 return on their investment (McQueen, 2001). Boating, canoeing, and rafting are popular activities. A 1990 study of whitewater rafters on the Youghiogheny River in Garrett County, Maryland, found that they contributed nearly \$1.2 million dollars to the local economy (Klapproth and Johnson, 2001). This included money paid to local rafting companies, lodging, food and beverages, entertainment, souvenirs, boating equipment, and auto-related items (Klapproth and Johnson, 2001).

Hunting and fishing continue to be popular activities. In 1991, 3 million migratory bird hunters generated \$1.3 billion in retail sales, with a total economic multiplier effect of \$3.9 billion, associated with 46,000 additional jobs and sales and income tax revenues of \$176 million (Sipple, 2007). In Pennsylvania, the opening of deer season is one of the most anticipated days of the year.

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A survey by the U.S. Fish and Wildlife Service (2003) revealed that in 2001, 1.9 million persons 16 years old and older engaged in fishing, hunting, or wildlife-watching activities in Maryland. Of these, 701,000 fished, 145,000 hunted, and 1,524,000 (the majority) participated in the passive observing, feeding, and photographing wildlife (U.S. Fish and Wildlife Service, 2003). In the same year, state residents and non-residents spent \$1.7 billion on wildlife-associated recreation in Maryland (U.S. Fish and Wildlife Service, 2003). This was a 55% increase from 1996 (\$1.1 billion: U.S. Fish and Wildlife Service, 1998), far exceeding the general rate of inflation (13%).

In 2001, residents and non-residents spent \$116 million on freshwater fishing in Maryland, which depends on forests and wetlands to maintain water quantity and quality. \$67 million was spent hunting deer and wild turkey, and \$3 million hunting squirrels, all of which are forest-dependent. People spent \$11 million hunting duck and geese; the largest percentage of this would be in marshes. People spent \$761 million watching wildlife in Maryland, not including home expenditures (bird feeders, bird baths, plantings, bird and wildlife food, etc.) (U.S. Fish and Wildlife Service, 2003).

Wildlife viewers in Maryland spent \$130 million on trip expenditures alone (U.S. Fish and Wildlife Service, 2003). 90% of wildlife viewers spent at least part of their time watching birds, and 82% of people viewing wildlife away from home visited parks and other public areas (U.S. Fish and Wildlife Service, 2003). In 1993, there were 273 million visitors to national parks and in 1994-5, there were 54.1 million birdwatchers in the U.S. (McQueen, 2001). If visits to parks in Maryland follow a similar ratio, passive recreation trip expenditures in 2001 were: \$130 million + (\$130 million * .90 * .82) * (273 million - 54.1 million) / 54.1 million = \$518 million.

On trips away from home, wildlife watchers in Maryland were 38% more likely to visit "woodlands" (upland forest) than wetlands (U.S. Fish and Wildlife Service, 2003). But upland forest was 4.72 times more numerous in the state than wetlands (1991-3 NLCD), implying that wetlands were 3.4 times more likely to be visited per acre than upland forest. We had no data to justify assigning different per acre expenditures for non-wildlife recreation, though. To summarize:

Wetland wildlife watching trips (MD total) = \$130 million * 0.5 / (0.69 + 0.5) = \$54.6 million
Forest wildlife watching trips (MD total) = \$130 million * 0.69 / (0.69 + 0.5) = \$75.4 million
Wetland wildlife watching trips (per ac) = \$54.6 million / 0.552 million ac = \$99/ac wetland
Forest wildlife watching trips (per ac) = \$75.4 million / 2.606 million ac = \$29/ac upland forest
Other passive recreation trips (MD total) =
(\$130 million * .90 * .82) * (273 million - 54.1 million) / 54.1 million = \$358 million
Other passive recreation trips = \$358 million / 3.158 million ac = \$133/ac forest or wetland
Other wildlife watching expenditures = \$631 million / 3.158 million ac = \$200/ac forest or wetland
Freshwater fishing = \$116 million / 2.928 million ac = \$40/ac upland forest or forested wetland
Forest game hunting = \$70 million / 2.606 million ac = \$27/ac upland forest
Waterfowl hunting = \$11 million / 0.230 million ac = \$48/ac marsh

Summing and converting from 2001\$ to 2006\$, we estimated the recreation value per year as \$486/ac of upland forest, \$534/ac of forested wetland, and \$544/ac of marsh.

