GREEN INFRASTRUCTURE VISION

VERSION 2.3 ECOSYSTEM SERVICE VALUATION

FOR VALUATION OF ECOSYSTEM SERVICES PROVIDED BY THE NATURAL RESOURCES INCLUDED IN THE CHICAGO WILDERNESS GREEN INFRASTRUCTURE VISION

Ecosystem Services Literature Review

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Summary Points

All Green Infrastructure Vision (GIV) Landscapes

- **According to analysis completed for this project, natural ecosystems contribute well more than $6 billion per year in economic value to a 7-county CMAP region. (In comparison, the GDP of the Chicago Metropolitan Statistical Area (which mostly overlaps the 7 counties) was $586 billion in 2013.) And this may undercount the total value since this estimate is only from ecosystem services that could be reliably measured, and this total does not include any of the economic activity supported by the region's recreation and ecotourism infrastructure.**

- **Land conservation provides at least a 100 to 1 return on investment if the values of ecological services are considered.**

- **Ecosystem resistance and resilience to stresses depends on species composition and diversity. Diverse ecosystems are more likely to contain species tolerant to disturbances like flooding, drought, or pests.**

- **Recreation and ecotourism generate significant economic benefits to the region. In 2011, Illinois residents and non-residents spent $3.8 billion on wildlife-associated recreation. They also spent 13.3 million days and $973 million fishing in Illinois (excluding Lake Michigan).**

- **In a 2008 survey, over 97% of Illinois residents thought outdoor recreation areas are important for health and fitness and almost 94% thought community recreation areas are important for quality of life and promote economic development. Over 80% thought more lands should be acquired for open space and/or for outdoor recreation.**

- **Many studies have also shown that parks, greenways and trees increase nearby residential and commercial property values.**

- **Access to open space, parks, and recreation is a top factor used by small businesses in choosing a new location.**

Woodlands/Forest

- **Forests help to reduce both the volume of stormwater runoff and the cost of stormwater treatment. A forest stand can intercept over 200,000 gallons per acre per year. An acre of forest saves an annual avoided stormwater treatment cost of $21 per acre per year and over $9,000 per acre per year in avoided gray infrastructure investment costs. A large tree can reduce 5,400 gallons of stormwater runoff per year in the Midwest.**

- **In addition to reducing the intensity and volume of stormwater runoff, forests play a significant filtration role. Forested buffers can remove up to 21 pounds of nitrogen and 4 pounds of phosphorus per acre per year from upland runoff. Forest buffers can reduce up to 98% of nitrogen, phosphorus, sediments, pesticides, pathogens, and other pollutants in surface and groundwater.**

- **A large tree can return 10 gallons of water a day to the atmosphere.**

- **Forest soils can store 50% more water than urban land and allow 34% more groundwater recharge.**

- **Forests help remove large amounts of CO_2 from the air. Even just one large tree can remove over 1,000 pounds per year of CO_2 from the atmosphere. During photosynthesis, trees convert CO_2 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. Larger and healthier trees sequester carbon at greater rates. A mature oak-hickory forest can contain over 130 tons of carbon per acre.**

- **Trees provide additional air quality benefits by absorbing sulfur dioxide (SO_2) and nitrogen oxide (NO_2), two major components of acid rain. Trees also can trap ozone (O_3), carbon monoxide (CO), and particles (PM_{10}) in the air, all of which can be harmful to humans.**

- **Trees in the seven-county Chicago region removed 18,080 tons of air pollution (CO, NO_2, O3, PM_{10}, SO_2) per year with an associated value of $157 million.**

Wetlands, Streams, Lakes, Groundwater

- **Wetlands play a significant role in stormwater mitigation and flood control. An acre of wetlands can typically store 1 - 1.5 million gallons of floodwater.**

- **In Wisconsin, watersheds with 30% wetland or lake area had flood peaks 60-80% lower than watersheds with no wetland or lake area.**

- **Not building in floodplains in the Chicago metropolitan area could save an average $900 per acre per year in flood damages.**

- **Wetlands also help reduce water pollution from runoff: they can filter 70-90% of nitrogen, 45% of phosphorous, and retain more than 70% of sediment.**

- **In a comparison of 11 types of best management practices (BMPs) for treating stormwater runoff, constructed wetlands were the most effective. The wetland removed 100% of suspended solids, 99% of nitrate, 100% of zinc, and 100% of petroleum byproducts, and reduced peak flows by 85%. This greatly exceeded the performance of standard retention ponds, as well as expensive manufactured devices.**

- **The average wastewater treatment costs using conventional methods are $4.36 per 1,000 gallons, but through wetlands construction, the cost is only $0.63/1,000 gallons ($2014).**

- **The cost of restoring and operating wetlands to remove nitrogen and phosphorus can be 50-70% less than the cost of constructing and operating engineered wastewater treatment systems.**

- **By serving as a natural detention and filtration system for stormwater, wetlands also help to recharge groundwater systems. Forested wetlands overlying permeable soil can release up to 100,000 gallons per acre per day into groundwater.**

- **Biological diversity and genetic information are not easy to translate into dollar terms, but a number of studies have quantified the economic value of habitat, with wetlands having a value up to $14,800 per acre per year ($2014).**

Prairie/Grassland/Savanna

- **Although less research exists regarding ecosystem valuation of prairies, they have been shown to contribute to flood control and carbon sequestration, among other benefits. Restored prairie in Wisconsin was found to store 728,000 gallons of water per acre.**

- **Restoring prairie vegetation rebuilds organic matter in the surface soil and sequesters carbon, taking centuries to reach maximum storage potential.**

- **Remnant prairie at Fermi National Accelerator Laboratory contained around 0.76 kg of carbon per square meter above ground and 13.5 kg per square meter below ground.**

Please see the full report for more details on these talking points and how they were derived.

Introduction and Overview

- **According to analysis completed for this project, natural ecosystems contribute well more than $6 billion per year in economic value to a 7-county CMAP region. (In comparison, the GDP of the Chicago Metropolitan Statistical Area (which mostly overlaps the 7 counties) was $586 billion in 2013.) And this may undercount the total value since this estimate is only from ecosystem services that could be reliably measured, and this total does not include any of the economic activity supported by the region's recreation and ecotourism infrastructure.**

- **Land conservation provides at least a 100 to 1 return on investment if the values of ecological services are considered.**

The Chicago Wilderness Green Infrastructure Vision

Green infrastructure is our natural life support system. At the regional level, it is an interconnected network of forests, wetlands, waterways, grasslands, and other natural areas that support native species, maintain natural ecological resources and processes, and contribute heavily to human health and quality of life. A recognized and delineated green infrastructure network serves as a shared vision that can lead to collaborative efforts. It can provide a systematic and strategic approach to land conservation and restoration, encouraging land use planning and practices that are beneficial to nature and people.

The original Chicago Wilderness Green Infrastructure Vision (GIV) identified large Resource Protection Areas and recommended protection approaches for each, including additional land preservation. GIV version 2 (Conservation Fund et al., 2012) is a refinement that is more spatially explicit in classifying and characterizing important resources in a consistent and analytically robust manner. Its primary products are GIS datasets that describe and characterize the regional green infrastructure network. The GIV version 2 gives "a high priority… to identifying and preserving important but unprotected natural communities, especially those threatened by development, and to protecting areas that can function as large blocks of natural habitat though restoration and management" (Chicago Wilderness, 2004). This report examines some of the economic benefits provided by components of the GIV.

Ecosystem Services Overview

Forests, wetlands, prairies, water bodies, and other natural ecosystems support our existence. They provide services like 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 hydrology and water supplies (Costanza et al. 1997). These resources 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.

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 $1,900/ac/year (adjusted to 2014 dollars – $2014). Because not all services were assessed, the authors considered this an underestimate. In Maryland, Pimentel (1998) estimated the value of biodiversity as about $2.7 billion (adjusted to 2010 dollars – $2014) annually. Weber (2007b) estimated a value of $14,000/ac/year ($2014) for forest in Cecil County, MD, and $51,000/ac/year for wetlands. 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 (CIA, 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.

Bagstad (2006) used economic value transfer methods to "conservatively estimate" that natural ecosystems contribute $1.69 billion per year in economic value ($2 billion in $2014) to Cook, DuPage, Kane, Lake, McHenry, and Will counties, Illinois. In comparison, the GDP of the Chicago Metropolitan Statistical Area (Cook, DuPage, Kane, Lake and Will Counties, IL, and Lake County, IN) was $586 billion in 2013.

Based on recent rates of land use change, Bagstad (2006) added that approximately $53 million ($60 million in $2014; 2.7% of the region's total) in economic value provided by ecosystems is lost yearly to poorly-planned growth. He classified 90 municipalities in the region as "facing extreme pressure on their natural resource base, with critically endangered, endangered, and threatened natural capital, based on existing ecosystem service values and high rates of population growth."

Selection of Key Ecosystem Services

In the text, we summarize key relevant literature regarding quantification of ecosystem services identified as priorities in an initial scoping webinar. Nine services (flood control, water purification, groundwater recharge, air purification, microclimate moderation, carbon storage, supporting native flora and fauna, recreation, and increasing property values) were selected from a larger set listed below in Table 1. We used studies and figures from the CMAP area where possible, within Illinois as our second choice, and elsewhere in the U.S. as a third choice. In a few cases, we had to use global values. We converted values

to 2014 U.S. dollars ($2014) using the Consumer Price Index (http://www.usinflationcalculator.com/).

Table 1. Initial list of ecosystem services distilled from MARC & AES (2013), Conservation Fund (2013), Weber (2007), Millennium Ecosystem Assessment (2005), and Costanza et al. (1997). The nine services researched in this report are ***bolded***.

Ecosystem Service	Description
REGULATING & SUPPORTING	
Hazard Amelioration	
Water Flow Regulation / Flood Control	***Maintain water flow stability and protect areas against flooding (e.g., from storms).***
Water Purification	***Maintain water quality sufficient for human consumption, recreational uses like swimming and fishing, and aquatic life.***
Erosion Control and Sediment Retention	Maintain soil and slope stability, and retain soil and sediment on site.
Groundwater Recharge	***Maintain natural rates of groundwater recharge and aquifer replenishment***
Air Purification	***Remove particulates and other pollutants from the air***
Climate	
Microclimate Moderation	***Lower ambient and surface air temperature through shading***
Regulation of Water Temperature	Moderate water temperature in streams
Carbon Storage	***Sequester carbon in vegetation and soils, thereby reducing atmospheric CO_2 and global climate change***
Biological	
Native Flora and Fauna	***Maintain species diversity and biomass***
Pollination	Provide pollinators for crops and other vegetation important to humans
Pest and Disease Control	Provide biota which consume pests and control diseases
Provisioning	
Food Production	Production of plant or fungal-based food for human consumption
Game and Fish Production	Production of wild game and fish for human consumption
Fiber Production	Production of wood and other natural fibers for human use
Soil Formation	Long-term production of soil and peat for support of vegetation and other uses
Biochemical Production	Provision of biochemicals, natural medicines, pharmaceuticals, etc.
Genetic Information	Genetic resources for medical and other uses, including those not yet realized

Ecosystem Service	Description
Cultural	
Recreation and Ecotourism	***Outdoor, nature-based experiences like hiking, birding, hunting, camping, etc.***
Savings in Community Services	Savings in community services from not converting natural land to houses
Increase in Property Values	***Provide attractive location for homes and businesses***
Science and Education	Existence of natural systems and areas for school excursions, advancement of scientific knowledge, etc.
Spiritual and Aesthetic	Aesthetic enjoyment or spiritual or religious fulfillment
Bequest value	The value placed on knowing that future generations will have the option to utilize the resource.
Existence value	The non-use value of simply knowing that particular resources exist, even if they are not used.

Of the nine ecosystem services examined from Table 1, six were sufficiently quantified and readily cross-walked with Chicago Wilderness GIV version 2 layers. These were:

- **Water Flow Regulation / Flood Control**
- **Water Purification**
- **Groundwater Recharge**
- **Carbon Storage**
- **Native Flora and Fauna**
- **Recreation and Ecotourism**

Methods for Valuing Ecosystem Services

Farber et al. (2002) list six methods for valuing methods for valuing ecosystem services in monetary terms:

- **Avoided cost**: Services allow society to avoid costs that would have been incurred in the absence of those services (e.g., natural flood control preventing property damages or natural waste treatment preventing health costs)
- **Replacement cost**: Services could be replaced with man-made systems (e.g., natural waste treatment having to be replaced by costly engineered systems)
- **Factor income**: Services provide for the enhancement of incomes (e.g., water quality increasing commercial fisheries catches and fishermen incomes)
- **Travel cost**: Service demand may require travel, whose costs can reflect the implied value of the service (e.g., value of ecotourism or recreation is at least what a visitor is willing to pay to get there)

- **Hedonic pricing**: Service demand may be reflected in the prices people will pay for associated goods (e.g., increase in housing prices due to water views or access to parks)
- **Contingent valuation**: Service demand may be elicited by posing hypothetical scenarios that involve some valuation of alternatives (e.g., how much people are willing to pay for increased availability of fish or wildlife).

Table 2 summarizes relevant metrics and types of economic analyses for the ecosystem services examined in this report.

Table 2. Types of analyses available for selected ecosystem services relevant to the Chicago Wilderness Green Infrastructure Vision.

Ecosystem Service	Metrics	Types of economic analyses
Water Flow Regulation / Flood Control	Reduction of flood damage, Reduction of stormwater flows, Reduction of peak discharges, Reduction of combined sewer system costs, Reduction of soil erosion	Avoided cost, Replacement cost
Water Purification	Reduction of N, P, Cl^-, sediment, bacteria, and other pollutants for drinking water, swimming, fishing, aquatic life, and other uses.	Avoided cost, Replacement cost
Groundwater Recharge	Supply of water to groundwater rather than surface runoff	Avoided cost, Replacement cost, Price of public water supply
Carbon Storage	Reduction of atmospheric CO_2 and associated climate effects	Avoided cost, Market price of carbon
Support Native Flora and Fauna	Protection of wildlife habitat Maintenance of ecosystem functions and resilience	Willingness to pay (contingent valuation)
Recreation and Ecotourism	Money spent on nature-based recreation (hunting, fishing, birding, hiking, etc.)	Surveys of money expended on nature-based recreation
Air Purification	Removal of SO_x, NO_x, O_3, CO, and PM_{10} from the air	Avoided cost, Replacement cost
Microclimate Moderation	Energy savings, Reduction of CO_2 emissions	Avoided cost
Increase in Property Values	Increase of property prices	Hedonic pricing

References in this section

Bagstad, K. 2006. Valuing Ecosystem Services in the Chicago Region. CW Journal 4(2):18-26.

Balmford, A., A. Bruner, P. Cooper, R. Costanza, S. Farber, R. E. Green, M. Jenkins, P. Jefferiss, V. Jessamy, J. Madden, K. Munro, N. Myers, S. Naeem, J. Paavola, M. Rayment, S. Rosendo, J. Roughgarden, K. Trumper, and K. Turner. 2002. Economic reasons for conserving wild nature. Science 297:950- 953.

Chicago Wilderness. 2004. Chicago Wilderness Green Infrastructure Vision: Final Report.

Conservation Fund, The; CMAP, and Chicago Wilderness. 2012. Refinement of the Chicago Wilderness Green Infrastructure Vision, June.

Conservation Fund, The. 2013. Houston-Galveston Green Infrastructure and Ecosystem Services Assessment.

Costanza, R., R. d'Arge, R. de Groot, S. Farber, M. Grasso, B. Hannon, K. Limburg, S. Naeem, R. O'Neill, J. Paruelo, R. Raskin, P. Sutton, and M. van den Belt. 1997. The value of the world's ecosystem services and natural capital. Nature 387:252- 259.

DeGroot, R., M. Stuip, M. Finlayson, and N. Davidson. 2006. Valuing wetlands: Guidance for valuing the benefits derived from wetland ecosystem services. Ramsar Technical Report No. 3, CBD Technical Series No. 27. Ramsar Convention Secretariat, Gland, Switzerland.

Farber, S.C., R. Costanza and M.A. Wilson. 2002. Economic and ecological concepts for valuing ecosystem services. Ecological Economics 41: 375-392.

Marino, B. D. V., and H. T. Odum. 1999. Biosphere 2: research past and present. Elsevier.

Mid-America Regional Council (MARC) & Applied Ecological Services (AES). 2013. Kansas City Natural Resources Inventory II Phase 4: Ecosystem Services Method Development.

Millennium Ecosystem Assessment. 2005. Ecosystems and human well-being: synthesis. Island Press, Washington DC.

Odum, E.P. 1970. Optimum population and environment: A Georgia microcosm. Current History 58: 355-359.

Pimentel, D. 1998. Economic and environmental benefits of biological diversity in the state of Maryland. pp. 63-75 in Therres, G. D. (ed.) Conservation of biological diversity: a key to the restoration of the Chesapeake Bay ecosystem and beyond. Maryland Dept. Nat. Res., Annapolis, MD.

U.S. Central Intelligence Agency (CIA). 2006. The World Factbook. Online at http://www.cia.gov/cia/publications/factbook/index.html.

Weber, T. 2007b. Ecosystem services in Cecil County's Green Infrastructure: Technical Report for the Cecil County Green Infrastructure Plan. The Conservation Fund, Annapolis, MD.

Water Flow Regulation / Flood Control

- **A large tree can reduce 5,400 gallons of stormwater runoff per year in the Midwest. A forest stand can intercept over 200,000 gallons per acre per year.**

- **An acre of forest provides an annual avoided stormwater treatment cost of $21 per acre per year and over $9,000 per acre per year in avoided gray infrastructure investment costs.**

- **An acre of wetlands can typically store 1-1.5 million gallons of floodwater.**

- **In Wisconsin, watersheds with 30% wetland or lake area had flood peaks 60-80% lower than watersheds with no wetland or lake area.**

- **Not building in floodplains in the Chicago metropolitan area could save an average $900 per acre per year in flood damages.**

Floods caused more fatalities and property damage than any other type of natural disaster in the U.S. during the twentieth century (Kousky et al., 2013). Wet basements decrease property values by 10-25%, and that almost 40% of small businesses never reopen their doors following a flooding disaster (CNT, 2014). Between 2007–2011, over 181,000 flood damage claims and sewer- and drain-backup claims were made across 97% of Cook County ZIP codes, totaling $773 million (CNT, 2014). There was no correlation between damage payouts and presence of FEMA floodplains in the ZIP code, but floodplains constituted just 0.3% of the total acreage in Cook County (CNT, 2014).

Forest, wetlands, and prairies can help maintain water flow stability and protect areas against flooding from storms. Londoño and Ando (2013) found that residents of Champaign and Urbana, Illinois were each, on average, willing to pay around $21/year to reduce basement flooding. The Conservation Fund (2013) grouped flood protection and erosion control because both are services tied to stormwater regulation, and to treat them separately would partially double count them. For example, a basin built to capture stormwater runoff would also capture eroding sediment, although this would not include the negative effects where the soil is lost.

Woodlands/Forest

Forest

Forests perform an important service by reducing downstream flooding through their ability to percolate stormwater (HGAC, 2010). Aerial surveys of a 1986 flood demonstrate that Forest Preserve lands in Lake and Cook counties reduced the property damage along the Des Plaines River (Forest Preserves of Cook County, 2013).

Batker et al. (2010) reported a water flow regulation value of $9.61/ac/year ($2006; **$11.36** in $2014) for forest, and a value between $5.72/ac/year and $170.89/ac/year ($2006; $6.76-$202.04 in $2014) for urban green space.

American Forests (2000) estimated that between 1972 and 1999, tree losses in the Houston metro area (including 159,438 acres of areas with >50% tree cover and 101,183 acres with 20-49% tree cover) resulted in an estimated 360 million cubic feet (ft^3) increase of stormwater flow during peak storm events. Replacing the lost stormwater retention capacity with engineered systems, at $0.66/$ft^3$ of storage (estimated by the Harris County Flood Control District), would have cost $237 million (American Forests, 2000). The Conservation Fund (2013) considered areas with >50% tree cover as forest, and divided the area of 20-49% tree cover in half, arriving at an estimated $1462 per acre of forest lost ($2010; **$1600** in $2014). American Forests (2000) calculated the annual benefits based on stormwater management facilities' construction costs, plus the cost of the loan or bond to finance construction (but apparently not including operation and maintenance costs) as $17 million annually, or $105/ac/year of forest ($2010; **$115** in $2014).