Savings in community services

Cost-benefit analyses of development versus land preservation tend to show a net loss over time for developed lands (Balmford et al, 2002; Moore, 2002). Sprawl development often increases the cost of public services by requiring huge investments in new roads, sewers, schools and other public infrastructure (Benedict and McMahon, 2002). The conversion of farms and forests to residential development can drain a community's resources. Many studies show that farming and forestry generate much more revenue than the public services they require (Benedict and McMahon, 2002). For example, a study by the American Farmland Trust (AFT) found that farms and forests cost governments only 37 cents for every dollar received from the landowners in taxes (McQueen, 2001). On the other hand, urban sprawl and the inefficient use of land and resources require communities to stretch services across a

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larger area, and at a higher cost than the revenue generated by taxing these new residents (Benedict and McMahon, 2002). The AFT study found that residential development costs local governments \$1.15 in required public services for every dollar collected in taxes (McQueen, 2001).

In Cecil County, residential development from July 2000 to June 2001 generated \$72,232,503 in revenues to cover expenditures of \$84,308,241, resulting in a deficit of \$12,075,738 (American Farmland Trust, 2002). Cecil County's population was 85,951 in 2000 (U.S. Census Bureau), so the per capita deficit was \$164.51 in 2006 dollars. In Maryland, low-density housing was 58% of development in 1997, and this percentage has been steadily increasing (American Farmland Trust, 2002). The Maryland Dept. of Planning estimates that Cecil County will lose 1.17 acres of agricultural and forest land with each new household between 1997 and 2020 (American Farmland Trust, 2002). The average family size in the county was 3.12 in 2000 (U.S. Census Bureau). Thus for each acre of forest converted to housing (single detached homes usually belong to families), the county loses around \$439 per year in net expenditures ($\$164.51 * 3.12 / 1.17$).

Increase in property values

Many studies have shown that parks and greenways increase adjacent property values (Bockstael, 1996; McQueen, 2001). Reviewing 25 major studies examining the effects of open space on property values, Crompton (2001) found that 20 of the studies concluded that open space and parks increased nearby property values. Four of the five other studies reached ambivalent conclusions (Crompton, 2001). A 2002 survey of home buyers found that nearby trails and parks were among the most important amenities, well ahead of ball fields and golf courses (National Association of Home Builders and National Association of Realtors, 2002).

The quality of life of a community is an increasingly important factor in the location decisions of businesses. In one survey, corporate CEOs said that quality of life for employees was the third most important factor in locating a business, behind only access to domestic markets and availability of skilled labor. More than 80 percent of the 450 members of the Sierra Business Council in California and Nevada cited the region's rural landscape and wildlands as a significant attraction of the region. The Trust for Public Land found that access to open space, parks, and recreation was the number one factor used by small businesses in choosing a new location (McQueen, 2001).

Unfortunately, very few studies contain information needed to translate acres of forest or wetland into neighboring property values. In an exception, Geoghegan et al. (2003) compared 1993-1996 home sales data for Calvert, Carroll, and Howard counties to the amount of open space surrounding the house. They found that a 1% increase in easements or public parks within 1,600 meters of the house (equivalent to a 20-minute walk from the front door) increased property values between \$0 and \$1,306, depending on the county. A 1% increase in protected land was $(0.01)(1600m * 1600m * 3.1416) / (1 \text{ ac}/4047 \text{ m}^2) = 20 \text{ ac}$. Taking the midpoint of the value range (\$653), dividing by the area, and converting to 2006\$, gives a value of \$42/ac.

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SUMMARY OF ECOSYSTEM SERVICES

We lumped ecosystems into four broad classes, based on documented differences in ecosystem services:

- Upland forests – includes forest without any wetland characteristics, and temporarily flooded or saturated wetlands (water regime modifiers A and B in Cowardin code), unless subject to flooding from adjacent streams or rivers.
- Riparian forests and wetlands – Forested areas and wetlands subject to flooding from adjacent streams or rivers; on, or connected to, alluvial soils.
- Non-riparian wetlands – all non-riverine wetlands flooded at least seasonally.
- Tidal marsh – Hydrology greatly influenced by tides, and vegetation dominated by emergent plants (shrubs may also be present on higher elevations).