Simulations by Tilley et al. (2012) showed that less runoff was generated from forested watersheds than urban watersheds. Forests, by dampening stormwater discharges, lessen the negative effects of high storm flows, like accelerated erosion and the need for larger public works. The public value of stormwater mitigation by forests was $290/ac/year ($2000; **$400** in $2014), and the fair payment price ranged from $9 to $96/ac/year ($2000).

McPherson et al. (2006) and CNT (2010) reported a sample large tree (hackberry, 37 foot spread, 40 years old) intercepted, on average, 5,387 gallons/year of rainfall in the Midwest region, and reduced stormwater runoff by an equivalent amount. A sample medium-sized tree (red oak, 27 foot spread, 40 years old) intercepted 2,690 gallons/year. When converted to acres, assuming a continuous tree canopy (i.e., forest at least 40 years old), both sizes of trees intercept 205,000-218,000 gallons/year/ac, with the higher number corresponding to larger trees.

McPherson et al. (2006) used 2004 sewer service fees for the City of Minneapolis as a "conservative proxy" for the value of rainfall intercepted and potential cost reductions in stormwater-management control—a value that includes the cost of collection, conveyance, and treatment. This fee, $0.0046/gal, was well below the average price of stormwater runoff reduction ($0.089/gal) assessed in similar studies. Multiplying the Minnesota rate by 212,000 gallons/ac/year, the midpoint for medium-sized and large Midwest trees, gives a value of $975/ac/year in 2004 dollars (**$1,230** in $2014). At $0.089/gal, the value is $18,868/ac/year (presumably also in 2004 dollars; **$23,800** in $2014). McPherson et al. (2006) went with the lower number, though (e.g., reporting a value of $24.78 per 40 year old hackberry, or $1,004/ac/year).

Mittman et al. (2014) reported that in Lancaster, PA, green infrastructure practices (including tree planting and bioretention) would reduce the volume and rate of runoff entering sewer systems. In combined sewer systems such as Lancaster's, this could reduce

both the storage and treatment required to manage CSOs. This, in turn, could reduce both the capital and operational costs of "gray infrastructure systems" such as storage tanks and pumping stations. Over 25 years, the avoided capital cost of implementing gray infrastructure would be $120 million and the avoided operational cost $661,000 per year. The unit cost of wastewater treatment and pumping was $0.00125/gallon, and the unit cost for CSO reduction through gray infrastructure storage was $0.23/gallon of CSO treated in an average year. Multiplying $0.23125/gallon by 212,000 gallons/ac/year intercepted by trees (McPherson et al., 2006) gives **$49,000**/ac/year.

For the Metropolitan Water Reclamation District (MWRD) of Greater Chicago, CNT (2009, 2010) reported a marginal cost of treating its wastewater and stormwater of $0.0000919 per gallon. The annual avoided cost for stormwater treatment associated with an acre of forest would therefore be (using the midpoint between the two tree sizes) $19/ac/year (c. $2009; **$21** in $2014). It was not clear how this cost per gallon was calculated, though.

CNT (2010) then added avoided grey infrastructure needs, citing a study in Portland, Oregon (Evans, 2008) that estimated that it costs the city $2.71/square foot in infrastructure costs to manage the stormwater generated from impervious areas. Thus, an acre of natural land would avoid $126,000 in additional costs. Annualized over 20 years, with a 4% interest rate, and excluding maintenance costs, this is **$9,265**/ac/year ($2014).

Dividing MWRD's $581,701,000 in expenses in 2013 (MWRD, 2012) by 1.4 billion gallons of wastewater per day (511 billion gallons of wastewater per year) gives $0.001138/gallon treated. There is no reason to assume a linear relationship between each gallon of stormwater reduced and total budget, but this would give a value of **$241**/ac/year in 2013 dollars.

Ford and Sheaffer (1988) reported that during a 100-year flood, the 66,930 acres of land owned and managed by the Forest Preserve District of Cook County, Illinois, stored 63,806 acre-feet of stormwater runoff. About 20% of this land was within the 100-year floodplain. District lands provided about 80% of publicly owned flood storage in the county, much more than engineered structures. The average construction cost for an acre-foot of flood storage in a surface reservoir in Cook County was $9,024 per acre-foot (from a 1987 report). Using this as a replacement cost, the 66,930 acres of District land had a flood storage value of $575,785,344 ($1987), or $18,042/acre ($2014).

We annualized costs by applying the equivalent annual cost (EAC) equation, which is the cost per year of owning and operating an asset over its entire lifespan. The formula is:

$$\text{EAC} = (\text{Asset Price} \times \text{Discount Rate}) / (1 - (1 + \text{Discount Rate})^{-\text{Number of Periods}})$$

We used the average annual federal inflation rate (3%) for the discount rate, and two different lifespan periods: 20 and 50 years (NVRC (2007) reported that stormwater ponds can be expected to function 20-50 years, assuming regular maintenance). Then, annual operation and maintenance costs must be added. SEWRPC (1991) reported annual operation and maintenance costs about 5% of capital cost for treating large drainage areas

(20-1,000 ac); $902/ac/year in this case. For a 20 year lifespan, avoided costs were **$2,116**/ac/year ($2014); for 50 years, **$1,603**/ac/year.

Johnston et al. (2004) found that using conservation practices compared to conventional development could reduce 100 year flood damages in a suburban Chicago watershed by $4,337 to $11,732 per acre. For infrastructure benefits, considering only downstream road culverts, the use of conservation design practices upstream would avoid $3.3 million to $4.5 million in costs of culvert replacement or upgrades.

As a note, Dlugolecki (2012) reported that the cost of floodwater-caused erosion on downstream users is between $6.40 and $46.10 per ton of sediment. NRCS (2007) estimated Maryland's annual soil loss to erosion at 3.6 tons/ac. With soil retailing at $42/ton, the value of forest in preventing soil erosion is thus $151/ac/year. Avoiding the cost of dredging could be also added to this estimate.

Riparian Forest

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 $1,400 per acre-foot ($2006), must be built to capture and store sediment (Klapproth and Johnson, 2001).

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.

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 (2007a) 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 (i.e. depletion of oxygen in water).

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 (i.e., 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). Locations 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).

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 Neponist 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). Brody et al. (2011) found a highly significant ($p<0.01$) relationship between permits to disturb wetlands and flood damage in dollars in Coastal Texas between 1997 and 2007.

Based on cost differences between channelization versus using wetlands, Ko (2007) estimated the value of wetlands for flood mitigation as $5,800 per acre in a case study. The detention plan included costs of land acquisition, excavation, and structure. Utilizing an already preserved area, which may not require a budget for land acquisition, would have a significantly higher cost savings.

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). Hey et al. (2004) wrote that restoring the 100-year flood zone of the Upper Mississippi five-state watershed could store 39 million acre-feet of floodwater,

the volume that caused this flood, and save over $16 billion in projected flood damage costs.

The cost of replacing the natural flood control function of 5,000 acres of drained wetlands in Minnesota was $1.5 million annually, or **$388**/ac/year in $2014 (EPA, 2006; Sipple, 2007). This was the lowest of available estimates.

Wetlands protected by the Greenseams™ Program of the Milwaukee Metropolitan Sewerage District can store 1.325 billion gallons of water, at a cost of $22.5 million to protect the land, or $0.017 per gallon (c. $2011). One acre of hydric soils alone (not including surface storage) can hold 2 acre-feet of water, or 651,702 gallons (unpublished data). In contrast, the Milwaukee County Grounds detention basin can store 315 million gallons, at a cost of over $100 million, or $0.31 per gallon (unpublished 2011 data). Protecting an equivalent area of wetlands (483 ac) could save $219,000/ac ($2014). Annualizing over 20 years with a 4% interest rate, this is **$15,960**/ac/year.

Wetlands surrounding the Boston area have been estimated to prevent $43,700 (adjusted to 2014 dollars) of flood damage per acre of intact wetland (Dlugolecki, 2012; EPA, 2012). Annualizing over 20 years with a 4% interest rate, this is **$3,173**/ac/year ($2014).

According to EPA (2001, 2006), an acre of wetlands can typically store 1-1.5 million gallons of floodwater. Given a replacement cost of $0.27/gallon (American Forests, 1999), this translates to $390,000-$585,000/ac ($2014). Annualizing over 20 years with a 4% interest rate, this is **$28,000-43,000**/ac/year.

Leschine et al. (1997) compared flood protection effectiveness and cost between engineered systems and existing wetlands. Three wetland systems studied by Leschine et al. (1997) provided $39,000-$55,000/ac of flood protection ($2010). A channel and detention pond, costing $195,000 ($1989), would reduce peak flow by 56%, while 23.7 acres of wetlands would reduce it by 80%. After considering the differences in reduction efficiency, Leschine et al. (1997) estimated the value of wetlands for flood mitigation as $20,400 per acre for an isolated wetland and $61,800/ac for a series of wetlands ($2010). Annualizing over 20 years with a 4% interest rate, this is **$1,620**/ac/year for isolated wetlands and **$4,900**/ac/year for wetlands in series ($2014).

Wossink and Hunt (2003) compared the annualized construction, land opportunity, and maintenance costs of restored wetlands to stormwater ponds. Weber (2007b) 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 one acre Coastal Plain wetland in Maryland. According to their data, a one acre wetland could treat runoff from a 100 acre watershed. The equivalent constructed pond would be 0.0075*100 = 0.75 ac, and have a construction cost of $13,909*100*0.672 = $307,111. The 20-year maintenance cost would be $9,202*100*0.269 = $31,760 (present value), giving a total present value of $338,871 ($2006). Annualized over 20 years, with a 4% interest rate, this is **$29,079**/ac/year ($2014). Weber (2007b) did not include land opportunity costs, which would increase this value, especially in urban areas.

From CH2MHill (2009), the average construction cost for five detention ponds in the Calumet-Sag Channel watershed in Cook County, IL, was $0.25/gallon ($2014). We examined other watershed plans, but the project costs included other flood control categories besides storage. Multiplying by 1-1.5 million gallons/ac of floodwater (EPA 2001, 2006) gives a replacement cost of $250,000-$375,000/ac. Following the methodology reported under the forest section, we annualized over 20 to 50 years with a 3% discount rate and 5% annual operation and maintenance costs, giving **$22,000-$44,000**/ac/year ($2014).

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; **$8,419**/ac/year in $2014). Because of this, the Army Corps of Engineers preserved the wetlands rather than constructing extensive flood control structures (Leschine et al., 1997).

Examining results from 39 studies, Woodward and Wui (2001) reported a value between $89/ac/yr and $1747/ac/yr (mean $393/ac/yr) for flood control by wetlands ($1990). Converting to $2014, this is **$162-$3,180**/ac/yr (mean $715/ac/yr).

As a cautionary note, artificially increasing runoff to wetlands (e.g., by directing stormwater flow there) may impact their natural functions. Increased hydroperiods and water depths may kill or stress vegetation, and could change the community to an open water system. Sedimentation may bury plants and seeds.

Wetland vegetation helps control erosion in coastal, lacustrine (i.e. near lakes) 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).

Lakes/Streams

Floodplains

California Dept. of Water Resources (2005) reported that reconnecting the Napa River to its floodplain would cost about $250 million, but save about $1.6 billion in flood damage over the next century.

The Resource Coordination Policy Committee (1998) reported over $39 million in average annual damages from flooding in the watersheds of the Chicago metropolitan area ($58 million/year in 2014 dollars). These watersheds totaled 3,874 mi^2, and the area subject to flooding was 64,438 acres. Not building in floodplains could save an average **$900**/ac/year ($2014) in damages.

Kousky et al. (2013) compared flood damage prevention to land purchase costs in the East River Watershed, WI. Preventing additional development in the 100 year floodplain forecast between 2010 and 2025 by purchasing easements would preserve 7403 acres of open space and avoid an average annualized loss (AAL) of $2.63 million/year ($2010), or **$388**/ac/year ($2014).

Purchasing all floodplain properties would cost more than this, approximately $3 million/year when annualized over 100 years at a 5% discount rate (Kousky et al., 2013). However, some of these properties were disproportionately expensive. Targeting based on costs, flood depth, and parcel acreage, would cost $298,000/year for 417 parcels totaling 6379 acres, and prevent flood damages around $1.5 million/year. (Note: for the purposes of this study, we are only estimating benefits, which would be added together for the different ecosystem services, and then easement or fee simple costs could be subtracted. Subtracting easement costs for each separate service would count the same cost multiple times.)

Ford and Sheaffer (1988) reported that each floodplain acre in Cook County, IL, that is acquired and maintained as open space stores an average of 3.88 acre-feet of floodwater. The average construction cost for an acre-foot of flood storage in a surface reservoir in Cook County was $9,024 per acre-foot ($1987). Using this as a replacement cost, natural floodplains had a flood storage value of $35,000/acre ($1987). Following the methodology reported under the forest section, we annualized over 20 and 50 years with a 3% discount rate and 5% annual operation and maintenance costs, giving **$6,500-$8,600**/ac/year ($2014).

Stream buffers

Once a stream is degraded by erosion, it is very expensive to restore. According to MD 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). MD DNR estimates that stream restoration in non-urban watersheds costs approximately $0.6 million per mile (Moore, 2002), or around $140 per foot in 2010 dollars. This figure does not include monitoring costs. Maryland's State Highway Administration (SHA) estimated the following construction costs for stream restoration (S. Hertz, SHA, personal communication, July 24, 2007):

- Full stream restoration (new channel): $300 - $500 per linear foot
- Bank armoring only/spot restoration: $100 - $300 per linear foot
- Vegetative stream restoration (e.g. fascines - wood lined trenches): $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 (S. 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 rate, this totaled $15/ft/year ($2006). 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, MD, which is still primarily rural, the value of riparian forest (usually recommended for restoration purposes to be 100 ft from either bank) was correspondingly $15/year * 43,560 ft^2/ac / 200 ft^2 = $3,267/ac/year (in $2014, $3,855/ac/year).

Lakes and ponds

From CH2MHill (2009), the average construction cost for five detention ponds in the Calumet-Sag Channel watershed in Cook County, IL, was $83,100/ac-ft ($2014). If we assume an average depth of 5 feet, this is $415,500/ac. Following the methodology reported under the forest section, we annualized over 20 and 50 years with a 3% discount rate and 5% annual operation and maintenance costs, giving **$37,000-$49,000**/ac/year ($2014). Storage should be computed separately for each lake and pond by estimating additional storage capacity (i.e., beyond base conditions) rather than just surface area.

Prairie/Grassland/Savanna

Gulf Coast prairies contain deep-rooted grasses and vertisol soils, which can absorb and retain considerable volumes of water. They typically contain wetlands, but many are smaller than the National Wetlands Inventory (NWI) minimum mapping unit (1-3 ac). In the Armand Bayou watershed, prairie pothole wetlands provide at least 3,000 acre-feet of detention over and above the natural storage of the native soils in the area (189,000 acres of prairie pothole habitat in the watershed, which is about 30% depressional wetlands, with about 1 ft average depth.) (unpublished data).

Batker et al. (2010) reported a water regulation value of $1.65/ac/year ($2006; **$1.95** in $2014) for grassland from Costanza et al., 1997.

Brye et al. (2000) reported the mean volumetric water storage for a restored prairie in Wisconsin to be 0.68 m^3/m^3 (180 gallons/m^3) in the upper 1.4 m of soil. This converts to 728,000 gallons/ac. Multiplying by $0.25/gallon (CH2MHill 2009; see wetland methodology) gives a replacement cost of $182,000/ac ($2014). Following the methodology reported under the forest section, we annualized over 20 and 50 years with a 3% discount rate and 5% annual operation and maintenance costs, giving **$16,000-$21,000**/ac/year ($2014).

Spatial Assessments

MARC and AES (2013) assigned quantitative values to areas for water flow regulation. They ignored variations in precipitation and potential best management practices (BMPs), but assigned a TR55 curve number to each land cover type: the greater the percentage of impervious cover, the greater the estimated runoff potential. They also assigned a hydrologic group (A to D, high to low infiltration rate, converted to a numerical value) to SSURGO soil polygons, and converted this to a grid. They added the two factors (land cover runoff potential plus soil infiltration) together. They did not attempt to compute a dollar value for this or other services.

Kozak et al. (2011) found that in the Des Plaines watershed in the Chicago area, value estimates for wetland ecosystem services varied by nearly three orders of magnitude, showing huge sensitivity to decay parameters. They also stated that ecosystem services are more likely to be scarce in urban than rural landscapes, and therefore more valuable per household at the margin.

The Conservation Fund (2013) assigned the public value of $290/ac/year from Tilley et al. (2012) to forest cells. Nontidal wetlands were $7,990/ac/year (Thibodeau and Ostro, 1981).
Tidal wetlands were $3,820/ac/year (Costanza et al., 2008). Then, the authors estimated the number of households at risk of flooding, by watershed. From 2010 census data, they identified block centroids falling within FEMA 100 year floodplains. They then summed the number of households in 100 year floodplains by HUC10 watershed. At the watershed level, they hoped spatial errors of omission and commission would cancel each other out.

Because the housing calculation did not consider damage to businesses or institutions, the Conservation Fund (2013) also examined developed land vulnerable to flooding. First, they reclassified 2006 NLCD (National Land Cover Database), giving developed land a relative weight between 1 and 4 (low intensity = 1, medium = 2, and high = 4). They based the reclassification on the principle that on average, high intensity development contains a higher density of buildings and invested resources than low intensity development. Next, they identified which developed land falls (using the above relative impact values) within FEMA 100 year floodplains. As with the centroid data, they assumed spatial errors were less important at the watershed level. The results closely resembled those of flood vulnerable households. Watersheds with more buildings in the floodplain were more vulnerable to flooding, and conservation and restoration efforts in those watersheds should have more economic benefit.

Industrial Economics (2011) applied the InVEST storm peak mitigation model to the Red Clay Creek watershed in the Piedmont region of Delaware to quantify how the presence of wetlands affects the probability of stormwater reaching inland properties. The model estimated the relative contribution of particular areas to flood potential following a storm. It only considered one type of potential flooding - properties within floodplains of streams and rivers. Additional flooding potential could be associated with, for example, ponding of stormwater in inland areas. They calculated storm surge from tidal waters using different methodologies. In this watershed, Industrial Economics (2011) projected $57-$1,690/year

($2010) of additional flood damage impacts to residential structures (other impacts not considered) as 53 acres of wetlands were lost (**$1.20-$35**/ac/year in $2014).

References in this section

American Forests. 1999. Regional ecosystem analysis: Chesapeake Bay region and the Baltimore-Washington corridor. American Forests, Washington, DC.

American Forests. 2000. Urban ecosystem analysis for the Houston Gulf Coast region: calculating the value of nature. American Forests, Washington, DC.

Batker, D., M. Kocian, B. Lovell, and J. Harrison-Cox. 2010. Flood protection and ecosystem services in the Chehalis River Basin. Earth Economics, Tacoma, WA.

Brody, S. D., W. E. Highfield, and J. E. Kang. 2011. Rising waters: the causes and consequences of flooding in the United States. Cambridge Univ. Press, Cambridge, UK. 195 pp.

Brye, K. R., J. M. Norman, L. G. Bundy, and S. T. Gower. 2000. Water-Budget Evaluation of Prairie and Maize Ecosystems. Soil Sci. Soc. Am. J. 64:715–724.

California Dept. of Water Resources. 2005. Multi-Objective Approaches to Floodplain Management on a Watershed Basis: Natural Floodplain Functions and Societal Values. Online at http://www.economics.water.ca.gov/studies.cfm. 34 pp.

Center for Neighborhood Technology (CNT). 2009. Green Values Calculator. http://greenvalues.cnt.org/national/benefits_detail.php#reduced-treatment.