Table 1 sums the ecosystem service values described above. The caveats mentioned in the overview should be kept in mind. We were unable to estimate many of the values for marsh and riparian buffers, and hope that more information might be available. The higher values, such as for flood and erosion control, demonstrate the high cost of engineered replacements for ecosystem services. The value of carbon sequestration might be considerably higher if one considers the consequences of unchecked global warming. However, since the scale of climate change is global, and sequestration is only one part of a complex picture, we decided to only use existing market values.

Table 1. Estimates of ecosystem service values for Cecil County.

Ecosystem service	Estimated value (2006\$/ac/yr)			
	Upland forest	Riparian forests and wetlands	Non-riparian wetlands	Tidal marsh
Carbon sequestration	31	65	65	65
Clean air	191	191	191	?
Soil and peat formation	17	946	450	1,351
Stormwater management/flood control	679	>32,000 ⁵	32,000	1,430
Water supply	8,630	8,630	8,630	N/A
Clean water	1,100	1,925 ⁶	1,100 ⁷	11,000 ⁸
Erosion and sediment control	151	3,418 ⁹	151 ¹⁰	12,700
Regulation of water temperature	N/A	4,450	N/A	N/A
Pest control	50	50	50	N/A
Pollination	75	75	75	N/A
Wood products	142	N/A	N/A	N/A
Fish and wildlife habitat	(included in recreation)	(included in recreation)	(included in recreation)	617
Genetic information and biological diversity	(ensure species survival)	(ensure species survival)	(ensure species survival)	(ensure species survival)
Recreation	486	534	534	544
Savings in community services	439	439	439	439
Increase in property values	42	42	?	?
TOTAL	12,033	52,765	43,685	28,146

⁵ The value for riparian wetlands should probably be higher than the value for non-riparian wetlands, but we lacked data to quantify this.

⁶ Value of forest plus the value specific to riparian buffers.

⁷ The value from Hey et al. was \$1000/ac/yr, but this value should be at least as great as upland forest.

⁸ Value from Louisiana study. While the water quality value of tidal marsh is not relevant to drinking water, it is very important for controlling pollution of the Chesapeake Bay.

⁹ \$3,267 for stream stabilization + \$151 for value of soil

¹⁰ Value as sediment basin (see text) captured in stormwater management value (i.e., alternative to stormwater basin).

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Wetlands had a much higher value per acre than upland forest, primarily because of their added hydrologic services.

Finally, Table 2 compares our results to some other available studies in the U.S., which have lower values, but assess fewer services. Pimentel (1998) also assesses many services, but not the ones with the most expensive engineered substitutes (hydrologic and erosion control).

Table 2. Some ecosystem value estimates by land cover type.

Land cover type	Value/ac/year (2006 \$)	Number of ecosystem services evaluated	Location	Source
Upland forest	12,033	13	Maryland	This study
Forest	1,114	4	Massachusetts	Breunig, 2003
Forest	443-2,175	4	Global	Wilson et al, 2004
Riparian forest	52,765	13	Maryland	This study
Non-riparian wetlands	43,685	12	Maryland	This study
Tidal marsh	28,146	10	Maryland	This study
Coastal marsh	4,000-28,000	4	Louisiana	Mitsch and Gosselink, 1993
Freshwater wetland	17,497	5	Massachusetts	Breunig, 2003
Freshwater wetland	1,981-25,213	6	Global	Wilson et al, 2004
Saltwater wetland	14,245	4	Massachusetts	Breunig, 2003
Saltwater wetland	11,293-13,010	4	Global	Wilson et al, 2004
Forests and wetlands	637	8	Maryland	Pimentel, 1998

APPLICATION IN CECIL COUNTY'S GREEN INFRASTRUCTURE

The values in Table 1 were summed within Green Infrastructure (GI) hubs to very roughly estimate a dollar figure of their value. As discussed earlier, large contiguous blocks of forest and wetland ("hubs") are more likely to contain fully functioning ecosystems, and more likely to provide corresponding values to humans. Hub delineations were based on 2002 land use and 2005 aerial photography.