Center for Neighborhood Technology (CNT). 2010. The value of green infrastructure: a guide to recognizing its economic, environmental and social benefits. Center for Neighborhood Technology, Chicago, IL.

Center for Neighborhood Technology (CNT). 2014. The prevalence and cost of urban flooding: a case study of Cook County, IL. Center for Neighborhood Technology, Chicago, IL.

CH2MHill. 2009. Detailed Watershed Plan for the Calumet-Sag Channel Watershed. Metropolitan Water Reclamation District of Greater Chicago, Chicago, IL.

Conservation Fund, The. 2013. Houston-Galveston Green Infrastructure and Ecosystem Services Assessment.

Dlugolecki, L. 2012. Economic Benefits of Protecting Healthy Watersheds: A Literature Review. U.S. Environmental Protection Agency.

Evans, D. and Associates, Inc. 2008. Cost Benefit Evaluation of Ecoroofs. City of Portland Bureau of Environmental Services, Portland, OR.

Ford, C. R., and J. R. Sheaffer. 1988. Forest Preserve District of Cook County, Illinois: An evaluation of floodwater storage. Sheaffer & Roland, Inc. Wheaton, IL.

Forest Preserves of Cook County. 2013. Floodplain & Stormwater Management. http://fpdcc.com/conservation/floodplain-stormwater-management/. Accessed Aug. 29, 2014.

Hey, D. L., et al. 2004. Flood damage reduction in the Upper Mississippi River basin: an ecological alternative. The Wetlands Initiative, Chicago, IL.

Houston-Galveston Area Council (HGAC). 2010. Eco-logical: Creating a regional decision support system for the Houston-Galveston region. Houston-Galveston Area Council, Houston, TX. 63 pp.

Industrial Economics, Inc. 2011. Economic valuation of wetland ecosystem services in Delaware: Final report. Delaware Department of Natural Resources and Environmental Control, Division of Water Resources, Dover, DE.

Johnston, D. M., J. B. Braden, and T. H. Price. 2004. The Downstream Economic Benefits from storm Water Management: a Comparison of Conservation and Conventional Development. UCOWR Conference Proceedings, Paper 23. http://opensiuc.lib.siu.edu/ucowrconfs_2004/23

Klapproth, J. C., and J. E. Johnson. 2001. Understanding the science behind riparian forest buffers: benefits to communities and landowners. Virginia Cooperative Extension. Publication Number 420-153.

Ko, J-Y. 2007. The economic value of ecosystem services provided by the Galveston Bay/estuary system. Texas Commission on Environmental Quality, Galveston Bay Estuary Program, Webster, TX.

Kousky, C., S. M. Olmstead, M. A. Walls, and M. Macauley. 2013. Strategically placing green infrastructure: cost-effective land conservation in the floodplain. Environ. Sci. Technol. 47 (8):3563–3570.

Kozak, J., C. Lant, S. Shaikh, and G. Wang. 2011. The geography of ecosystem service value: The case of the Des Plaines and Cache River wetlands, Illinois. Applied Geography 31:303-311.

Leschine, T. M., K. F. Wellman, and T. H. Green. 1997. The economic value of wetlands: wetlands' role in flood protection in western Washington. Ecology Publication No. 97-100. Washington State Dept. of Ecology, Bellevue, WA.

Londoño Cadavid, C. and A. W. Ando. 2013. Valuing preferences over stormwater management outcomes including improved hydrologic function. Water Resources Research 49(7):4114–4125.

Maryland Department of the Environment. 2006. Prioritizing sites for wetland restoration, mitigation, and preservation in Maryland. Draft version: April 27, 2006. Maryland Department of the Environment Wetlands and Waterways Program, Baltimore, MD.

McPherson, E., J. R. Simpson, P. J. Peper, S. L. Gardner, K. E. Vargas, S. E. Maco, and Q. Xiao. 2006. Midwest Community Tree Guide: Benefits, Costs, and Strategic Planting. General Technical Report PSW-GTR-199. United States Department of Agriculture, Forest Service, Pacific Southwest Research Station. Davis, CA.

Metropolitan Water Reclamation District of Greater Chicago (MWRD). 2012. 2013 Budget. www.mwrd.org.

Mid-America Regional Council (MARC) & Applied Ecological Services (AES). 2013. Kansas City Natural Resources Inventory II Phase 4: Ecosystem Services Method Development.

Mitsch, W. J., and J. G. Gosselink. 1993. Wetlands, 2nd edition. Van Nostrand Reinhold, New York.

Mittman, T., et. al. 2014. The economic benefits of green infrastructure: a case study of Lancaster, PA. EPA 800-R-14-007. U.S. Environmental Protection Agency, Washington, DC.

Moore, T. (ed.) 2002. Protecting Maryland's Green Infrastructure. The case for aggressive public policies. Maryland Dept. of Natural Resources, Annapolis, MD.

Natural Resources Conservation Service (NRCS). 2007. National Resources Inventory 2003 Annual NRI. Online at http://www.nrcs.usda.gov/.

Northern Virginia Regional Commission (NVRC). 2007. Maintaining stormwater systems: a guidebook for private owners and operators in Northern Virginia. Northern Virginia Regional Commission, Fairfax, VA.

Osmond, D.L., D.E. Line, J.A. Gale, R.W. Gannon, C.B. Knott, K.A. Bartenhagen, M.H. Turner, S.W. Coffey, J. Spooner, J. Wells, J.C. Walker, L.L. Hargrove, M.A. Foster, P.D. Robillard, and D.W. Lehning. 1995. Values of wetlands. Online at http://www.water.ncsu.edu/watershedss/info/wetlands/values.html.

Resource Coordination Policy Committee. 1998. Our community and flooding: a report on the status of floodwater management in the Chicago metropolitan area.

Sather, J. H. and R.D. Smith. 1984. An overview of major wetland functions and values. U.S. Fish and Wildlife Service FWS/OBS-84/18. Washington, DC.

Sipple, B. 2007. Wetlands functions and values. http://www.epa.gov/watertrain/wetlands/.

Southeastern Wisconsin Regional Planning Commission (SEWRPC). 1991. Costs of urban nonpoint source water pollution control measures. Southeastern Wisconsin Regional Planning Commission, Waukesha, WI.

Thibodeau, F.R. and B.D. Ostro. 1981. An Economic Analysis of Wetland Preservation. Journal of Environmental Management, 12:19-30.

Tilley, D., E. Campbell, T. Weber, P. May, and C. Streb. 2011. Ecosystem based approach to developing, simulating and testing a Maryland ecological investment corporation that pays forest stewards to provide ecosystem services: Final report. Department of Environmental Science & Technology, University of Maryland, College Park, MD.

U.S. Environmental Protection Agency (EPA). 2001. Functions and values of wetlands. EPA Publication 843-F-01-002c.

U.S. Environmental Protection Agency (EPA). 2006. Wetlands: protecting life and property from flooding. EPA843-F-06-001.

U.S. Environmental Protection Agency (EPA). 2012. The economic benefits of protecting healthy watersheds. EPA Publication 841-N-12-004.

Weber, T. 2007b. Ecosystem services in Cecil County's Green Infrastructure: Technical Report for the Cecil County Green Infrastructure Plan. The Conservation Fund, Annapolis, MD.

Woodward, R. T. and Y.-S. Wui. 2001. The economic value of wetland services: a meta-analysis. Ecological Economics 37:257-270.

Wossink, A., and B. Hunt. 2003. An evaluation of cost and benefits of structural stormwater best management practices in North Carolina. North Carolina Coop. Ext. Service.

Water Purification

- **Forested buffers can remove up to 21 pounds of nitrogen and 4 pounds of phosphorus per acre per year from upland runoff. Forest buffers can reduce up to 98% of nitrogen, phosphorus, sediments, pesticides, pathogens, and other pollutants in surface and groundwater.**

- **Wetlands can filter 70-90% of nitrogen, 45% of phosphorous, and retain more than 70% of sediment.**

- **In a comparison of 11 types of best management practices (BMPs) for treating stormwater runoff, constructed wetlands were the most effective. The wetland removed 100% of suspended solids, 99% of nitrate, 100% of zinc, and 100% of petroleum byproducts, and reduced peak flows by 85%. This greatly exceeded the performance of standard retention ponds, as well as expensive manufactured devices.**

- **The average wastewater treatment costs using conventional methods are $4.36 per 1,000 gallons, but through wetlands construction, the cost is only $0.63/1,000 gallons ($2014).**

- **The cost of restoring and operating wetlands to remove nitrogen and phosphorus can be 50-70% less than the cost of constructing and operating engineered wastewater treatment systems.**

The recent crisis in Toledo, Ohio, where a *Microcystis* algal bloom rendered the city's water supply unsafe, highlights our dependence on clean drinking water. Forests, wetlands, and prairies protect water bodies from pollutants and sedimentation by absorbing and filtering water. They help maintain water quality sufficient for human consumption, recreational uses like swimming and fishing, and aquatic life. Compared to 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. Pollutants of particular interest in the Chicago region include nitrogen (N), phosphorus (P), and chloride (Cl^-). Londoño and Ando (2013) found that residents of Champaign and Urbana, Illinois were each, on average, willing to pay $37/year to avoid further deterioration of water quality in streams.

Woodlands/Forest

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 nitrate (which can impair water bodies

through eutrophication) 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).

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. Further, for every 10% increase in forest cover in the watershed, treatment and chemical costs decreased about 20%, up to about 60% forest cover (see Figure 1). The study had insufficient data for watersheds with more than 65% forest cover (Ernst, 2004).

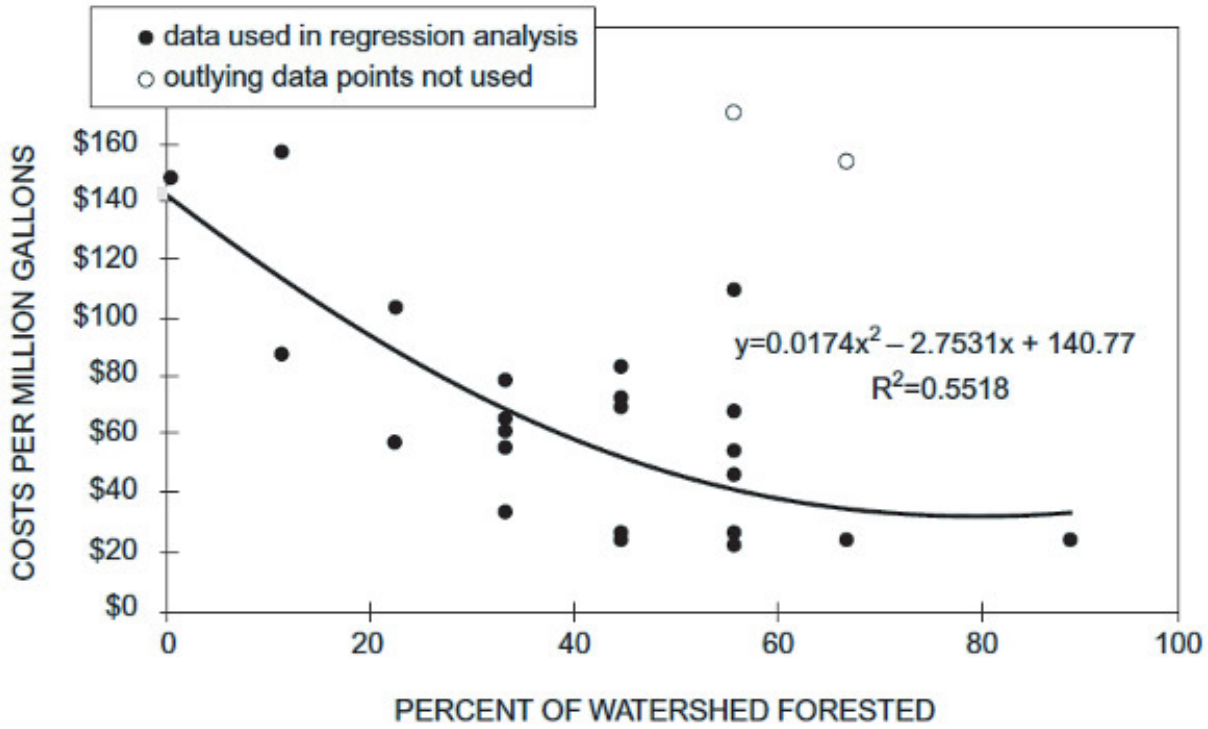

Figure 1. Water treatment costs vs. watershed forest cover (Ernst, 2004).

Forest can filter nitrogen, phosphorus, and sediment from overland runoff. According to Industrial Economics (2011), the economic value of nitrogen removal was $188/kg ($2010), which represented the cost of removing nitrogen by connecting an onsite wastewater treatment and disposal system to sewer districts. As nitrogen is removed, phosphorous is simultaneously filtered. The cost of sediment treatment is much lower than nitrogen.

New York City 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; Hanson et al., 2011). The Catskill/Delaware watersheds that supply 90% of New York City's drinking water cover 1,583 mi^2 (1 million acres), and are primarily (89%) forested (Mehaffey et al., 2001). On average, this supply of clean drinking water is worth **$1,300** per acre of forest per year ($2014).

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 (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 **$820**/ac/year ($2014). This value is lower than that calculated for general forest in New York, which is counterintuitive, and demonstrates the uncertainty of these calculations.

Other nonpoint pollution, such as bacteria, can also be attenuated by stream buffers, although these can be grass. Scientists in Minnesota estimated a buffer 118 feet wide would be required to reduce total coliform bacteria to levels acceptable for human recreational use (Klapproth and Johnson, 2009). Other researchers found that even a narrow (7 foot) filter strip removed nearly 95 percent of fecal coliform bacteria (Klapproth and Johnson, 2009). Rogers and Haines (2005) wrote that effective buffers should be at least 10 meters wide and at least 90% vegetated.

Wetlands

Numerous studies have demonstrated 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).

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). Rogers and Haines (2005) reported 96-99.9% removal of fecal indicator bacteria by wetlands.

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).

USACE (2003) reported average wastewater treatment costs using conventional methods to cost $3.24 per 1000 gallons, but through wetlands construction, only $0.47/1,000 gallons ($2001). With an acre of wetlands typically able to store 1.0-1.5 million gallons of floodwater (EPA, 2006), the gross value of wetlands (they may exist already, not needing

construction) for wastewater treatment is **$4,350-$6,530**/ac/year ($2014). (Author's note: a one acre wetland flooded with one foot of water would equal 326,000 gallons. On the other hand, a wetland temporarily holding all the precipitation falling on it in one year (not including surface inflows) = 39 inches (Illinois average) * 326,000 gallons/acre-feet * 1 foot/12 inches = 1.1 million gallons/acre.)

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 (EPA, 2006), and multiplying by 0.8-0.9, this translates to $40,000-$67,500/ac/year ($2006; **$47,300-$79,800** in $2014).

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

- A 1978 Michigan study estimated that an average acre of wetlands along the shores of the Great Lakes could provide over **$19,000** ($2014) worth of water quality improvement annually.
- Natural waste assimilation by marsh in the Charles River Basin of Massachusetts substituted, per acre, for annual capital costs of **$235 plus $4,110** in maintenance and operation costs of a tertiary waste treatment plant ($2014; 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 (1993 report; **$700** in $2014).

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 treatment systems. To achieve the standards of 3.0 mg/L of nitrogen and 1.0 mg/L of phosphorus that 189,000 acres of wetlands could achieve, $184 million/year of annualized costs would be required to build and operate treatment systems. This translates to a wetland value of **$1,200**/ac/year ($2014).

Ko (2007) found that an 1,800 acre natural wetland could save $275,000/year ($2010) in annualized capital costs and operation and maintenance to filter wastewater at 1 million gallons per day (**$170**/ac/year; $2014).

Industrial Economics (2011) reported that wetlands filter 63% of nitrogen, 45% of phosphorous, and retains 69-94% of sediment. The economic value of nitrogen removal was $188/kg ($2010), which represents the cost of removing nitrogen by connecting an onsite wastewater treatment and disposal system to sewer districts. As nitrogen is removed, phosphorous is simultaneously filtered. The cost of sediment treatment is much

lower than nitrogen. They reported a $770,000 ($2010) annualized municipal water treatment cost of losing 3,132 acres of wetlands over 15 years, or **$280**/ac/year ($2014).

Using results from 39 studies, Woodward and Wui (2001) reported a water quality value between $126/ac/yr and $1,378/ac/yr (mean $417/ac/yr) for wetlands ($1990; **$230-$2,513** in $2014)

Prairie/Grassland/Savanna

Industrial Economics (2011) reported that rangeland filters 32% of nitrogen, 40% of phosphorous, and retains 99% of sediment. The economic value of nitrogen removal was $188/kg ($2010), which represents the cost of removing nitrogen by connecting an onsite wastewater treatment and disposal system to sewer districts. As nitrogen is removed, phosphorous is simultaneously filtered. The cost of sediment treatment is much lower than nitrogen.

Batker et al. (2010) reported a water quality value of $47.91/ac/year ($2006; **$57**/ac/year in $2014) for grassland from Costanza et al., 1997.

Spatial Assessments

MARC and AES (2013) assigned quantitative values to land cover types for phosphorus export, using values from Jeje (2006). They did not model transport to water bodies.

Bateman et al. (2006) found that in the central UK, the willingness to pay for water quality improvements to the heavily polluted River Tame declined following a log-linear function, reaching zero at a distance of 20-28 km, with bigger improvements having greater WTP amounts and distances.

The Conservation Fund (2013) used the program InVEST (v.2.2.2) to calculate non-point nitrogen retention by subwatershed (HUC-12). The economic value of nitrogen removal was $188/kg ($2010) (Industrial Economics, 2011, which represents the cost of removing nitrogen by connecting an onsite wastewater treatment and disposal system to a centralized sewer. As nitrogen is removed, phosphorus is simultaneously filtered; we did not double count. And the cost of sediment treatment is much lower than nitrogen. We calculated $/ac/year for each cell, which ranged from near $0 to $80,000/ac.

References in this section

Allen, W. L., and T. C. Weber. 2007. Baltimore County land preservation model: water quality assessment. The Conservation Fund, Arlington, VA.

Baltimore County. 2005. NPDES - Municipal Stormwater Discharge Permit 2005 Annual Report.

Bateman, I. J., B. H. Day, S. Georgiou, and I. Lake. 2006. The aggregation of environmental benefit values: welfare measures, distance decay and total WTP. Ecological Economics 60:450-460.

Batker, D., M. Kocian, B. Lovell, and J. Harrison-Cox. 2010. Flood protection and ecosystem services in the Chehalis River Basin. Earth Economics, Tacoma, WA.

California Dept. of Water Resources. 2005. Multi-Objective Approaches to Floodplain Management on a Watershed Basis: Natural Floodplain Functions and Societal Values. Online at http://www.economics.water.ca.gov/studies.cfm. 34 pp.

California Stormwater Quality Association. 2003. Sediment basin. BMP fact sheet SE-2 in Stormwater best management practice construction handbook. California Stormwater Quality Association, Menlo Park, CA.

Casey, J. F. 2004. The value of riparian forest buffers in the Chesapeake Bay watershed: an economic framework for policy-making. National Oceanic and Atmospheric Administration, Washington DC.

Chesapeake Bay Commission. 2004. Cost-effective strategies for the Bay: 6 smart investments for nutrient and sediment reduction. Chesapeake Bay Commission, Annapolis, MD.

Chesapeake Bay Program. 2000. Riparian forest buffers. Online at http://www.chesapeakebay.net/info/forestbuff.cfm

Conservation Fund, The. 2013. Houston-Galveston Green Infrastructure and Ecosystem Services Assessment.

Costanza, R., O. Pérez-Maqueo, M. Luisa Martinez, P. Sutton, S. Anderson, and K. Mulder. 2008. The value of coastal wetlands for hurricane protection. Ambio 37(4):241-248.

Ernst, C. 2004. Land conservation and the future of America's drinking water: protecting the source. Trust for Public Land, San Francisco, CA.

Hanson, C., et al. 2011. Forests for water: exploring payments for watershed services in the US south. World Resources Institute Issue Brief, Issue 2, p.15.

Hey, D. L., J. A. Kostel, A. P. Hurter, and R. H. Kadlec. 2005. Nutrient farming and traditional removal: an economic comparison. Water Environment Research Foundation, Alexandria, VA.

Industrial Economics, Inc. 2011. Economic valuation of wetland ecosystem services in Delaware: Final report. Delaware Department of Natural Resources and Environmental Control, Division of Water Resources, Dover, DE.

Jeje, Y. 2006. Export coefficients for total phosphorus, total nitrogen and total suspended solids in the southern Alberta region: a review of literature. Alberta Environment, Edmonton, Canada.

Jordan, T. 2002. Vegetated riparian zones, stream buffers. Critical Area Workshop. May 14, 2002.

Klapproth, J. C., and J. E. Johnson. 2001. Understanding the science behind riparian forest buffers: benefits to communities and landowners. Virginia Cooperative Extension. Publication Number 420-153.

Klapproth, J. C., and J. E. Johnson. 2009. Understanding the science behind riparian forest buffers: effects on water quality. Virginia Cooperative Extension. Publication Number 420-151.

Ko, J-Y. 2007. The economic value of ecosystem services provided by the Galveston Bay/estuary system. Texas Commission on Environmental Quality, Galveston Bay Estuary Program, Webster, TX.

Landers, J. 2006. Test results permit side-by-side comparisons of BMPs. Civil Engineering News, April 2006, pp. 34-35.

Langland, M., and T. Cronin (eds.) 2003. A summary report of sediment processes in Chesapeake Bay and watershed. Water-Resources Investigations Report 03-4123. U.S. Geological Survey, New Cumberland, PA.

Londoño Cadavid, C. and A. W. Ando. 2013. Valuing preferences over stormwater management outcomes including improved hydrologic function. Water Resources Research 49(7):4114–4125.

Maryland Department of the Environment. 2006. Prioritizing sites for wetland restoration, mitigation, and preservation in Maryland. Draft version: April 27, 2006. Maryland Department of the Environment Wetlands and Waterways Program, Baltimore, MD.

Mehaffey, M. H., M. S. Nash, T. G. Wade, C. M. Edmonds, D. W. Ebert, K. B. Jones, and A. Rager. 2001. A landscape assessment of the Catskill/Delaware watersheds 1975-1998. EPA/600/R-01/075. Env. Prot. Agency, Las Vegas, NV.

Mid-America Regional Council (MARC) & Applied Ecological Services (AES). 2013. Kansas City Natural Resources Inventory II Phase 4: Ecosystem Services Method Development.

Moore, T. (ed.) 2002. Protecting Maryland's Green Infrastructure. The case for aggressive public policies. Maryland Dept. of Natural Resources, Annapolis, MD.

Osmond, D.L., D.E. Line, J.A. Gale, R.W. Gannon, C.B. Knott, K.A. Bartenhagen, M.H. Turner, S.W. Coffey, J. Spooner, J. Wells, J.C. Walker, L.L. Hargrove, M.A. Foster, P.D. Robillard, and

D.W. Lehning. 1995. Values of wetlands. Online at http://www.water.ncsu.edu/watershedss/info/wetlands/values.html.

Rogers, S., and J. Haines. 2005. Detecting and mitigating the environmental impact of fecal pathogens originating from confined animal feeding operations: review. EPA/600/R-06/021.

Roth, N. E., M. T. Southerland, G. Mercurio, J. C. Chaillou, P. F. Kazyak, S. S. Stranko, A. P. Prochaska, D. G. Heimbuch, and J. C. Seibel. 1999. State of the Streams: 1995-1997 Maryland Biological Stream Survey Results. Maryland Dept. of Natural Resources, Annapolis, MD.

Sather, J. H. and R.D. Smith. 1984. An overview of major wetland functions and values. U.S. Fish and Wildlife Service FWS/OBS-84/18. Washington, DC.

Sipple, B. 2007. Wetlands functions and values. http://www.epa.gov/watertrain/wetlands/.

U.S. Army Corps of Engineers (USACE). 2003. Applicability of constructed wetlands for Army installations. Public Works Technical Bulletin 200-1-21. U.S. Army Corps of Engineers, Washington, DC.

U.S. Environmental Protection Agency (EPA). 2006. Wetlands: protecting life and property from flooding. EPA843-F-06-001.

Woodward, R. T. and Y.-S. Wui. 2001. The economic value of wetland services: a meta-analysis. Ecological Economics 37:257-270.

World Resources Institute. 1998. 1998-99 world resources. World Resources Institute, Washington, DC.

Groundwater Recharge

- **Forest soils can store 50% more water than urban land and allow 34% more groundwater recharge.**

- **Forested wetlands overlying permeable soil can release up to 100,000 gallons per acre per day of groundwater.**

With increasing droughts around the world, humans rely more and more on groundwater for drinking water, irrigation, and other purposes, especially in dry areas with suitable aquifers. In many of these areas, the water table is dropping as water is pumped from the ground faster than it can recharge. In California, wells that used to reach water 500 feet below the surface must now be drilled down 1,000 feet or more, at a cost of more than $300,000 for a single well (Dimick, 2014).

The CMAP region relies primarily on the Cambrian-Ordovician aquifer for groundwater (Sasman et al., 1977). Sand and gravel deposits, coupled with dolomitic materials in underlying shallow bedrock, also contain accessible groundwater (e.g., Baxter & Woodman, Inc., et al., 2006). In some areas, artesian pressure declined more than 850 feet between 1864 and 1971 (Sasman et al., 1977; see Figure 2 from USGS, 1995). Gibb (1973) reported that concrete-cased 36-inch inside diameter wells cost about $24/foot in 1978 ($88/ft in $2014), not including the cost for finishing the well top ($200 in 1978) or the cost of pumping.

Forests, wetlands, and prairies can help maintain natural rates of groundwater recharge and aquifer replenishment. Londoño and Ando (2013) found that residents of Champaign and Urbana, Illinois were each, on average, willing to pay up to $30/year to improve groundwater infiltration.

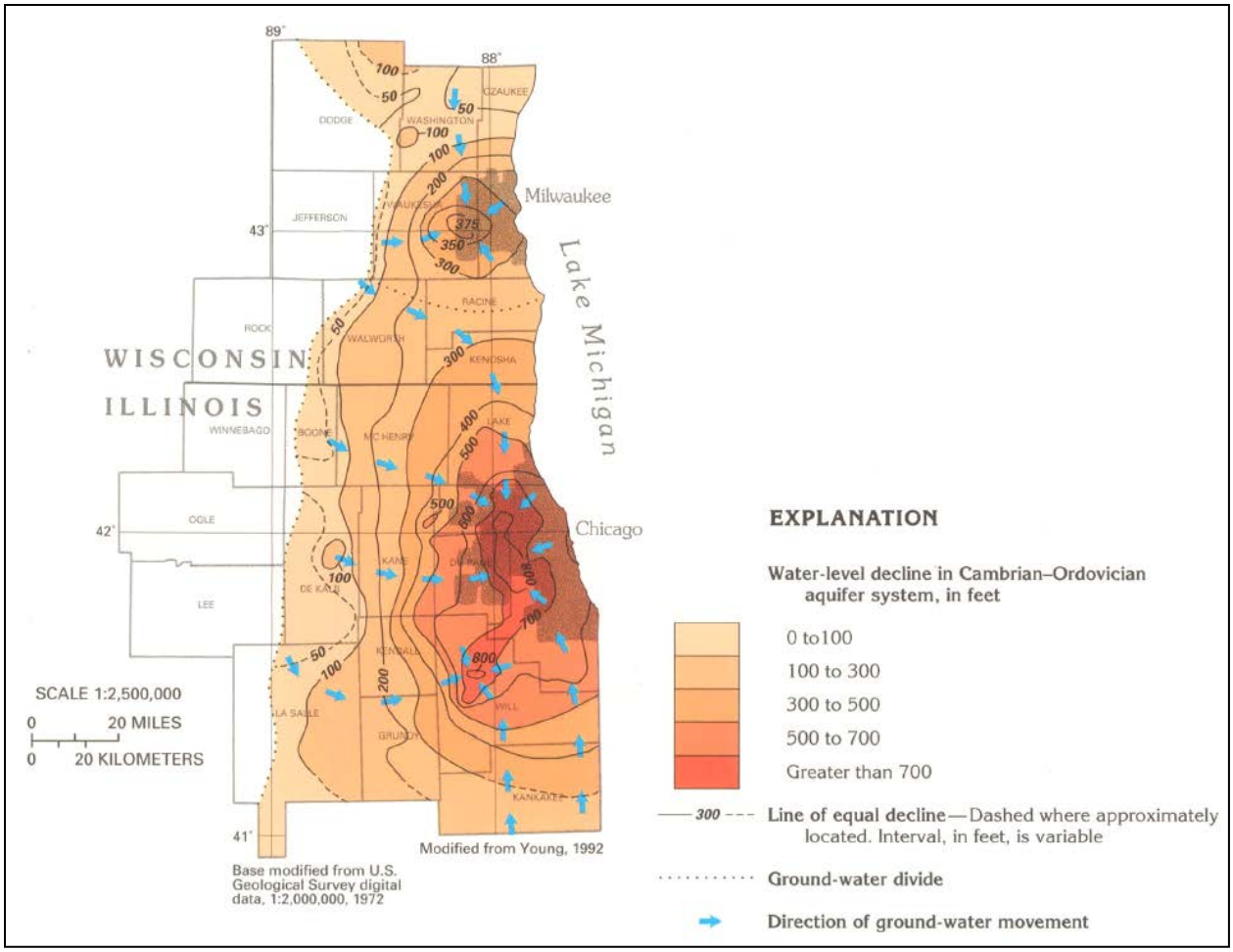

Figure 2. Aquifer level decline in the Chicago-Milwaukee region between 1864 and 1980 (USGS, 1995).

Woodlands/Forest

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 unaltered landscape (Moore, 2002). The overwhelming majority of rain water that falls on impervious land is therefore not retained. 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).

Simulations by Tilley et al. (2012) showed that more water accumulated in forest soils than urban ones (1.59 cm vs. 0.87 cm). Forest stored 50% more water than urban land and allowed 34% more groundwater recharge. Land use was more important in determining sub-surface water storage than physiographic region. The public value of groundwater recharge by forests was $194/ac/year ($2000; **$269** in $2014), and the fair payment price (if landowners were paid to retain forest for groundwater recharge) ranged from $6 to $58 per acre per year ($2000).

Streams and Lakes

Batker et al. (2010) reported water supply values of **$2,105.11, $4,806.25,** and **$13,015.08**/ac/year **($2006)** for riparian buffers.

Batker et al. (2010) reported water supply values of **$32.34; $429.30; $565.91; $617.46** and **$834.44**/ac/year **($2006)** for rivers and lakes.

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 groundwater. The effect of wetlands on groundwater recharge and discharge is variable. Some wetlands recharge groundwater, 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/ac/day into the groundwater (Osmond et al., 1995). Groundwater 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 groundwater 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 groundwater would be reduced by an estimated 45% (Osmond et al., 1995).

Water supply costs vary greatly from one source to another (California Dept. of Water Resources, 2005). For example, "typical" development costs for the following types of water supply options in California are:

- Groundwater/conjunctive use: $150 - $500 per acre-foot
- Brackish groundwater recovery: $500 - $1,000 per acre-foot
- Water recycling: $250 - $1,000 per acre-foot
- New reservoirs: $250 - $1,500 per acre-foot
- Sea water desalination: up to $2,000 per acre-foot

Often, the supply source is located away from the service area, thus transportation costs are also incurred. For the California State Water Project, transportation costs (capital and O&M) are over $170 per acre-foot to deliver water from the Sacramento-San Joaquin Delta to the metropolitan Los Angeles area. Once within the service area, additional local storage, delivery and treatment costs are incurred before final delivery to the water users (California Dept. of Water Resources, 2005).

A 1975 Massachusetts study cited by California Dept. of Water Resources (2005) concluded that an average acre of wetlands could supply water at a savings of **$13,000** per year compared to other water sources ($2014).

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 translated to $9,320 in annual water supply per wetland acre ($2010; **$10,190** in $2014) (California Dept. of Water Resources, 2005).

Prairie potholes and other wetlands can contribute significantly to recharging regional groundwater. 20% of wetland water storage can go into groundwater (Mitsch and Gosselink, 1993). Multiplying 20% of 1-1.5 million gallons/ac/year by $0.00331/gallon (approved 2014 water rate for the City of Chicago) gives **$660-990**/ac/year.

Using results from 39 studies, Woodward and Wui (2001) reported a water quantity value between $6/ac/yr and $2571/ac/yr (mean $127/ac/yr) by wetlands ($1990; **$11-$4688** in $2014).

Batker et al. (2010) reported water supply values of **$199.11; $542.65; $1,287.83; $2,001.85; $2,192.67; $3,598.28; $10,488.00;** and **$31,404.56**/ac/year **($2006)** for freshwater wetlands.

Spatial Assessments

MARC and AES (2013) assigned groundwater recharge values to areas based on soils, land cover, and geology. They assigned TR55 curve numbers based on both the land cover type

and soil hydrologic group (following IDNR, 2009). They subtracted this from 100 and multiplied by the transmission rate of the surficial geological material.

Many aquifers in Illinois are confined, which means they cannot be recharged by surface water sources (IDNR, 2014). The relative thickness of the loess soils generally does not allow water to penetrate down to, or percolate up from, the water table (IDNR, 2014). Wetlands and other natural areas can only recharge groundwater supplies in recharge zones, where the substrate is permeable enough to allow an aquifer to be refilled by surface waters. This would have to be mapped as a mask to determine which areas this ecosystem service applies to.

References in this section

Bacon, T. 2002. Deforestation Decreases Rainfall. http://www.magicalliance.org/Forests/deforestation_decreases_rainfall.htm.

Batker, D., M. Kocian, B. Lovell, and J. Harrison-Cox. 2010. Flood protection and ecosystem services in the Chehalis River Basin. Earth Economics, Tacoma, WA.

Baxter & Woodman, Inc., Ayres Associates, A. Visocky, Environmental Planning and Economics, Inc., and Planning and Management Consultants, Inc. 2006. County of McHenry, Illinois Groundwater Resources Management Plan. McHenry County Dept. of Planning & Development, Woodstock, IL.

California Dept. of Water Resources. 2005. Multi-Objective Approaches to Floodplain Management on a Watershed Basis: Natural Floodplain Functions and Societal Values. Online at http://www.economics.water.ca.gov/studies.cfm. 34 pp.

Dimick, D. 2014. If you think the water crisis can't get worse, wait until the aquifers are drained. National Geographic. Aug. 19, 2014.

Gibb, J. P. 1973. Wells and pumping systems for domestic water supplies. ISWS-73-CIR117. Illinois State Water Survey, Urbana, IL.

Illinois Department of Natural Resources (IDNR). 2009. Illinois Statewide Comprehensive Outdoor Recreation Plan 2009–2014.

Illinois Department of Natural Resources (IDNR). 2014. Wetlands: ground water recharge. https://dnr.state.il.us/wetlands/ch2f.htm (Accessed 25 July, 2014)

Londoño Cadavid, C. and A. W. Ando. 2013. Valuing preferences over stormwater management outcomes including improved hydrologic function. Water Resources Research 49(7):4114–4125.

Mid-America Regional Council (MARC) & Applied Ecological Services (AES). 2013. Kansas City Natural Resources Inventory II Phase 4: Ecosystem Services Method Development.

Mitsch, W. J., and J. G. Gosselink. 1993. Wetlands, 2nd edition. Van Nostrand Reinhold, New York.

Moore, T. (ed.) 2002. Protecting Maryland's Green Infrastructure. The case for aggressive public policies. Maryland Dept. of Natural Resources, Annapolis, MD.

Natural Resources Conservation Service (NRCS). 2007. National Resources Inventory 2003 Annual NRI. Online at http://www.nrcs.usda.gov/.

Osmond, D.L., D.E. Line, J.A. Gale, R.W. Gannon, C.B. Knott, K.A. Bartenhagen, M.H. Turner, S.W. Coffey, J. Spooner, J. Wells, J.C. Walker, L.L. Hargrove, M.A. Foster, P.D. Robillard, and D.W. Lehning. 1995. Values of wetlands. Online at http://www.water.ncsu.edu/watershedss/info/wetlands/values.html.

Sather, J. H. and R.D. Smith. 1984. An overview of major wetland functions and values. U.S. Fish and Wildlife Service FWS/OBS-84/18. Washington, DC.

Sasman, R. T., C. R. Benson, J. S. Mende, N. F. Gangler, and V. M. Colvin. 1977. Water-level decline and pumpage in deep wells in the Chicago Region, 1971-1975. SWS/CIR-125/77. Illinois State Water Survey, Urbana, IL.

U.S. Geological Survey (USGS). 1995. Ground water atlas of the United States: Segment 10. Hydrologic Investigations Atlas 730-K. USGS, Reston, VA.

Tilley, D., E. Campbell, T. Weber, P. May, and C. Streb. 2011. Ecosystem based approach to developing, simulating and testing a Maryland ecological investment corporation that pays forest stewards to provide ecosystem services: Final report. Department of Environmental Science & Technology, University of Maryland, College Park, MD.

Woodward, R. T. and Y.-S. Wui. 2001. The economic value of wetland services: a meta-analysis. Ecological Economics 37:257-270.

Carbon Storage

- **Forests help remove large amounts of CO_2 from the air. During photosynthesis, trees convert CO_2 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. Larger and healthier trees sequester carbon at greater rates.**

- **A large tree can remove over 1,000 pounds per year of CO_2 from the atmosphere.**

- **A mature oak-hickory forest can contain over 130 tons of carbon per acre.**

- **Restoring prairie vegetation rebuilds organic matter in the surface soil and sequesters carbon, taking centuries to reach maximum storage potential.**

- **Remnant prairie at Fermi National Accelerator Laboratory contained around 0.76 kg of carbon per square meter above ground and 13.5 kg per square meter below ground.**

The majority of scientists agree that global temperatures are rising due to human activities (e.g., 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, and by the end of the century, our planet could be a radically different place. Vegetation and soils can sequester carbon and thereby help to reduce atmospheric CO_2 and global climate change.

Woodlands/Forest

The Stern Review (Stern, 2006) estimated that the economic costs of climate change would be at least 5-20% of global GDP. If current trends continue (using the Intergovernmental Panel on Climate Change (IPCC) A2 scenario – See IPCC, 2000), hurricane damage, real estate losses, energy costs, and water costs will cost the U.S. close to 2% of GDP, or $2 trillion ($2010) annually by 2100 (Ackerman and Stanton, 2008). Factoring in impacts to human and ecosystem health, the cost will be 3.6% of GDP (Ackerman and Stanton, 2008), or $3.6 trillion.

Forests help remove large amounts of CO_2 from the air. During photosynthesis, trees convert CO_2 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. Larger and healthier trees sequester carbon at greater rates (Nowak et al., 2013). Barford et al. (2001) found a mean sequestration rate around 2.0 Mg C/ha/year for a mature northern red oak stand. While reforesting abandoned land, restoring wetlands, and preserving natural areas help to reduce and maintain CO_2 levels, developing these lands produces the opposite effect and increases CO_2 by releasing previously stored carbon into the atmosphere (Strebel, 2002).

According to Strebel (2002), Maryland's vegetation absorbs about 55 million Mg (MMT) of CO_2 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.

Using Forest Inventory and Analysis (FIA) data, Industrial Economics (2011) reported that Delaware forest stores approximately 75 Mg/ha of aboveground carbon, 15 Mg/ha belowground (i.e., roots), and 60 Mg/ha in the soil. Palustrine forested wetlands store approximately 75 Mg/ha of aboveground carbon, 15 Mg/ha belowground (i.e., roots), and 126 Mg/ha in the soil. Industrial Economics (2011) reported the median value of the social cost of carbon as $118 per Mg of carbon ($2010).