We separated the landscape into the four ecosystem service categories in Table 1; all other areas (agriculture, development, mines, open water, etc.) were ignored in this exercise. Forest cover¹¹ was obtained from the National Land Cover Database (NLCD), which had a 30m resolution and was classified based on 2000-01 satellite imagery. Wetland locations and classifications were obtained from Maryland Department of Natural Resources (DNR), based on 1988 to 1995 aerial photography. Appendix A cross-walks Cowardin wetland codes in the DNR data to the ecosystem service classes in Table 1. We converted all GIS layers (source data in Appendix B) to grids with a cell size of 10m.

First, all tidal marsh was assigned to a unique category. The next category, riparian wetlands and forest, required looking at several data sets. Some riparian wetlands could be identified from the wetland codes. Riparian wetlands were also identified by their proximity to streams and shorelines¹². Available soil data¹³ was insufficiently accurate to delineate alluvial soils. Thus, upland riparian forest was defined as that within 30m of the stream bank. Non-riparian wetlands were wetlands classified in Appendix A as "non-riparian", or classified as "depends on location" and not identified earlier as adjacent to streams or

¹¹ Classes 41, 42, 43, and 90. There were no pixels classified as 52 (shrub-scrub).

¹² Streams and shorelines were extracted from hydrology delineated in Feb. 2007 by the Cecil County Planning and Zoning department. DNR wetlands classified in Appendix A as "riparian", "depends on location", "upland forest", or "upland" were placed in the riparian category if they were within 10m (to allow for spatial errors) of streams or shorelines. Wetlands classified as "non-riparian" were usually impounded.

¹³ Natural Soils Groups from Maryland Dept. of Planning. SSURGO soils were unavailable for Cecil County.

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shorelines. Lastly, to identify upland forest, we selected forests and woody wetlands from NLCD¹⁴, and removed areas identified earlier as riparian forest or other functional wetlands.

We divided the values from Table 1 by 40.4686 to scale to 10m cells, and assigned these to each cell¹⁵ corresponding to the appropriate functional class (Table 3). We summed the total value within the county, the entire GI network, and each hub (Table 4).

Table 3. Estimates of ecosystem service values per grid cell.

Ecosystem type	Value (\$/ac)	Value (\$/cell)
Upland forest	\$12,033	\$297
Riparian forests and wetlands	\$52,765	\$1,304
Non-riparian wetlands	\$43,685	\$1,079
Tidal marsh	\$28,146	\$696

Table 4. Estimates of ecosystem service values from forest and wetlands in Cecil County and Cecil Green Infrastructure.

Area	Area (ac)				Estimated value (2006\$/yr)
	Upland forest	Riparian forests and wetlands	Non-riparian wetlands	Tidal marsh	
Cecil County	60,050	25,370	633	1,857	\$2.1 billion
Cecil Green Infrastructure	45,446	19,620	563	1,724	\$1.7 billion

Forests and wetlands in Cecil County provide \$2.1 billion in ecosystem services each year according to our estimates. This amount is two-thirds that of the county's economic output (\$2.9 billion from all sectors in 2001, according to IMPLAN data; which is \$3.3 billion in 2006 dollars), and does not include ecosystem services from bodies of water, like the Chesapeake Bay. 80% of ecosystem service value was within the Green Infrastructure, which represents 37% of the county's land¹⁶. Protection of these areas is therefore a vital investment.

Ecosystem service value by hub (Fig. 1) was highly correlated¹⁷ with hub area (>99%), and also highly correlated with interior forest (99%), stream and shoreline length (98%), and unmodified wetland area (88%). Thus, hub area can be used to identify relative value in Cecil County's Green Infrastructure; the bigger the hub, the more valuable to humans. A more spatially explicit ecosystem service analysis might find differing emphases. Also, the contributions of biodiversity and genetic information were not given a monetary value, so rare species locations did not receive special weighting. A more comprehensive assessment of hub ecological value is discussed in the document, *An Assessment of Cecil County's Green Infrastructure*.

¹⁴ Classes 41, 42, 43, and 90. There were no pixels classified as 52 (shrub-scrub).