According to the U.S. Forest Service (Smith, J. E., et al., 2005), a 125-year old oak-hickory forest in the northeast U.S. contains 132.2 tons of carbon/acre. The forest in question would be older than this (~165 years) by 2100 if left undisturbed, and an estimate of 150 tons carbon/acre is reasonable. The IPCC A2 scenario (IPCC, 2000) projected 1,773 gigatonnes of carbon added to the atmosphere between 1990-2100. An acre of undisturbed oak-hickory forest would sequester 150 tons of this, contributing a reduction of approximately $300/ac/year ($2010; **$330** in $2014) of climate-related damages (using Ackerman and Stanton, 2008, estimates) by 2100.

Smith, P.D., et al. (2005) found that trees in Houston's regional forests (8 counties) store 39.2 million tons of carbon, valued at $721 million based on 1994 marginal social cost estimates of $20.3 per metric ton. They sequester 1.6 million tons of carbon each year, at a value of $29 million (Smith, P.D., et al., 2005). Dividing by 2,152 mi^2 (1,377,280 ac) of forest, this translated to $31/ac/year of forest ($2010). Using the more recent estimates of $49/ton of carbon ($2010) from Nordhaus (2011), this translated to $75/ac/year of forest ($2010; **$82** in $2014). This value could be greater if Houston's regional forests are allowed to mature, or are sustainably harvested and the wood products retained or buried (i.e., not burned or allowed to oxidize). Tree mortality, fire, and clearing will release carbon into the atmosphere.

Mittman et al. (2014) reported that in Lancaster, PA, tree planting and new green roofs would sequester approximately 34 million lbs of CO_2/year. They averaged lower- and upper-bound carbon prices, using a value of $0.02308/lb; the total estimated benefit was therefore $786,000/year.

Batker et al. (2010) reported a gas and climate regulation value between $27.43/ac/yr and $623.33/ac/yr ($2006; **$32-$737** in $2014) for mid-seral forest and $99/ac/yr and $990/ac/yr ($2006; **$117-$1,170** in $2014) for late-seral forest.

McPherson et al. (2006) reported that even in public areas like parks, large trees (example: hackberry, 40 years old) remove a net 1062 lbs/year of CO_2 from the atmosphere. This

includes both direct (sequestration minus decomposition and tree care-related emissions) and indirect (avoided power plant emissions) mechanisms. They used a value of $15/ton CO_2 reduction, based on the average of high and low estimates by CO2e.com (2002). This web site no longer exists. CNT (2010) used an average price of $0.00756/lb CO_2 from the European Union's Emissions Trading System (EU ETS) as an example of a fully functioning carbon cap and trade market, and a value from Stern (2006) of $0.0386/lb CO_2 that represents the economic impact of climate change. The ETS figure gives a value of $8/large tree/year ($2002), or **$430**/ac/year ($2014), although there is currently no carbon cap and trade system that covers Illinois. The avoided damages approach gives a value of $41/large tree/year ($2006), or **$1,960**/ac/year ($2014).

Based on 2007 data, Nowak et al. (2013) estimated trees in the seven-county Chicago region (including the city of Chicago) sequester about 677,000 tons of carbon per year (2.5 million tons per year of CO_2) with an associated value of $14.0 million per year. Net carbon sequestration in the Chicago region is estimated at about 476,000 tons per year (1.7 million tons per year of carbon dioxide) based on estimated carbon loss due to tree mortality and decomposition. Given a tree area of 403,000 ac, the carbon sequestration value of forest and woodland was $35/ac/year ($2007; **$40** in $2014).

The Conservation Fund (2013) used the Carbon On Line Estimator (COLE; http://www.ncasi2.org/COLE/index.html; accessed Oct. 4, 2012) for the 13-county Houston-Galveston region. We aggregated plots across the region, but separated out upland forest by physiography (class = "xeric" or "mesic" except for floodplains and bottomlands). To note, wetlands (class = "hydric") did not have enough sample points. We filtered out "nonstocked" and "nonforest" plots. Using regression equations, mature upland forest (100 years after reforestation) in this region stores, on average, the following weight of carbon in its soil and vegetation components:

- Lobolly pine: 181.46 Mg/ha (73.43 Mg/ac)
- Lobolly pine/hardwood: 127.61 Mg/ha (51.64 Mg/ac)
- Mixed upland hardwoods: 120.19 Mg/ha (48.64 Mg/ac)
- Sweetgum/nuttall oak/willow oak: 159.57 Mg/ha (64.58 Mg/ac)

We also aggregated plots (filtered as above) by county (if it had enough plots) or groups of counties:

- Walker: 145.55 Mg/ha
- Montgomery: 204.05 Mg/ha
- Harris: 152.03 Mg/ha
- Chambers and Liberty: 126.43 Mg/ha
- Galveston, Brazoria, and Matagorda: 126.66 Mg/ha
- Austin, Colorado, Wharton, Waller, and Fort Bend: 109.78 Mg/ha

Finally, we decided on a hybrid approach, splitting the study area into the Outer Coastal Plain and Southeastern Mixed Forest biotic provinces (231 and 232) vs. Prairie Parkland (255), using USFS ecological sections (232E, 232F, and 231E vs. 255C and 255D). We filtered out hydric, bottomland, nonstocked and nonforest plots. We crosswalked COLE

forest types and National Land Cover Dataset (NLCD). All areas identified in the green infrastructure network design as bottomland forest received a value described in the next section. To note, we used all plots occurring in the study area. Three of the community types (sassafras/persimmon, sweetgum/yellow popular and elm/ash/black locust) may have been mischaracterized (pers. comm. Mickey Merritt 11/27/12 and 12/19/12), but since they were all aggregated (Tables 3 and 4), it would not have affected the calculations.

Table 3. Carbon storage in Outer Coastal Plain and Southeastern Mixed Forest provinces:

COLE forest type	**NLCD class**	**Mg/ha**	**Mg/ac**
Lobolly (n=104), shortleaf (n=4), or slash (n=2) pine	Evergreen forest (42)	182.30	73.77
Lobolly pine/hardwood (n=37)	Mixed forest (43)	139.31	56.38
Post oak/blackjack oak (n=6), Sassafras/persimmon (n=2), Sweetgum/yellow poplar (n=5), Elm/ash/black locust (n=1), Mixed upland hardwoods (n=29)	(all other upland forest)	147.21	59.57

Table 4. Carbon storage in Prairie Parkland province:

COLE forest type	**NLCD class**	**Mg/ha**	**Mg/ac**
Lobolly (n=33) or shortleaf (n=1) pine	Evergreen forest (42)	166.63	67.43
Lobolly pine/hardwood (n=13)	Mixed forest (43)	113.61	45.98
Post oak/blackjack oak (n=8), White oak/red oak/hickory (n=1), Sassafras/persimmon (n=1), Southern scrub oak (n=5), Mixed upland hardwoods (n=16)	(all other upland forest)	115.73	46.83

We divided the estimated $3.6 trillion ($2010) annual price tag of increased greenhouse gas emissions in 2100 (Ackerman and Stanton, 2008) by the projected 1,773 gigatonnes of carbon added to the atmosphere between 1990 and 2100 (IPCC A2 scenario; IPCC, 2000). If the effect is linear (a simplifying assumption), each tonne (Mg) of carbon emitted into the atmosphere is projected to cause $2 of damage annually. Thus, the values ranged from **$94-148**/ac/year of avoided climate-related damages.

The Conservation Fund (2013) used COLE (accessed Oct. 4, 2012) for the 13-county H-GAC region. We aggregated plots across the region, but separated out bottomland forest by physiography. We filtered out "nonstocked" and "nonforest" plots. Using regression equations, mature bottomland forest (100 years after reforestation) in the Outer Coastal Plain and Southeastern Mixed Forest provinces stored 166.04 Mg/ha (67.19 Mg/ac) of carbon on average, and in the Prairie Parkland province, stored 129.99 Mg/ha (52.61 Mg/ac). At $2/Mg/year, this equates **$105**/ac/year of avoided climate-related damages.

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 CO_2 better than any other ecosystem type (Strebel estimated 50% of Net Primary Production – NPP, i.e. the production of organic compounds from atmospheric or aquatic carbon dioxide), although this depends on hydroperiod and other parameters. Wetlands with long periods of inundation are especially effective at storing carbon, in the form of peat.

Industrial Economics (2011) reported that vegetated estuarine wetlands (i.e. tidal marsh) stores approximately seven Mg/ha in plant biomass and 99 Mg/ha in the soil (total 43 Mg/ac), palustrine emergent wetlands store approximately 20 Mg/ha in plant biomass and 104 Mg/ha in the soil (total 50 Mg/ac); palustrine scrub-shrub wetlands store approximately 20 Mg/ha in plant biomass and 149 Mg/ha in the soil (total 68 Mg/ac); and palustrine forested wetlands store approximately 75 Mg/ha of aboveground carbon, 15 Mg/ha belowground (i.e., roots), and 126 Mg/ha in the soil (total 87 Mg/ac). They reported the median value of the social cost of carbon as $118 per Mg of carbon ($2010). Note that this is not a yearly rate.

Using $2/Mg/year from the Ackerman and Stanton (2008) and IPCC calculations, we estimated the values of avoided climate-related damages as $100/ac/year for emergent wetlands, $136/ac/year for scrub-shrub wetlands, and $175/ac/year for forested wetlands.

Prairie/Grassland/Savanna

Industrial Economics (2011) reported that rangeland stores approximately 3 Mg/ha of aboveground carbon, 2 Mg/ha belowground (i.e., roots), and 73 Mg/ha in the soil. The median value of the social cost of carbon was $118 per Mg of carbon ($2010). This is not a yearly rate. At $2/Mg/year, the value is **$63**/ac/year ($2014).

Batker et al. (2010) reported a gas and climate regulation value of $3.85/ac/year ($2006; **$4.55** in $2014) for grassland from Costanza et al., 1997.

Belowground Carbon

In a study to determine carbon (C) sequestration potential in the Midwest U.S., Fissore et al. (2010) reported mean C sequestration rates for restored prairie pothole wetlands of 3.1 Mg C/ha/ yr. De Luca (2011) remarked that 3-5 Mg C/ha is temporarily retained in the soil each year as metabolic carbon. Much is slowly transformed and eventually respired before the next growing season. The conversion of cropland to grassland on CRP lands results in carbon sequestration rates of 0.5–1 Mg/ha/yr (0.22–0.45 tons/ac/yr) (Follett et al., 2001). Gleason et al. (2008) said this was a conservative estimate.

Brye and Kucharik (2003) measured C sequestration at two prairie sites in Southern Wisconsin, and found soil C concentration and content in the top 25 cm, averaged across restored and remnant prairies, were significantly higher ($p < 0.001$) in fine than coarse-textured soil. Soil C concentration ranged from 15.5 to 37.3 g/kg in the top 25 cm for the restored and remnant prairies at the fine-textured location, while soil C content ranged from 5.1 to 12.2 kg C/m^2. Soil C concentration ranged from 5.6 to 12.2 g/kg in the top 25 cm for the restored and remnant prairies at the coarse-texture location, while soil C content ranged from 2.1 to 4.5 kg C/m^2 (Brye and Kucharik, 2003).

According to Matamala et al. (2008), tallgrass prairie has 0.7-2.0 kg/m^2 of C in root biomass. Decomposition of roots builds up carbon in the soil. Soil organic carbon (SOC) is depleted in plowed fields to the depth of plowing (top 25 cm). Restoring prairie vegetation rebuilds organic matter in the surface soil. Prior studies cited by the authors reported SOC accumulations of 0.05-0.06 kg C/m^2/year following grassland restoration.

Matamala et al. (2008) reported cumulative soil organic carbon to range around 11.6-21.9 kg C/m^2 for remnant prairie.

Matamala et al. (2008) examined C and N stocks in cultivated land, restored prairie, and remnant prairie at Fermi National Accelerator Laboratory in Batavia, IL. They found that soil carbon increased at 0.043 kg C/m^2/year during the first 26 years of restoration, should reach 50% of storage potential (~12 kg C/m^2) in the first ~100 years, and 95% in 444 years. Belowground root mass accrued at 0.018-0.021 kg C/m^2/year, and was predicted to reach 50% of storage potential (~0.7 kg C/m^2) in the first 11-15 years, and 95% in 46-64 years. Microbial biomass accrued at 0.005-0.009 kg C/m^2/year, and was predicted to reach 50% of storage potential (~0.3-0.7 kg C/m^2) in the first 14-39 years, and 95% in 59-168 years. Remnant prairie sites totaled ~13.5 kg C/m^2 below ground (soil organic + roots + microbial).

Aboveground Carbon

Matamala et al. (2008) found that aboveground biomass for restored prairie accrued at 0.06 kg C/m^2/year, and reaches 50% of storage potential (0.76 kg C/m^2) in the first 3 years, and 95% in 13 years.

Using the National Biomass and Carbon Dataset (Kellndorfer et al., 2012), we found that core prairies in the CMAP region average 2.25 metric tons of aboveground biomass per hectare, equivalent to approximately 1.125 metric tons of aboveground carbon.

Kucharik et al. (2006) compared the world's oldest prairie restoration with an adjacent remnant in Southern Wisconsin and found the annual average aboveground net primary productivity (NPP) to be 271 ±51 and 330 ±55 g C/m^2 respectively. Another study (Brye et al., 2002) reported NPP on a restored prairie (Goose Pond Sanctuary near Arlington, WI) of 2.6 Mg C/ha/yr.

Gleason et al. (2008) found vegetable organic carbon in native prairie catchments to be 1.47 ± 0.14 Mg/ha (0.66 ± 0.06 Mg/ac).

Combining storages

We used the remnant prairie numbers from Matamala et al. (2008) since they were collected in the CMAP region. Total carbon varied 50-92 Mg/ac. At $2/Mg/year, the value is **$100-$184**/ac/year ($2014).

Spatial Assessments

In Table 5, Industrial Economics (2011) reported values for carbon storage by land cover type.

Table 5. Aboveground biomass, belowground biomass, and soil carbon storage for land cover types (Industrial Economics, 2011)

Cover type	Aboveground carbon (Mg/ha)	Belowground carbon (Mg/ha)	Soil carbon (Mg/ha)
Built	0	0	39
Agriculture	10	5	55
Rangeland	3	2	73
Forest	75	15	60
Water	0	0	0
Bare Soil/Sand	0	0	41
Non-Vegetated Estuarine Wetlands	3	4	158
Vegetated Estuarine Wetlands	3	4	99
Palustrine Aquatic Bed Wetlands	20	(included in aboveground value)	61
Palustrine Emergent Wetlands	20	(included in aboveground value)	104
Palustrine Forested Wetlands	75	15	126
Palustrine Scrub-Shrub Wetlands	20	(included in aboveground value)	149

MARC and AES (2013) assigned ranks to land cover classes based on their ability to store carbon in the soil (Table 6).

Table 6. Ranks assigned by MARC and AES (2013) to land cover classes based on their ability to sequester carbon in the soil. 5 is the highest rank and 0 the lowest.

Land cover type	**Relative value**
Deciduous forest, Forested wetland	5
Coniferous forest, Upland shrub-scrub	3
Wetland shrub-scrub	2
Herbaceous wetland, Grassland	1
Cultivated, Buildings and Transportation, Barren, Water	0

In the Houston-Galveston region, The Conservation Fund (2013) classified upland forest, as identified during the green infrastructure network design, according to its NLCD classification and USFS ecoregion. We assigned carbon stocks for mature forest (assuming the forest would be allowed to reach maturity) as described previously. We did not attempt to model logging or other disturbances, which would release some carbon back into the atmosphere. We classified bottomland forest by ecoregion, and assigned corresponding carbon values.

COLE had too few wetland plots in the study area, so for forested wetlands, we used the vegetation values for bottomland forest by ecoregion, and the soil value (126 Mg/ha) from Industrial Economics (2011). For other wetland types, we used vegetation and soil carbon values from Industrial Economics (2011; Table 7).

Table 7. Reported carbon storage by different classes of wetlands Industrial Economics (2011).

Wetland type	**Vegetation carbon (tons/ha)**	**Soil carbon (tons/ha)**	**Total carbon (tons/ha)**
Estuarine emergent	7	99	106
Estuarine scrub-shrub	20	149	169
Lacustrine emergent	20	104	124
Palustrine aquatic bed	20	61	81
Palustrine emergent	20	104	124
Palustrine forested	90	126	216
Palustrine scrub-shrub	20	149	169

For prairie, the Conservation Fund (2013) assigned 78 Mg/ha of carbon storage as reported for rangeland by Industrial Economics (2011). Finally, we merged the values for wetland, forest, and prairie (with wetlands on top). We multiplied these by $2/Mg of avoided annual damage by 2100 to give $/ac/year. Values ranged from $63 to $195/year in $2010 for the year 2100. These values would be lower before 2100 and greater afterward.

References in this section

Ackerman, F., and E. A. Stanton. 2008. The cost of climate change: What we'll pay if global warming continues unchecked. http://www.nrdc.org/globalwarming/cost/cost.pdf.

Barford, C. C., S. C. Wofsy, M. L. Goulden, J. W. Munger, E. H. Pyle, S. P. Urbanski, L. Hutyra, S. R. Saleska, D. Fitzjarrald, and K. Moore. 2001. Factors controlling long- and short-term sequestration of atmospheric CO_2 in a mid-latitude forest. Science 294:1688-1691.

Batker, D., M. Kocian, B. Lovell, and J. Harrison-Cox. 2010. Flood protection and ecosystem services in the Chehalis River Basin. Earth Economics, Tacoma, WA.

Brye, K.R., S. T. Gower, J. M. Norman, and L. G. Bundy. 2002. Carbon budgets for a prairie and agroecosystems: effects of land use and interannual variability. Ecological Applications 12(4): 962-979.

Brye, K. R and C. J. Kucharik. 2003. Carbon and nitrogen sequestration in two prairie topochronosequences on contrasting soils in southern Wisconsin. American Midland Naturalist, 149(1):90-103.

Center for Neighborhood Technology (CNT). 2010. The value of green infrastructure: a guide to recognizing its economic, environmental and social benefits. Center for Neighborhood Technology, Chicago, IL.

Conservation Fund, The. 2013. Houston-Galveston Green Infrastructure and Ecosystem Services Assessment.

Costanza, R., R. d'Arge, R. de Groot, S. Farber, M. Grasso, B. Hannon, K. Limburg, S. Naeem, R. O'Neill, J. Paruelo, R. Raskin, P. Sutton, and M. van den Belt. 1997. The value of the world's ecosystem services and natural capital. Nature 387:252- 259.

DeLuca, T. H. and C. A. Zabinski. 2011. Prairie ecosystems and the carbon problem. Frontiers in Ecology and the Environment 9(7): 407-413.

Fissore, C., J. Espeleta, E. A. Nater, S. E. Hobbie, and P. B. Hobbie. 2010. Limited potential for terrestrial carbon sequestration to offset fossil-fuel emissions in the upper midwestern U.S. Frontiers in Ecology and the Environment 8(8):409-413.

Follett, R. F., E. G. Pruessner, S. E. Samson-Liebig, J. M. Kimble, and S. W. Waltman. 2001. Carbon sequestration under the Conservation Reserve Program in the historic grassland soils of the United States of America, in Lal, R., ed., Carbon sequestration and greenhouse effect. Soil Science Society of America, Special Publication No. 57, pp. 27–40.

Gleason, R. A., M. K. Laubhan, and N. H. Euliss, Jr. (eds.). 2008. Ecosystem services derived from wetland conservation practices in the United States Prairie Pothole Region with an emphasis on the U.S. Department of Agriculture Conservation Reserve and Wetlands Reserve Programs: U.S. Geological Professional Paper 1745. 58 pp.

Industrial Economics, Inc. 2011. Economic valuation of wetland ecosystem services in Delaware: Final report. Delaware Department of Natural Resources and Environmental Control, Division of Water Resources, Dover, DE.

Intergovernmental Panel on Climate Change (IPCC). 2000. Emissions Scenarios: Summary for Policymakers. ISBN: 92-9169-113-5. http://www.ipcc.ch/pdf/special-reports/spm/sres-en.pdf.

Kellndorfer, J., Walker, W., LaPoint, E., Bishop, J., Cormier, T., Fiske, G., Hoppus, M., Kirsch, K., and Westfall, J. 2012. NACP Aboveground Biomass and Carbon Baseline Data (NBCD 2000), U.S.A., 2000. Data set. Available on-line [http://daac.ornl.gov] from ORNL DAAC, Oak Ridge, Tennessee, U.S.A.

Kucharik, C. J., N. J. Fayram, and K. N. Cahill. 2006. A paired study of prairie carbon stocks, fluxes, and phenology: comparing the world's oldest prairie restoration with an adjacent remnant. Global Change Biology 12(1):122-139.

Matamala, R., J. D. Jastrow, R. M. Miller, and C. T. Garten. 2008. Temporal changes in C and N stocks of restored prairie: implications for C sequestration strategies. Ecological Applications 18(6):1470-1488.

McPherson, E., J. R. Simpson, P. J. Peper, S. L. Gardner, K. E. Vargas, S. E. Maco, and Q. Xiao. 2006. Midwest Community Tree Guide: Benefits, Costs, and Strategic Planting. General Technical Report PSW-GTR-199. United States Department of Agriculture, Forest Service, Pacific Southwest Research Station. Davis, CA.

Mid-America Regional Council (MARC) & Applied Ecological Services (AES). 2013. Kansas City Natural Resources Inventory II Phase 4: Ecosystem Services Method Development.

Mittman, T., et. al. 2014. The economic benefits of green infrastructure: a case study of Lancaster, PA. EPA 800-R-14-007. U.S. Environmental Protection Agency, Washington, DC.

Nordhaus, W. 2011. Estimates of the Social Cost of Carbon: Background and Results from the RICE-2011 Model. Cowles Foundation for Research in Economics, Yale University, New Haven, CT.

Nowak, D. J., R. E. Hoehn III, A. R. Bodine, D. E. Crane, J. F. Dwyer, V. Bonnewell, and G. Watson. 2013. Urban trees and forests of the Chicago region. Resour. Bull. NRS-84. U.S. Department of Agriculture, Forest Service, Northern Research Station, Newtown Square, PA.

Smith, J. E., L. S. Heath, K. E. Skog, and R. A. Birdsey. 2005. Methods for Calculating Forest Ecosystem and Harvested Carbon with Standard Estimates for Forest Types of the United States. U.S. Dept. of Agriculture Forest Service, Northeastern Research Station, General Technical Report NE-343. http://www.treesearch.fs.fed.us/pubs/22954.

Smith, P. D., M. Merritt, D. Nowak, and D. Hitchcock. 2005. Houston's Regional Forests. Texas Forest Service.

Stern, N. 2006. Stern Review on The Economics of Climate Change. HM Treasury, London, UK.

Strebel, D. E. 2002. Carbon sequestration potential in Maryland (draft version). Versar, Inc., prepared for Maryland Dept. Nat. Res., Annapolis, MD.

Native Flora and Fauna

- **Ecosystem resistance and resilience to stresses depends on species composition and diversity. Diverse ecosystems are more likely to contain species tolerant to disturbances like flooding, drought, or pests.**

- **Biological diversity and genetic information are not easy to translate into dollar terms, but a number of studies have quantified the economic value of habitat, with wetlands having a value up to $14,800 per acre per year ($2014).**

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 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). 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 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 (Weber, 2007b). As illustrated by a 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.

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, for example, 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 1,000 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.

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, 2002b). 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 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 Illinois have unknown potentials for agricultural, pharmaceutical, and biotechnology advances. Illinois 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, with a goal to ensure their long-term survival as an investment for future generations. Just as we preserve scientific, engineering, and cultural knowledge in libraries, one could argue we should preserve our world's genetic library.

In a 2008 survey, 84.6% of Illinois residents thought "more wildlife habitat should be protected and restored" (IDNR, 2009). 80.6% thought "more high quality undisturbed prairie, forest and wetlands should be acquired/protected." Londoño and Ando (2013) found that residents of Champaign and Urbana, Illinois were each, on average, willing to pay over $18/year to improve fish habitat.

Woodlands/Forest

Batker et al. (2010) reported habitat values of $269.85; $452.57; and $500.24/ac/year ($2006) for forest. This translates to **$319, $535,** and **$591**/ac/year in $2014.

Streams and Lakes

Batker et al. (2010) reported habitat values of $58.89; $269.91; and $500.24/ac/year ($2006) for riparian buffers. This translates to **$70, $319,** and **$591**/ac/year in $2014.

Batker et al. (2010) reported habitat values of $17.13, $58.89; $269.91; and $1,479.84/ac/year ($2006) for lakes and rivers. This translates to **$20, $70, $319,** and **$1,749**/ac/year in $2014.

Wetlands

Batker et al. (2010) reported habitat values of $58.89; $269.91; $1,479.84; $5,147.20; and $12,537.14/ac/year ($2006) for freshwater wetlands. This translates to **$70, $319, $1,749, $6,083,** and **$14,816**/ac/year in $2014.

Using results from 39 studies, Woodward and Wui (2001) reported a wildlife habitat value between $95/ac/yr and $981/ac/yr (mean $306/ac/yr) for wetlands ($1990; **$173-$1,789** in $2014).

Spatial Assessments

Large contiguous blocks of natural land are more likely to contain fully functioning ecosystems (e.g., MacArthur and Wilson, 1967; Forman and Godron, 1986; Weber, 2007a), and provide corresponding benefits to humans. Smaller, fragmented ecosystems are more likely to be impaired (Weber et al., 2004, p.59; Weber, 2007b). 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).

Kozak et al. (2011) reported a study showing that wetland improvements in California to support salmon populations decayed exponentially with a 472 km half-life, a much more gradual decline than the UK case.

MARC and AES (2013) assigned qualitative values for support of native wildlife species diversity at a regional scale, especially of area-sensitive and specialist species. They derived the values from land cover class, polygon size, and distance to roads. First, they weighted land cover class as likely to support area-sensitive and specialist species, with natural communities given a score = 5, grassland = 2, cultivated land = 1 and impervious cover and barren land = 0. They scaled habitat patch size and distance to roads geometrically (Table 8).

Table 8. Patch size and distance from roads vs. wildlife support (MARC and AES, 2013).

Wildlife Group	**Habitat Patch Size (acres)**	**Road Distances (meters)**
Area-Sensitive & Specialist Wildlife	>1,000	>400
Intermediate Conditions	101-1000	41-400
Generalist Wildlife	11-100	5-40
Low Habitat Integrity	≤10	≤4

References in this section

Anderson, G. S., and B. J. Danielson. 1997. The effects of landscape composition and physiognomy on metapopulation size: the role of corridors. Landscape ecology 12:261-271.

Batker, D., M. Kocian, B. Lovell, and J. Harrison-Cox. 2010. Flood protection and ecosystem services in the Chehalis River Basin. Earth Economics, Tacoma, WA.

Beier, P., and R. F. Noss. 1998. Do habitat corridors provide connectivity? Conservation Biology 12(6):1241-1252.

Bennett, A. F. 1998. Linkages in the landscape: the role of corridors and sensitivity in wildlife conservation. IUCN, Gland, Switzerland and Cambridge, UK.

Forman, R. T. T., and M. Godron. 1986. Landscape Ecology. John Wiley and Sons, New York, NY.

Illinois Department of Natural Resources (IDNR). 2009. Illinois Statewide Comprehensive Outdoor Recreation Plan 2009–2014.

Jenkins, M. D., and B. Groombridge. 2002. World Atlas of Biodiversity: Earth's Living Resources in the 21st Century. University of California Press.

Kozak, J., C. Lant, S. Shaikh, and G. Wang. 2011. The geography of ecosystem service value: The case of the Des Plaines and Cache River wetlands, Illinois. Applied Geography 31:303-311.

Londoño Cadavid, C. and A. W. Ando. 2013. Valuing preferences over stormwater management outcomes including improved hydrologic function. Water Resources Research 49(7):4114–4125.

MacArthur, R. H. and E. O. Wilson. 1967. The theory of island biogeography. Princeton University Press, Princeton, NJ.

Madritch, M. D., and M. D. Hunter. 2002. Phenotypic diversity influences ecosystem functioning in an oak sandhills community. Ecology 83(8):2084-2090.

Mid-America Regional Council (MARC) & Applied Ecological Services (AES). 2013. Kansas City Natural Resources Inventory II Phase 4: Ecosystem Services Method Development.

Pimentel, D. 1998. Economic and environmental benefits of biological diversity in the state of Maryland. pp. 63-75 in Therres, G. D. (ed.) Conservation of biological diversity: a key to the restoration of the Chesapeake Bay ecosystem and beyond. Maryland Dept. Nat. Res., Annapolis, MD.

Ramsar Convention on Wetlands. 2000a. Reservoirs of biodiversity. Ramsar Convention Bureau, Gland, Switzerland.

Ramsar Convention on Wetlands. 2000b. Wetland values and functions. Ramsar Convention Bureau, Gland, Switzerland.

Söndgerath, D., and B. Schröder. 2002. Population dynamics and habitat connectivity affecting the spatial spread of populations - a simulation study. Landscape ecology 17:57-70.

Soule, M. E., and J. Terbough. 1999. Continental conservation: scientific foundations of regional reserve networks. Island Press, Washington, DC. 227 pp.

Weber, T. 2003. Maryland's green infrastructure assessment: a comprehensive strategy for land conservation and restoration. Maryland Dept. Nat. Res., Annapolis, MD. 246pp. plus appendices.

Weber, T. 2007a. Development and application of a statewide conservation network in Delaware, U.S.A. Journal of Conservation Planning 3:17-46.

Weber, T. 2007b. Ecosystem services in Cecil County's Green Infrastructure: Technical Report for the Cecil County Green Infrastructure Plan. The Conservation Fund, Annapolis, MD.

Weber, T., J. Wolf, P. Blank, R. Aviram, and J. Lister. 2004. Restoration targeting in Maryland's Green Infrastructure. Maryland Dept. Nat. Res., Annapolis, MD.

Woodward, R. T. and Y.-S. Wui. 2001. The economic value of wetland services: a meta-analysis. Ecological Economics 37:257-270.

Recreation and Ecotourism

- **In 2011, Illinois residents and non-residents spent $3.8 billion on wildlife-associated recreation. They also spent 13.3 million days and $973 million fishing in Illinois (excluding Lake Michigan).**

- **In a 2008 survey, over 97% of Illinois residents thought outdoor recreation areas are important for health and fitness and almost 94% thought community recreation areas are important for quality of life and promote economic development. Over 80% thought more lands should be acquired for open space and/or for outdoor 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 many states, the opening of deer season is one of the most anticipated days of the year.

In a 2000 study, researchers found that when previously inactive adults incorporated moderate physical activity into their routines, annual mean medical expenditures were reduced by $865 per person (CNT, 2010).

A survey by USFWS and USCB (2014) revealed that in 2011, 3.8 million persons 16 years old and older engaged in fishing, hunting, or wildlife-watching activities in Illinois. Of these, 1.0 million fished, 512 thousand hunted, and 3.0 million (the majority) participated in passive observing, feeding, and photographing wildlife. In the same year, state residents and non-residents spent $3.8 billion on wildlife-associated recreation in Illinois.

In 2011, residents and non-residents spent 13.3 million days and $973 million fishing in Illinois, presumably most of this in publicly accessible water bodies (USFWS and USCB, 2014). This data excluded Lake Michigan, from which inadequate data existed.

Residents and non-residents spent 7.8 million days and $1,216 million hunting (USFWS and USCB, 2014). Of this, $274 million was spent on trip-related expenses, $303 million on equipment, and $573 million on magazines, books, and DVDs, membership dues and contributions, land leasing and ownership, and licenses, stamps, tags, and permits. Most of the time (around 90%) was spent on private land. Of trip-related and hunting equipment expenses ($516 million), 68% was spent hunting big game (primarily deer, with wild turkey a distant second), 21% hunting small game (primarily pheasant, with squirrel hunted half as often), and 11% hunting migratory birds (waterfowl and doves; presumably mostly ducks).

Residents and non-residents spent 6.4 million days watching wildlife away from their home, and spent $166 million on trip-related expenditures alone (i.e., excluding equipment) (USFWS and USCB, 2014). Total equipment expenditures, excluding bird food, plantings, bird houses, etc. were $817 million. Since around 37% of wildlife watchers visited parks or natural areas (either away from home or within a mile of their home), we estimated equipment expenditures of $300 million to visit natural areas to view wildlife.

In 2006, there were 257,250 visits to the Minnesota Valley National Wildlife Refuge in Bloomington, MN. Almost all visits were for non-consumptive recreation, primarily trail use, birding, and observation platforms (Fermata, Inc., 2010). Residents (within 30 miles of the refuge) accounted for 80% of all visitations. Total visitor recreation expenditures in 2006 were $1.3 million, with non-residents accounting for 51% of the total expenditures. The total economic effect was $1.48 returned for every $1 in budgeted expenditures (Fermata, Inc., 2010).

In a 2008 survey, 58.2% of Illinois residents spent time observing birds and other wildlife in 2008 (IDNR, 2009). Of these, 54.7% did so away from home: 6.3% in private areas, 25.8% in city or county parks, 18.4% in state parks, and 4.2% in national parks or areas.

45.4% of residents spent time fishing, primarily at state parks. Fishing and hunting ranked first and second as outdoor activities that rural respondents wanted to start or participate in more often. Over half of the respondents (50.7%) indicated that if lands and facilities were more conveniently located, they might engage in outdoor activities more often (IDNR, 2009).

In the same survey, 97.5% of Illinois residents thought outdoor recreation areas are important for health and fitness (IDNR, 2009). 93.6% thought community recreation areas are important for quality of life and promote economic development. 80.3% thought "more lands should be acquired for open space and/or for outdoor recreation."

In Illinois, state, local, and federal governments spent $1,529,117,770 on land conservation between 1998 and 2011, conserving 216,066 acres of land. In that same period, referendums approved $1,261,809,549 for land preservation (Trust for Public Land, 2013). On average, 53% of people voting on 70 separate referendums voted for spending new money on land preservation.

Woodlands/Forest

Batker et al. (2010) reported aesthetic and recreation values of $4.89, $5.52, $5.94, $11.78, $17.84, $23.78, $40.76, $104.34, $169.13, $190.66, $538.99, $569.01, and $637.81/ac/year ($2006) for forest. In $2014, this ranged from **$6-$754**/ac/year.

Streams and Lakes

A study in Philadelphia estimated that restoring riparian vegetation would increase recreational trips by almost 350 million over 40 years, and translate to $951.40/ac/year (presumably $2009) (CNT, 2010; **$1,057**/ac/year in $2014).

Batker et al. (2010) reported aesthetic and recreation values of $1,043; $1,474.20; $2,297.39; $4,420.54; and $10,624.14/ac/year ($2006) for riparian buffers. In $2014, this ranged from **$1,233-$12,558**/ac/year.

Batker et al. (2010) reported aesthetic and recreation values ranging between $1.69 and $19,699/ac/year (median $283.79; $2006) for rivers and lakes. In $2014, this ranged from **$2-$23,284**/ac/year (median **$335**).

Wetlands

Using results from 39 studies, Woodward and Wui (2001) reported a value ($1990) for wetlands between $95/ac/yr and $1,342/ac/yr (mean $357/ac/yr) for recreational fishing, between $25/ac/yr and $197/ac/yr (mean $70/ac/yr) for waterfowl hunting, and between $528/ac/yr and $2,782/ac/yr (mean $1212/ac/yr) for bird watching.

Batker et al. (2010) reported aesthetic and recreation values of $31.47, $34.75, $100.68, $103.35, $656.33, $1,044.66, $1,212.84, $2,100.39, $2,318.09, $4,187.89, $4,626.73, and $9,347.33/ac/year ($2006) for freshwater wetlands.

In $2014, these values ranged from **$37-$11,049**/ac/year (median **$1,434**).

Prairie/Grassland/Savanna

Batker et al. (2010) reported an aesthetic and recreation value of $1.01/ac/year ($2006) for grassland (**$1**/ac/year in $2014).

Spatial Assessments

MARC and AES (2013) ranked areas for recreation potential based on their proximity to public land, roads or trails, and land cover (Table 9).

Table 9. Ranks assigned by MARC and AES (2013) to areas based on their recreation potential. 5 is the highest rank and 0 the lowest.

Type of area	**Relative value**
Natural communities that intersect public lands or access points	5
Natural communities, grassland & cropland that are <200m of public roads & trails	4
Natural communities, grassland & cropland that are >200m from public roads & trails	3
All other land cover polygons	1

In Maryland, Weber (2007b) allocated USFWS (2003) data to ecosystem types. 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.) (USFWS, 2003).

Wildlife viewers in Maryland spent $130 million on trip expenditures alone (USFWS, 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. 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 followed 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 (USFWS, 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. There was 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$, Weber (2007b) estimated the recreation value per year as $486/ac for upland forest, $534/ac for forested wetlands, and $544/ac for marsh.

Baerenklau et al. (2010) estimated the access value for trailheads using a multiple-site zonal travel cost model. Zonal models typically use zip codes as the spatial unit of analysis, which facilitates incorporation of distance and census data as explanatory variables in the regression. The price of a trip from each zip code was estimated as the sum of driving costs and time costs. Driving costs were a function of distance (derived from Google Maps), the average per-mile cost of operating a typical car (from AAA, $0.561/mile in 2005), and the average number of passengers per vehicle (1.5; authors' dataset). Time costs were a function of travel time (derived from Google Maps) and the opportunity cost of time which was evaluated at one-third of the average hourly per-capita income for each zip code (a standard assumption). They found a highly skewed distribution of recreation values, with the highest values corresponding to parcels with the best view.

References in this section

Balmford, A., A. Bruner, P. Cooper, R. Costanza, S. Farber, R. E. Green, M. Jenkins, P. Jefferiss, V. Jessamy, J. Madden, K. Munro, N. Myers, S. Naeem, J. Paavola, M. Rayment, S. Rosendo, J. Roughgarden, K. Trumper, and K. Turner. 2002. Economic reasons for conserving wild nature. Science 297:950- 953.

Baerenklau, K.A., A. González-Cabán, C. Paez, and E. Chavez. 2010. Spatial allocation of forest recreation value. Journal of Forest Economics 16:113-126.

Batker, D., M. Kocian, B. Lovell, and J. Harrison-Cox. 2010. Flood protection and ecosystem services in the Chehalis River Basin. Earth Economics, Tacoma, WA.

Center for Neighborhood Technology (CNT). 2010. The value of green infrastructure: a guide to recognizing its economic, environmental and social benefits. Center for Neighborhood Technology, Chicago, IL.

Fermata, Inc. 2010. Hackmatack National Wildlife Refuge: Viability study.

Illinois Department of Natural Resources (IDNR). 2009. Illinois Statewide Comprehensive Outdoor Recreation Plan 2009–2014.

Klapproth, J. C., and J. E. Johnson. 2001. Understanding the science behind riparian forest buffers: benefits to communities and landowners. Virginia Cooperative Extension. Publication Number 420-153.

McQueen, M. 2001. Land and water conservation: an assessment of its past, present and future. The Conservation Fund, Arlington, VA.

Mid-America Regional Council (MARC) & Applied Ecological Services (AES). 2013. Kansas City Natural Resources Inventory II Phase 4: Ecosystem Services Method Development.

Sipple, B. 2007. Wetlands functions and values. http://www.epa.gov/watertrain/wetlands/.

Trust for Public Land. 2013. Land Conservation in Illinois. http://www.conservationalmanac.org/secure/almanac/midwest/il/index.html. Accessed July 17, 2014.

U.S. Fish and Wildlife Service (USFWS). 2003. 2001 National Survey of Fishing, Hunting, and Wildlife-Associated Recreation: Maryland. FHW/01-MD-Rev.

U.S. Fish and Wildlife Service and U.S. Census Bureau (USFWS and USCB). 2014. 2011 National Survey of Fishing, Hunting, and Wildlife-Associated Recreation. FHW/11-IL (RV).