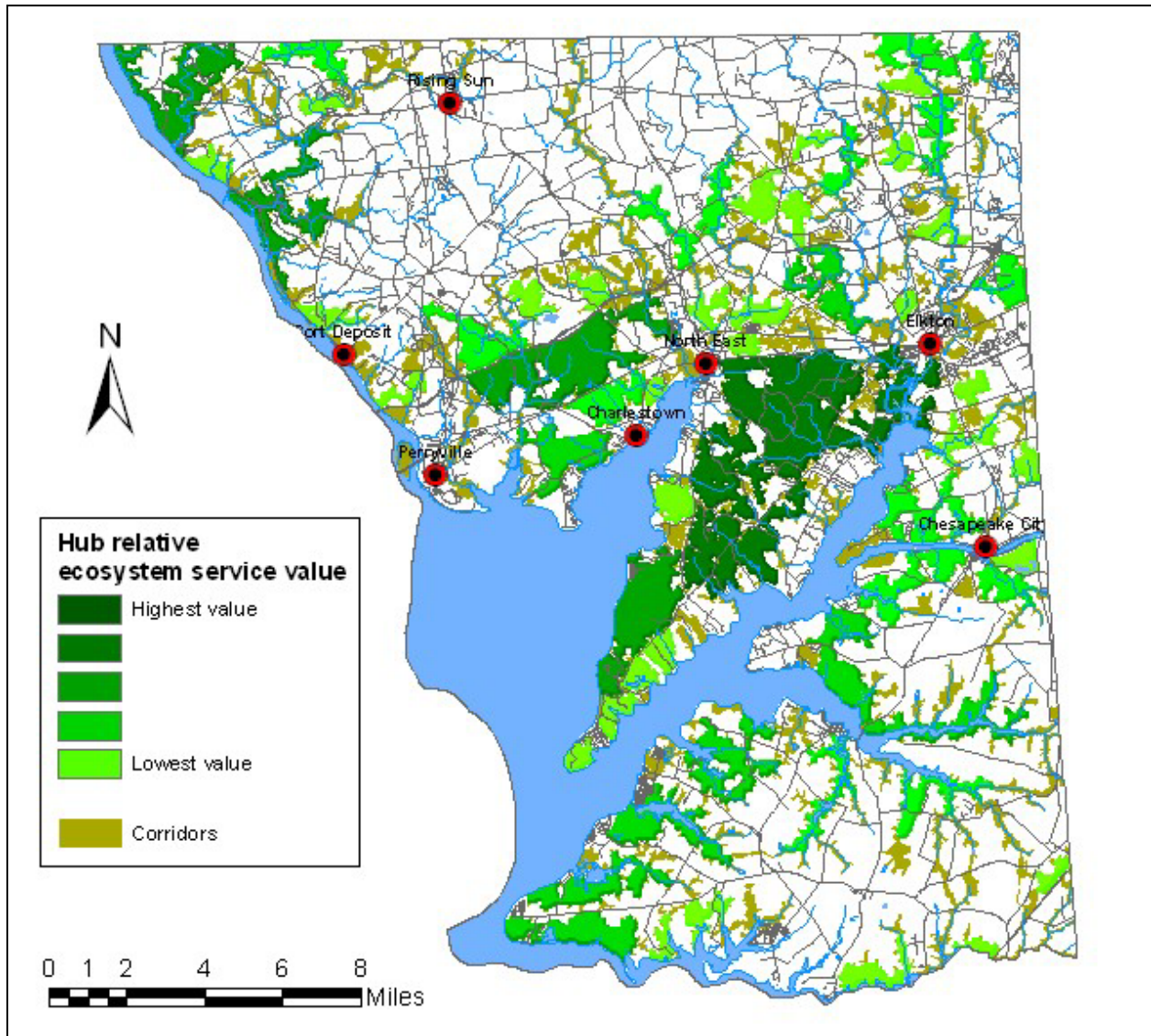
¹⁵ $\text{merge}((\text{tidal_marsh} * 696), (\text{rip_for_wetl} * 1898), (\text{nonrip_wetl} * 1079), (\text{upland_forest} * 297))$

¹⁶ Land was defined as all classes from NLCD other than open water.

¹⁷ Spearman rank correlations.

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Fig. 1. Relative ecosystem service value by hub in Cecil County's Green Infrastructure.



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APPENDIX A. Cross-walk table between wetland Cowardin codes and ecosystem service classes.

Wetland class	Acre in Cecil Co.	Human modified? (1 = yes)	Water regime	Ecosystem service class	Wetland class	Acre in Cecil Co.	Human modified? (1 = yes)	Water regime	Ecosystem service class
E2EM1/SS1P6	0.6		P	Tidal marsh	PFO1R	150.5		R	Riparian wetland
E2EM1P6	1279.1		P	Tidal marsh	PFO1S	7.1		S	Riparian wetland
E2SS1/EM1P6	4.3		P	Tidal marsh	PFO5/1Fb	3.3		F	Non-riparian wetland
E2SS1P6	8.7		P	Tidal marsh	PSS1/4A	1.0		A	Upland
E2US2P6	24.9		P	N/A	PSS1/4C	0.3		C	depends on location
E2USN6	625.2		N	N/A	PSS1/4Cb	0.5		C	Non-riparian wetland
PAB3Fb	0.5		F	Non-riparian wetland	PSS1/4R	3.0		R	Riparian wetland
PAB4Fb	1.1		F	Non-riparian wetland	PSS1/5Fb	1.8		F	Non-riparian wetland
PEM1/FO1A	2.7		A	Upland	PSS1/EM1A	18.3		A	Upland
PEM1/SS1A	20.0		A	Upland	PSS1/EM1C	8.3		C	depends on location
PEM1/SS1C	18.9		C	depends on location	PSS1/EM1Cb	11.0		C	Non-riparian wetland
PEM1/SS1Ch	2.0	1	C	Non-riparian wetland	PSS1/EM1Ch	17.6	1	C	Non-riparian wetland
PEM1/SS1E	14.0		E	depends on location	PSS1/EM1E	92.9		E	depends on location
PEM1/SS1Eb	9.6		E	Non-riparian wetland	PSS1/EM1Eb	27.9		E	Non-riparian wetland
PEM1/SS1Eh	3.8	1	E	Non-riparian wetland	PSS1/EM1Eh	14.4	1	E	Non-riparian wetland
PEM1/SS1F	5.6		F	depends on location	PSS1/EM1F	17.0		F	depends on location
PEM1/SS1Fh	2.9	1	F	Non-riparian wetland	PSS1/EM1Fh	16.8	1	F	Non-riparian wetland
PEM1/SS1R	7.1		R	Tidal marsh	PSS1/EM1R	40.3		R	Riparian wetland
PEM1A	67.7		A	Upland	PSS1/FO1A	34.3		A	Upland
PEM1C	91.3		C	depends on location	PSS1/FO1Ch	1.2	1	C	Non-riparian wetland
PEM1Cb	8.9		C	Non-riparian wetland	PSS1/FO1E	5.7		E	depends on location
PEM1Ch	57.3	1	C	Non-riparian wetland	PSS1/FO1F	1.8		F	depends on location
PEM1Chs	19.2	1	C	Non-riparian wetland	PSS1/FO1R	6.3		R	Riparian wetland
PEM1Cs	29.3	1	C	Non-riparian wetland	PSS1/FO1T	1.6		T	Riparian wetland
PEM1Cx	3.1	1	C	Non-riparian wetland	PSS1A	37.1		A	Upland
PEM1E	53.5		E	depends on location	PSS1C	15.5		C	depends on location
PEM1Eb	26.0		E	Non-riparian wetland	PSS1Cb	4.6		C	Non-riparian wetland
PEM1Eh	17.2	1	E	Non-riparian wetland	PSS1Ch	5.1	1	C	Non-riparian wetland
PEM1F	48.7		F	depends on location	PSS1E	89.0		E	depends on location
PEM1Fb	65.6		F	Non-riparian wetland	PSS1Eb	13.6		E	Non-riparian wetland
PEM1Fh	200.7	1	F	Non-riparian wetland	PSS1Eh	2.7	1	E	Non-riparian wetland
PEM1Fhs	1.1	1	F	Non-riparian wetland	PSS1F	142.6		F	depends on location
PEM1Fs	25.5	1	F	Non-riparian wetland	PSS1Fb	35.5		F	Non-riparian wetland
PEM1Fx	29.3	1	F	Non-riparian wetland	PSS1Fh	7.7	1	F	Non-riparian wetland
PEM1R	547.2		R	Tidal marsh	PSS1R	113.4		R	Riparian wetland
PEM1T	16.0		T	Tidal marsh	PSS1S	3.1		S	Riparian wetland
PFO/SS1C	1.3		C	depends on location	PSS1T	0.8		T	Riparian wetland
PFO/SS1E	2.8		E	depends on location	PSS4/EM1R	2.6		R	Riparian wetland
PFO1/5F	22.1		F	depends on location	PSS4A	1.4		A	Upland
PFO1/5Fb	19.6		F	Non-riparian wetland	PUB/FO1Fb	0.9		F	Non-riparian wetland
PFO1/5Fh	1.4	1	F	Non-riparian wetland	PUB/FO5F	0.9		F	N/A
PFO1/EM1A	20.7		A	Upland	PUB/FO5Fb	13.7		F	N/A
PFO1/EM1Cb	3.1		C	Non-riparian wetland	PUB/FO5Hh	4.8	1	H	N/A
PFO1/SS1A	4.1		A	Upland forest	PUB/SS1Fx	2.1	1	F	Non-riparian wetland
PFO1/SS1C	23.7		C	depends on location	PUBF	20.2		F	N/A