Weber, T. 2007b. Ecosystem services in Cecil County's Green Infrastructure: Technical Report for the Cecil County Green Infrastructure Plan. The Conservation Fund, Annapolis, MD.

Woodward, R. T. and Y.-S. Wui. 2001. The economic value of wetland services: a meta-analysis. Ecological Economics 37:257-270.

The following three ecosystem services were researched but were not examined spatially.

Air Purification

- **Trees provide air quality benefits by absorbing sulfur dioxide (SO_2) and nitrogen oxide (NO_2), two major components of acid rain. Trees also can trap ozone (O_3), carbon monoxide (CO), and particles (PM_{10}) in the air, all of which can be harmful to humans.**

- **Trees in the seven-county Chicago region removed 18,080 tons of air pollution (CO, NO_2, O3, PM_{10}, SO_2) per year with an associated value of $157 million.**

Woodlands/Forest

Trees provide air quality benefits by absorbing sulfur dioxide (SO_2) and nitrogen oxide (NO_2), 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). Mechanisms for trees removing pollutants from the air include absorption through leaf stomata (i.e. pores for gaseous exchange) and interception by leaves. The forest soil is also a large and important sink for many air pollutants. This ecosystem service is especially important because of the immediate human health effects.

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 $114 million per year ($2010). With 555,090 acres of trees in this area, this translates to a benefit of $206/ac of trees. Tilley et al. (2012) found that ozone was the highest valued pollutant removed by forest in Maryland, at $48/ac/year ($2000; **$66** in $2014).

McPherson et al. (2006) reported that a single large tree (hackberry, 47 ft tall, 37 ft spread, 40 years old) could annually uptake 0.72 lbs. of O_3 and uptake and avoid 1.59 lbs. of NO_2, 0.98 lbs of SO_2 and 0.81 lbs of PM_{10} particulates. For the city of Chicago, Wang et al. (1994) reported the control costs of NO_x to be $7,990/ton, ROG $8,150/ton, PM_{10} $4,660/ton, SO_x $9,120/ton, and CO $2440/ton (1989 dollars). Following McPherson et al. (2006), we used control costs to estimate willingness to pay for air-quality improvements (instead of using damage costs, also reported by Wang et al, 1994). CNT (2010) gave a value for O_3 equivalent to NO_2. Combining and converting to 2014 dollars, this gives an air pollution control value of $29.93/tree/year, or **$1,213**/ac/year.

Based on 2007 data, Nowak et al. (2013) estimated trees in the seven-county Chicago region (including the city of Chicago) removed 18,080 tons of air pollution (CO, NO_2, O_3, PM_{10}, SO_2) per year with an associated value of $157 million ($2007). They based the dollar figure on 2007 national median externality costs associated with pollutants. Shrub cover in the Chicago region removed an additional estimated 6,090 tons per year, worth $46

million/year. Given an area of 2,602,000 ac, 15.5% tree cover, and 5.5% shrub cover, trees removed $340/ac/year and shrubs $321/ac/year ($2007). Converting to 2014 dollars, Chicago-area trees remove **$390**/ac/year and shrubs **$368**/ac/year.

Spatial Assessments

MARC and AES (2013) assigned ranks to land cover classes based on their ability to remove NO_x and SO_2 from the air (Table 10). Maes et al. (2011) reported removal rates of NO_x and SO_2 (reported by MARC and AES (2013) in lbs/ac/yr).

Table 10. Ranks assigned by MARC and AES (2013) to land cover classes based on their ability to remove NO_x and SO_2 from the air. 5 is the highest rank and 0 the lowest.

Land cover type	**Relative value**
Upland Deciduous Forest, Lowland Deciduous Forest	5
Mixed Forest	4.5
Coniferous Forest	3
Shrub-scrub	2
Herbaceous, Cultivated	1
Impervious Buildings, Impervious Other, Barren, Water	0

The Conservation Fund (2013) assigned the value of $312/ac/year (from Smith et al., 2005) to all forest cells. We recommended that more sophisticated studies attempt to differentiate the air quality value of forests based on their location in urban or rural areas or in relationship to the location of point and nonpoint air pollution sources.

References in this section

American Forests. 1999. Regional ecosystem analysis: Chesapeake Bay region and the Baltimore-Washington corridor. American Forests, Washington, DC.

Center for Neighborhood Technology (CNT). 2010. The value of green infrastructure: a guide to recognizing its economic, environmental and social benefits. Center for Neighborhood Technology, Chicago, IL.

Conservation Fund, The. 2013. Houston-Galveston Green Infrastructure and Ecosystem Services Assessment.

McPherson, E., J. R. Simpson, P. J. Peper, S. L. Gardner, K. E. Vargas, S. E. Maco, and Q. Xiao. 2006. Midwest Community Tree Guide: Benefits, Costs, and Strategic Planting. General Technical Report PSW-GTR-199. United States Department of Agriculture, Forest Service, Pacific Southwest Research Station. Davis, CA.

Mid-America Regional Council (MARC) & Applied Ecological Services (AES). 2013. Kansas City Natural Resources Inventory II Phase 4: Ecosystem Services Method Development.

Nowak, D. J., R. E. Hoehn III, A. R. Bodine, D. E. Crane, J. F. Dwyer, V. Bonnewell, and G. Watson. 2013. Urban trees and forests of the Chicago region. Resour. Bull. NRS-84. U.S. Department of Agriculture, Forest Service, Northern Research Station, Newtown Square, PA.

Smith, P. D., M. Merritt, D. Nowak, and D. Hitchcock. 2005. Houston's Regional Forests. Texas Forest Service.

Tilley, D., E. Campbell, T. Weber, P. May, and C. Streb. 2011. Ecosystem based approach to developing, simulating and testing a Maryland ecological investment corporation that pays forest stewards to provide ecosystem services: Final report. Department of Environmental Science & Technology, University of Maryland, College Park, MD.

Wang, M. Q., D.J. Santini, and S.A. Warinner. 1994. Methods of valuing air pollution and estimated monetary values of air pollutants in various U.S. regions. Center for Transportation Research, Energy Systems Division, Argonne National Laboratory, Argonne, IL.

Microclimate Moderation

- **Urban trees reduce energy costs from residential buildings by an estimated $44.0 million annually in the Chicago region and an additional $1.3 million in value per year by reducing carbon emissions from fossil-fuel based power sources.**

- **Even in public areas like parks, trees can save energy. 85% of energy savings are due to larger scale effects like lowering neighborhood air temperatures and wind speeds.**

Woodlands/Forest

Trees can reduce energy consumption by shading buildings, providing evaporative cooling, and blocking winter winds. Nowak et al. (2013) reported that urban trees reduced energy costs from residential buildings by an estimated $44.0 million annually. They also provided an additional $1.3 million in value per year by reducing the amount of carbon released by fossil-fuel based power sources (a reduction of 63,000 tons of carbon emissions or 232,000 tons of CO_2). Tree effects on energy use depend on distance and direction to space-conditioned buildings, so this service may not apply to areas far from such buildings.

McPherson et al. (2006) reported that even planted in public areas like parks, large trees (example: hackberry, 47 ft tall, 37 ft spread, 40 years old) can save 212 kWh/year of electricity (for cooling) during the summer and 4373 kBtu of natural gas (for heating) during the winter. They only attributed shade effects to residential yard trees, but wrote that 85% of energy savings were due to climate effects like lowering neighborhood air temperatures and windspeeds, which applied to street and park trees as well. At $0.0959/kWh and $0.0000123/Btu (CNT, 2010), this translates to a savings of $74/tree/year or $3,004/ac/year (c. $2010; **$3,282**/ac/year in $2014), assuming the trees are in an urban environment.

References in this section

Center for Neighborhood Technology (CNT). 2010. The value of green infrastructure: a guide to recognizing its economic, environmental and social benefits. Center for Neighborhood Technology, Chicago, IL.

McPherson, E., J. R. Simpson, P. J. Peper, S. L. Gardner, K. E. Vargas, S. E. Maco, and Q. Xiao. 2006. Midwest Community Tree Guide: Benefits, Costs, and Strategic Planting. General Technical Report PSW-GTR-199. United States Department of Agriculture, Forest Service, Pacific Southwest Research Station. Davis, CA.

Nowak, D. J., R. E. Hoehn III, A. R. Bodine, D. E. Crane, J. F. Dwyer, V. Bonnewell, and G. Watson. 2013. Urban trees and forests of the Chicago region. Resour. Bull. NRS-84. U.S. Department of Agriculture, Forest Service, Northern Research Station, Newtown Square, PA.

Increase in Property Values

- **Many studies have shown that parks, greenways and trees increase nearby property values.**

- **Access to open space, parks, and recreation is a top factor used by small businesses in choosing a new location.**

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).

Tyrväinen and Miettinen (2000) found that distance to a forested park has a price effect if the park is within walking distance from home (in Salo, Finland, up to 1000 m). The effect was greatest within 300 m, and dwellings with a forest view were on average 4.9% more expensive than dwellings with otherwise similar characteristics (Tyrväinen and Miettinen, 2000).

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).

Geoghegan et al. (2003) compared 1993-1996 home sales data for Calvert, Carroll, and Howard counties, Maryland, 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 ac/4047 m^2) = 20 ac. Taking the midpoint of the value range (\$653), dividing by the area, and converting to 2006\$, gave a value of \$42/ac.

McPherson et al. (2006) and CNT (2010) cited several studies showing that yard and street trees increase the sales price of residential properties. More applicable to this review, McPherson et al. (2006) estimated typical park trees to increase property values by \$0.19/ft^2 of leaf surface area. Large park trees (40-year-old hackberry example) would increase annual property value gains by \$35.47/year (\$2004), or **\$1,811**/ac/year (\$2014).

Whereas the gain from a yard tree would accrue primarily to the lot containing the tree, the gain from park trees presumably would be split among nearby properties, with adjacent properties receiving the highest gain (as in Tyrväinen and Miettinen, 2000).

Woodward and Wui (2001) reported an "amenity" value only between $1/ac/yr and $14/ac/yr (mean $3/ac/yr) for wetlands ($1990; **$2-26**/ac/yr in $2014).

References in this section

Bockstael, N. E. 1996. Modeling economics and ecology: the importance of a spatial perspective. Amer. J. Agr. Econ. 78: 1168-1180.

Center for Neighborhood Technology (CNT). 2010. The value of green infrastructure: a guide to recognizing its economic, environmental and social benefits. Center for Neighborhood Technology, Chicago, IL.

Crompton, J. L. 2001. The impact of parks and open space on property values and the property tax base. National Recreation and Park Association, Ashburn, VA.

Geoghegan, Jacqueline, Lori Lynch, and Shawn Bucholtz. 2003. Capitalization of open spaces into housing values and the residential property tax revenue impacts of agricultural easement programs. Agricultural and Resource Economics Review 32(1):33–45.

McPherson, E., J. R. Simpson, P. J. Peper, S. L. Gardner, K. E. Vargas, S. E. Maco, and Q. Xiao. 2006. Midwest Community Tree Guide: Benefits, Costs, and Strategic Planting. General Technical Report PSW-GTR-199. United States Department of Agriculture, Forest Service, Pacific Southwest Research Station. Davis, CA.

McQueen, M. 2001. Land and water conservation: an assessment of its past, present and future. The Conservation Fund, Arlington, VA.

National Association of Home Builders and National Association of Realtors. 2002. Consumers survey. Online at http://www.realtor.org/publicaffairsweb.nsf/Pages/SmartGrowthSurvey02?OpenDocument.

Tyrväinen, L., and A. Miettinen. 2000. Property Prices and Urban Forest Amenities. Journal of Environmental Economics and Management 39:205-223.

Woodward, R. T. and Y.-S. Wui. 2001. The economic value of wetland services: a meta-analysis. Ecological Economics 37:257-270.

Summary

Table 11 lists six ecosystem services with enough corresponding quantitative data to estimate values for the Chicago Wilderness GIV version 2 layers.

Table 11. Ecosystem services that can be mapped for the CMAP region in GIV 2.3.

Ecosystem Service	Description
Water Flow Regulation / Flood Control	Maintain water flow stability and protect areas against flooding (e.g., from storms).
Water Purification	Maintain water quality sufficient for human consumption, recreational uses like swimming and fishing, and aquatic life.
Groundwater Recharge	Maintain natural rates of groundwater recharge and aquifer replenishment
Native Flora and Fauna	Maintain species diversity and biomass
Recreation and Ecotourism	Outdoor, nature-based experiences like hiking, birding, hunting, camping, etc.
Carbon Storage	Sequester carbon in vegetation and soils, thereby reducing atmospheric CO_2 and global climate change

Based on the information in the text, Table 12 summarizes maximum, median, and minimum values for different landscape types in the CMAP region, and the number of individual estimates available. Some landscape types (e.g., wetlands) are much better studied than others (prairie). We found no quantitative values at all in some cases, and more information is needed.

The total values in Table 12 are only for six selected ecosystem services (Table 11) and actual totals are probably higher. Also, there is considerable variation within these landscape types. For example, wetlands could be forested, scrub/shrub, or herbaceous, and each of these has different carbon sequestration values, for example. Different types of forest and soils also have different sequestration rates. Flood control value depends on watershed and topographic position, soil permeability, downstream population and infrastructure vulnerability, and other factors. The preceding text contains more details.

Similarly, there is overlap between some of the ecosystem types. Forested wetlands should receive the greater value for each service in the table between forest and wetland. Herbaceous wetlands should receive the greater value between grassland and wetland.

Flood control value for lakes and streams are combined in the table. Two estimated avoided damages by not building in stream floodplains ($388/ac/year and $900/ac/year). The other estimated the replacement cost of an existing lake with equivalent constructed stormwater ponds ($31,740/ac/year, which assumed an average depth of 5 feet. Storage

should be computed separately for each lake and pond by estimating storage volume (i.e. using average depth) rather than just surface area.

Table 12. Estimated ecosystem service values for landscape types in the CMAP region. All numbers are in 2014 dollars per acre per year.

ECOSYSTEM SERVICE		LANDSCAPE TYPE			
		Woodlands / Forest	Prairie / Grassland / Savanna	Wetlands	Lakes/ Streams
Water Flow Regulation/ Flood control	Max.	$49,000	$21,000	$44,000	$49,000
	Median	$1,415	$16,000	$4,900	$8,600
	Min.	$11	$2	$1	$388
	# estimates	12	3	15	7
Water Purification	Max.	$1,300	$57	$79,800	
	Median	$1,060	$57	$3,429	
	Min.	$820	$57	$170	
	# estimates	2	1	12	N/A
Groundwater Recharge	Max.	$269		$37,120	$986
	Median	$269		$2,479	$669
	Min.	$269		$11	$38
	# estimates	1	0	14	5
Carbon Storage	Max.	$1,960	$184	$175	
	Median	$133	$82	$136	
	Min.	$32	$5	$100	
	# estimates	12	4	3	0
Support Native Flora and Fauna	Max.	$591		$14,816	$1,749
	Median	$535		$1,749	$319
	Min.	$319		$70	$20
	# estimates	3	0	7	5
Recreation and Ecotourism	Max.	$754	$1	$11,049	$23,284
	Median	$48	$1	$1,434	$2,229
	Min.	$6	$1	$37	$2
	# studies	13	1	15	8
TOTAL	Max.	$53,874	$21,242	$186,960	$75,020
	Median	$3,460	$16,140	$14,127	$11,817
	Min.	$1,457	$65	$389	$448

(note: If there is an even number of observations, there is no single middle value, and the median is defined to be the mean of the two middle values. For two observations, therefore, the median equals the mean).

Table 13 shows a crosswalk between the GIV landscape types and the GIV layers that would be used in ecosystem service valuation modeling.

Table 13. GIV Landscapes and associated GIS layers

Crosswalk GIV layer	GIS Model Reference	GIV 2.2 Data Inputs for CMAP Region
Woodlands/Forest		
Core woodland/forest designated areas	Woodland/Forest Layers 3a & 3b	Forest Blocks derived from land cover, State Natural Heritage databases, Audubon Important Bird Areas, Oak woodlands
Core woodland/forest	Woodland/Forest Layer 4	
Woodland sites	Woodland/Forest Layer 5	
Woodland/forest corridors	Woodland/Forest Layer 7	Forest land cover to facilitate functional connectivity modeling
Prairie/Grassland/Savanna		
Core prairies	PGS Layer 1	State Natural Heritage databases, City of Chicago Nature & Wildlife Prairie Sites, Midewin National Tallgrass Prairie Potential Vegetation
Core savannas	PGS Layer 2	State Natural Heritage databases, Will County FPD (savannas), Natural and Wild Sites from City of Chicago
Grassland blocks	PGS Layer 3	IL Natural Heritage Survey's Landscapes of Ecological Importance
Wetlands		
Core wetland designated areas	Wetland Layers 4a & 4b	Ducks Unlimited enhanced National Wetland Dataset (NWI), County ADID wetlands, Kane County Fens Study, CMAP land use wetland classes, State natural heritage databases, Illinois Audubon wetland dependent important bird areas, TNC's Shorebird Site Priority & Waterfowl Site Priority
Core wetlands	Wetland Layer 5	
Wetland sites	Wetland Layer 6	

Wetland complexes	Wetland Layer 7	Presettlement Vegetation Types Chicago Wilderness Wetlands Task Force, Hydric Soils
Wetland corridors	Wetland Layer 8	Wetland land cover to facilitate functional connectivity modeling
Streams and Lakes		
Undeveloped NHD+ stream buffer	Steams/Lakes Layer 2	National Hydrography Dataset Plus (NHDPlus) Waterbodies and Flowlines, Floodplains
Core lakes and streams	Steams/Lakes Layer 3	
Undeveloped freshwater systems	Steams/Lakes Layer 5	

The next step in the project was to apply the ecosystem service values spatially on the GIV version 2 map layers. GIV version 2 contains Characterization Models that allow the user to identify the relative suitability of locations within the GIV network for particular conservation or restoration purposes based on a 0-100 point scale. These models were re-engineered to utilize dollar value input for four of the services.

Full List of Literature Cited

Ackerman, F., and E. A. Stanton. 2008. The cost of climate change: What we'll pay if global warming continues unchecked. http://www.nrdc.org/globalwarming/cost/cost.pdf.

Allen, W. L., and T. C. Weber. 2007. Baltimore County land preservation model: water quality assessment. The Conservation Fund, Arlington, VA.

American Forests. 1999. Regional ecosystem analysis: Chesapeake Bay region and the Baltimore-Washington corridor. American Forests, Washington, DC.

American Forests. 2000. Urban ecosystem analysis for the Houston Gulf Coast region: calculating the value of nature. American Forests, Washington, DC.

Anderson, G. S., and B. J. Danielson. 1997. The effects of landscape composition and physiognomy on metapopulation size: the role of corridors. Landscape ecology 12:261-271.

Bacon, T. 2002. Deforestation Decreases Rainfall. http://www.magicalliance.org/Forests/deforestation_decreases_rainfall.htm.

Baerenklau, K.A., A. González-Cabán, C. Paez, and E. Chavez. 2010. Spatial allocation of forest recreation value. Journal of Forest Economics 16:113-126.

Bagstad, K. 2006. Valuing Ecosystem Services in the Chicago Region. CW Journal 4(2):18-26.

Balmford, A., A. Bruner, P. Cooper, R. Costanza, S. Farber, R. E. Green, M. Jenkins, P. Jefferiss, V. Jessamy, J. Madden, K. Munro, N. Myers, S. Naeem, J. Paavola, M. Rayment, S. Rosendo, J. Roughgarden, K. Trumper, and K. Turner. 2002. Economic reasons for conserving wild nature. Science 297:950- 953.

Baltimore County. 2005. NPDES - Municipal Stormwater Discharge Permit 2005 Annual Report.

Barbier, Acreman, and Knowler. 1997. Economic valuation of wetlands: a guide for policy makers and planners. RAMSAR Convention Bureau Department of Environmental Economics and Environmental Management.

Barford, C. C., S. C. Wofsy, M. L. Goulden, J. W. Munger, E. H. Pyle, S. P. Urbanski, L. Hutyra, S. R. Saleska, D. Fitzjarrald, and K. Moore. 2001. Factors controlling long- and short-term sequestration of atmospheric CO_2 in a mid-latitude forest. Science 294:1688-1691.