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Wetland class	Acres in Cecil Co.	Human modified? (1 = yes)	Water regime	Ecosystem service class	Wetland class	Acres in Cecil Co.	Human modified? (1 = yes)	Water regime	Ecosystem service class
PFO1/SS1Ch	3.1	1	C	Non-riparian wetland	PUBFb	80.1		F	N/A
PFO1/SS1E	51.0		E	depends on location	PUBFh	19.6	1	F	N/A
PFO1/SS1Eh	1.8	1	E	Non-riparian wetland	PUBFs	24.6	1	F	N/A
PFO1/SS1Fb	3.8		F	Non-riparian wetland	PUBFx	105.5	1	F	N/A
PFO1/SS1Fh	8.3	1	F	Non-riparian wetland	PUBH	20.5		H	N/A
PFO1/SS1R	19.5		R	Riparian wetland	PUBHh	791.8	1	H	N/A
PFO1/USA	3.9		A	Riparian wetland	PUBHx	178.0	1	H	N/A
PFO1A	894.5		A	Upland forest	PUBKx	13.3	1	K	N/A
PFO1C	568.8		C	depends on location	PUSCh	8.7	1	C	N/A
PFO1Cb	8.7		C	Non-riparian wetland	PUSCx	33.2	1	C	N/A
PFO1Ch	16.2	1	C	Non-riparian wetland	Pf	2.0	1	-	N/A
PFO1E	116.4		E	depends on location	R1EM2N	2.6		N	Riparian wetland
PFO1Eb	3.2		E	Non-riparian wetland	R1USN	143.4		N	N/A
PFO1Eh	5.7	1	E	Non-riparian wetland	R1USS	1.1		S	N/A
PFO1F	9.1		F	depends on location	R2USA	7.2		A	N/A
PFO1Fb	7.4		F	Non-riparian wetland	R2USC	6.1		C	N/A
PFO1Fh	4.5	1	F	Non-riparian wetland					

APPENDIX B. GIS DATA USED IN CECIL COUNTY ECOSYSTEM SERVICES ANALYSES

Data Layer	Original Source	Ground Condition Date	Spatial Resolution	Comments
Hydrography	Cecil County Planning and Zoning Department	Unknown	Unknown, but appeared accurate	This data set was much more accurate than other available hydrography data, and aligned well with aerial photos.
Land cover	US Geological Survey (USGS) National Land Cover Dataset (NLCD)	1999-2001	30 m	
Wetlands	Maryland Dept. of Natural Resources (DNR)	1988-1995	20 ft	0.5 acre minimum mapping unit
Cecil County updated Green Infrastructure network	Developed by The Conservation Fund for this project	2005	<10 m	See <i>An Assessment of Cecil County's Green Infrastructure</i> .