Bateman, I. J., B. H. Day, S. Georgiou, and I. Lake. 2006. The aggregation of environmental benefit values: welfare measures, distance decay and total WTP. Ecological Economics 60:450-460.

Batker, D., M. Kocian, B. Lovell, and J. Harrison-Cox. 2010. Flood protection and ecosystem services in the Chehalis River Basin. Earth Economics, Tacoma, WA.

Baxter & Woodman, Inc., Ayres Associates, A. Visocky, Environmental Planning and Economics, Inc., and Planning and Management Consultants, Inc. 2006. County of McHenry, Illinois Groundwater Resources Management Plan. McHenry County Dept. of Planning & Development, Woodstock, IL.

Beier, P., and R. F. Noss. 1998. Do habitat corridors provide connectivity? Conservation Biology 12(6):1241-1252.

Bennett, A. F. 1998. Linkages in the landscape: the role of corridors and sensitivity in wildlife conservation. IUCN, Gland, Switzerland and Cambridge, UK.

Bockstael, N. E. 1996. Modeling economics and ecology: the importance of a spatial perspective. Amer. J. Agr. Econ. 78: 1168-1180.

Brody, S. D., W. E. Highfield, and J. E. Kang. 2011. Rising waters: the causes and consequences of flooding in the United States. Cambridge Univ. Press, Cambridge, UK. 195 pp.

Brye, K. R., J. M. Norman, L. G. Bundy, and S. T. Gower. 2000. Water-Budget Evaluation of Prairie and Maize Ecosystems. Soil Sci. Soc. Am. J. 64:715–724.

Brye, K.R., S. T. Gower, J. M. Norman, and L. G. Bundy. 2002. Carbon budgets for a prairie and agroecosystems: effects of land use and interannual variability. Ecological Applications 12(4): 962-979.

Brye, K. R and C. J. Kucharik. 2003. Carbon and nitrogen sequestration in two prairie topochronosequences on contrasting soils in southern Wisconsin. American Midland Naturalist, 149(1):90-103.

California Dept. of Water Resources. 2005. Multi-Objective Approaches to Floodplain Management on a Watershed Basis: Natural Floodplain Functions and Societal Values. Online at http://www.economics.water.ca.gov/studies.cfm. 34 pp.

California Stormwater Quality Association. 2003. Sediment basin. BMP fact sheet SE-2 in Stormwater best management practice construction handbook. California Stormwater Quality Association, Menlo Park, CA.

Casey, J. F. 2004. The value of riparian forest buffers in the Chesapeake Bay watershed: an economic framework for policy-making. National Oceanic and Atmospheric Administration, Washington DC.

Center for Neighborhood Technology (CNT). 2009. Green Values Calculator. http://greenvalues.cnt.org/national/benefits_detail.php#reduced-treatment.

Center for Neighborhood Technology (CNT). 2010. The value of green infrastructure: a guide to recognizing its economic, environmental and social benefits. Center for Neighborhood Technology, Chicago, IL.

Center for Neighborhood Technology (CNT). 2014. The prevalence and cost of urban flooding: a case study of Cook County, IL. Center for Neighborhood Technology, Chicago, IL.

CH2MHill. 2009. Detailed Watershed Plan for the Calumet-Sag Channel Watershed. Metropolitan Water Reclamation District of Greater Chicago, Chicago, IL.

Chesapeake Bay Commission. 2004. Cost-effective strategies for the Bay: 6 smart investments for nutrient and sediment reduction. Chesapeake Bay Commission, Annapolis, MD.

Chesapeake Bay Program. 2000. Riparian forest buffers. Online at http://www.chesapeakebay.net/info/forestbuff.cfm

Chicago Wilderness. 2004. Chicago Wilderness Green Infrastructure Vision: Final Report.

Conservation Fund, The; CMAP, and Chicago Wilderness. 2012. Refinement of the Chicago Wilderness Green Infrastructure Vision, June.

Conservation Fund, The. 2013. Houston-Galveston Green Infrastructure and Ecosystem Services Assessment.

Costanza, R., O. Pérez-Maqueo, M. Luisa Martinez, P. Sutton, S. Anderson, and K. Mulder. 2008. The value of coastal wetlands for hurricane protection. Ambio 37(4):241-248.

Costanza, R., R. d'Arge, R. de Groot, S. Farber, M. Grasso, B. Hannon, K. Limburg, S. Naeem, R. O'Neill, J. Paruelo, R. Raskin, P. Sutton, and M. van den Belt. 1997. The value of the world's ecosystem services and natural capital. Nature 387:252- 259.

Crompton, J. L. 2001. The impact of parks and open space on property values and the property tax base. National Recreation and Park Association, Ashburn, VA.

DeGroot, R., M. Stuip, M. Finlayson, and N. Davidson. 2006. Valuing wetlands: Guidance for valuing the benefits derived from wetland ecosystem services. Ramsar Technical Report No. 3, CBD Technical Series No. 27. Ramsar Convention Secretariat, Gland, Switzerland.

DeLuca, T. H. and C. A. Zabinski. 2011. Prairie ecosystems and the carbon problem. Frontiers in Ecology and the Environment 9(7): 407-413.

Dimick, D. 2014. If you think the water crisis can't get worse, wait until the aquifers are drained. National Geographic. Aug. 19, 2014.

Dlugolecki, L. 2012. Economic Benefits of Protecting Healthy Watersheds: A Literature Review. U.S. Environmental Protection Agency.

Dreher, D., and T. Price. 1995. Application of urban targeting and prioritization methodology to Butterfield Creek, Cook and Will Counties, Illinois. National Conference on Urban Runoff Management. EPA/625/R-95/003. pp.119-134.

Ernst, C. 2004. Land conservation and the future of America's drinking water: protecting the source. Trust for Public Land, San Francisco, CA.

Evans, D. and Associates, Inc. 2008. Cost Benefit Evaluation of Ecoroofs. City of Portland Bureau of Environmental Services, Portland, OR.

Farber, S.C., R. Costanza and M.A. Wilson. 2002. Economic and ecological concepts for valuing ecosystem services. Ecological Economics 41: 375-392.

Fermata, Inc. 2010. Hackmatack National Wildlife Refuge: Viability study.

Fissore, C., J. Espeleta, E. A. Nater, S. E. Hobbie, and P. B. Hobbie. 2010. Limited potential for terrestrial carbon sequestration to offset fossil-fuel emissions in the upper midwestern U.S. Frontiers in Ecology and the Environment 8(8):409-413.

Follett, R. F., E. G. Pruessner, S. E. Samson-Liebig, J. M. Kimble, and S. W. Waltman. 2001. Carbon sequestration under the Conservation Reserve Program in the historic grassland soils of the United States of America, in Lal, R., ed., Carbon sequestration and greenhouse effect. Soil Science Society of America, Special Publication No. 57, pp. 27–40.

Forbes, M. et al. 2010. Freshwater wetland functional assessment study: Final report. Texas Commission on Environmental Quality.

Ford, C. R., and J. R. Sheaffer. 1988. Forest Preserve District of Cook County, Illinois: An evaluation of floodwater storage. Sheaffer & Roland, Inc. Wheaton, IL.

Forest Preserves of Cook County. 2013. Floodplain & Stormwater Management. http://fpdcc.com/conservation/floodplain-stormwater-management/. Accessed Aug. 29, 2014.

Forman, R. T. T., and M. Godron. 1986. Landscape Ecology. John Wiley and Sons, New York, NY.

Fowler, M. W. 2006. Plants, medicines and man. Journal of the Science of Food and Agriculture 86(12): 1797-1804.

Geoghegan, Jacqueline, Lori Lynch, and Shawn Bucholtz. 2003. Capitalization of open spaces into housing values and the residential property tax revenue impacts of agricultural easement programs. Agricultural and Resource Economics Review 32(1):33–45.

Gibb, J. P. 1973. Wells and pumping systems for domestic water supplies. ISWS-73-CIR117. Illinois State Water Survey, Urbana, IL.

Gleason, R. A., M. K. Laubhan, and N. H. Euliss, Jr. (eds.). 2008. Ecosystem services derived from wetland conservation practices in the United States Prairie Pothole Region with an emphasis on the U.S. Department of Agriculture Conservation Reserve and Wetlands Reserve Programs: U.S. Geological Professional Paper 1745. 58 pp.

Greenleaf, S. S., and C. Kremen. 2006. Wild bees enhance honey bees' pollination of hybrid sunflower. Proc. Natl. Acad. Aci. USA 103(37):13890-13895.

Hanson, C., et al. 2011. Forests for water: exploring payments for watershed services in the US south. World Resources Institute Issue Brief, Issue 2, p.15.

Harris, L. D. 1984. The fragmented forest. University of Chicago Press, Chicago, IL. 211pp.

Hey, D. L., et al. 2004. Flood damage reduction in the Upper Mississippi River basin: an ecological alternative. The Wetlands Initiative, Chicago, IL.

Hey, D. L., J. A. Kostel, A. P. Hurter, and R. H. Kadlec. 2005. Nutrient farming and traditional removal: an economic comparison. Water Environment Research Foundation, Alexandria, VA.

Houston-Galveston Area Council (HGAC). 2010. Eco-logical: Creating a regional decision support system for the Houston-Galveston region. Houston-Galveston Area Council, Houston, TX. 63 pp.

Illinois Department of Natural Resources (IDNR). 2009. Illinois Statewide Comprehensive Outdoor Recreation Plan 2009–2014.

Illinois Department of Natural Resources (IDNR). 2014. Wetlands: ground water recharge. https://dnr.state.il.us/wetlands/ch2f.htm (Accessed 25 July, 2014)

Industrial Economics, Inc. 2011. Economic valuation of wetland ecosystem services in Delaware: Final report. Delaware Department of Natural Resources and Environmental Control, Division of Water Resources, Dover, DE.

Intergovernmental Panel on Climate Change (IPCC). 2000. Emissions Scenarios: Summary for Policymakers. ISBN: 92-9169-113-5. http://www.ipcc.ch/pdf/special-reports/spm/sres-en.pdf.

Iowa Department of Natural Resources (IDNR). 2009. Iowa Stormwater Management Manual, Ver. 3. Des Moines, IA.

Jeje, Y. 2006. Export coefficients for total phosphorus, total nitrogen and total suspended solids in the southern Alberta region: a review of literature. Alberta Environment, Edmonton, Canada.

Jenkins, M. D., and B. Groombridge. 2002. World Atlas of Biodiversity: Earth's Living Resources in the 21st Century. University of California Press.

Johnston, D. M., J. B. Braden, and T. H. Price. 2004. The Downstream Economic Benefits from storm Water Management: a Comparison of Conservation and Conventional Development. UCOWR Conference Proceedings, Paper 23. http://opensiuc.lib.siu.edu/ucowrconfs_2004/23

Jordan, T. 2002. Vegetated riparian zones, stream buffers. Critical Area Workshop. May 14, 2002.

Kellndorfer, J., Walker, W., LaPoint, E., Bishop, J., Cormier, T., Fiske, G., Hoppus, M., Kirsch, K., and Westfall, J. 2012. NACP Aboveground Biomass and Carbon Baseline Data (NBCD 2000), U.S.A., 2000. Data set. Available on-line [http://daac.ornl.gov] from ORNL DAAC, Oak Ridge, Tennessee, U.S.A.

Klapproth, J. C., and J. E. Johnson. 2001. Understanding the science behind riparian forest buffers: benefits to communities and landowners. Virginia Cooperative Extension. Publication Number 420-153.

Klapproth, J. C., and J. E. Johnson. 2009. Understanding the science behind riparian forest buffers: effects on water quality. Virginia Cooperative Extension. Publication Number 420-151.

Ko, J-Y. 2007. The economic value of ecosystem services provided by the Galveston Bay/estuary system. Texas Commission on Environmental Quality, Galveston Bay Estuary Program, Webster, TX.

Kousky, C., S. M. Olmstead, M. A. Walls, and M. Macauley. 2013. Strategically placing green infrastructure: cost-effective land conservation in the floodplain. Environ. Sci. Technol. 47 (8):3563–3570.

Kozak, J., C. Lant, S. Shaikh, and G. Wang. 2011. The geography of ecosystem service value: The case of the Des Plaines and Cache River wetlands, Illinois. Applied Geography 31:303-311.

Kucharik, C. J., N. J. Fayram, and K. N. Cahill. 2006. A paired study of prairie carbon stocks, fluxes, and phenology: comparing the world's oldest prairie restoration with an adjacent remnant. Global Change Biology 12(1):122-139.

Landers, J. 2006. Test results permit side-by-side comparisons of BMPs. Civil Engineering News, April 2006, pp. 34-35.

Langland, M., and T. Cronin (eds.) 2003. A summary report of sediment processes in Chesapeake Bay and watershed. Water-Resources Investigations Report 03-4123. U.S. Geological Survey, New Cumberland, PA.

Leschine, T. M., K. F. Wellman, and T. H. Green. 1997. The economic value of wetlands: wetlands' role in flood protection in western Washington. Ecology Publication No. 97-100. Washington State Dept. of Ecology, Bellevue, WA.

Londoño Cadavid, C. and A. W. Ando. 2013. Valuing preferences over stormwater management outcomes including improved hydrologic function. Water Resources Research 49(7):4114–4125.

MacArthur, R. H. and E. O. Wilson. 1967. The theory of island biogeography. Princeton University Press, Princeton, NJ.

Madritch, M. D., and M. D. Hunter. 2002. Phenotypic diversity influences ecosystem functioning in an oak sandhills community. Ecology 83(8):2084-2090.

Maes, J., M.L. Paracchini and G. Zulian. 2011. A European assessment of the provision of ecosystem services. JRC63505/EUR 24750 EN, European Commission Joint Research Center, Brussels, Belgium.

Matamala, R., J. D. Jastrow, R. M. Miller, and C. T. Garten. 2008. Temporal changes in C and N stocks of restored prairie: implications for C sequestration strategies. Ecological Applications 18(6):1470-1488.

Marino, B. D. V., and H. T. Odum. 1999. Biosphere 2: research past and present. Elsevier.

Maryland Department of the Environment. 2006. Prioritizing sites for wetland restoration, mitigation, and preservation in Maryland. Draft version: April 27, 2006. Maryland Department of the Environment Wetlands and Waterways Program, Baltimore, MD.

McPherson, E., J. R. Simpson, P. J. Peper, S. L. Gardner, K. E. Vargas, S. E. Maco, and Q. Xiao. 2006. Midwest Community Tree Guide: Benefits, Costs, and Strategic Planting. General Technical Report PSW-GTR-199. United States Department of Agriculture, Forest Service, Pacific Southwest Research Station. Davis, CA.

McQueen, M. 2001. Land and water conservation: an assessment of its past, present and future. The Conservation Fund, Arlington, VA.

Mehaffey, M. H., M. S. Nash, T. G. Wade, C. M. Edmonds, D. W. Ebert, K. B. Jones, and A. Rager. 2001. A landscape assessment of the Catskill/Delaware watersheds 1975-1998. EPA/600/R-01/075. Env. Prot. Agency, Las Vegas, NV.

Metropolitan Water Reclamation District of Greater Chicago (MWRD). 2012. 2013 Budget. www.mwrd.org.

Mid-America Regional Council (MARC) & Applied Ecological Services (AES). 2013. Kansas City Natural Resources Inventory II Phase 4: Ecosystem Services Method Development.

Millennium Ecosystem Assessment. 2005. Ecosystems and human well-being: synthesis. Island Press, Washington DC.

Milwaukee Metropolitan Sewerage District. Greenseams Program, Flood and Stormwater Attenuation.

Mitsch, W. J., and J. G. Gosselink. 1993. Wetlands, 2nd edition. Van Nostrand Reinhold, New York.

Mittman, T., et. al. 2014. The economic benefits of green infrastructure: a case study of Lancaster, PA. EPA 800-R-14-007. U.S. Environmental Protection Agency, Washington, DC.

Moore, T. (ed.) 2002. Protecting Maryland's Green Infrastructure. The case for aggressive public policies. Maryland Dept. of Natural Resources, Annapolis, MD.

National Association of Home Builders and National Association of Realtors. 2002. Consumers survey. Online at http://www.realtor.org/publicaffairsweb.nsf/Pages/SmartGrowthSurvey02?OpenDocument.

Natural Resources Conservation Service (NRCS). 2007. National Resources Inventory 2003 Annual NRI. Online at http://www.nrcs.usda.gov/.

Nordhaus, W. 2011. Estimates of the Social Cost of Carbon: Background and Results from the RICE-2011 Model. Cowles Foundation for Research in Economics, Yale University, New Haven, CT.

Northern Virginia Regional Commission (NVRC). 2007. Maintaining stormwater systems: a guidebook for private owners and operators in Northern Virginia. Northern Virginia Regional Commission, Fairfax, VA.

Nowak, D. J., D. E. Crane, and J. C. Stevens. 2006. Air pollution removal by urban trees and shrubs in the United States. Urban Forestry & Urban Greening 4:115-123.

Nowak, D. J., R. E. Hoehn III, A. R. Bodine, D. E. Crane, J. F. Dwyer, V. Bonnewell, and G. Watson. 2013. Urban trees and forests of the Chicago region. Resour. Bull. NRS-84. U.S. Department of Agriculture, Forest Service, Northern Research Station, Newtown Square, PA.

Odum, E.P. 1970. Optimum population and environment: A Georgia microcosm. Current History 58: 355-359.

Osmond, D.L., D.E. Line, J.A. Gale, R.W. Gannon, C.B. Knott, K.A. Bartenhagen, M.H. Turner, S.W. Coffey, J. Spooner, J. Wells, J.C. Walker, L.L. Hargrove, M.A. Foster, P.D. Robillard, and D.W. Lehning. 1995. Values of wetlands. Online at http://www.water.ncsu.edu/watershedss/info/wetlands/values.html.

Pimentel, D. 1998. Economic and environmental benefits of biological diversity in the state of Maryland. pp. 63-75 in Therres, G. D. (ed.) Conservation of biological diversity: a key to the restoration of the Chesapeake Bay ecosystem and beyond. Maryland Dept. Nat. Res., Annapolis, MD.

Ramsar Convention on Wetlands. 2000a. Reservoirs of biodiversity. Ramsar Convention Bureau, Gland, Switzerland.

Ramsar Convention on Wetlands. 2000b. Wetland values and functions. Ramsar Convention Bureau, Gland, Switzerland.

Resource Coordination Policy Committee. 1998. Our community and flooding: a report on the status of floodwater management in the Chicago metropolitan area.

Rogers, S., and J. Haines. 2005. Detecting and mitigating the environmental impact of fecal pathogens originating from confined animal feeding operations: review. EPA/600/R-06/021.

Roth, N. E., M. T. Southerland, G. Mercurio, J. C. Chaillou, P. F. Kazyak, S. S. Stranko, A. P. Prochaska, D. G. Heimbuch, and J. C. Seibel. 1999. State of the Streams: 1995-1997 Maryland Biological Stream Survey Results. Maryland Dept. of Natural Resources, Annapolis, MD.

Sasman, R. T., C. R. Benson, J. S. Mende, N. F. Gangler, and V. M. Colvin. 1977. Water-level decline and pumpage in deep wells in the Chicago Region, 1971-1975. SWS/CIR-125/77. Illinois State Water Survey, Urbana, IL.

Sather, J. H. and R.D. Smith. 1984. An overview of major wetland functions and values. U.S. Fish and Wildlife Service FWS/OBS-84/18. Washington, DC.

Sipple, B. 2007. Wetlands functions and values. http://www.epa.gov/watertrain/wetlands/.

Smith, J. E., L. S. Heath, K. E. Skog, and R. A. Birdsey. 2005. Methods for Calculating Forest Ecosystem and Harvested Carbon with Standard Estimates for Forest Types of the United States. U.S. Dept. of Agriculture Forest Service, Northeastern Research Station, General Technical Report NE-343. http://www.treesearch.fs.fed.us/pubs/22954.

Smith, P. D., M. Merritt, D. Nowak, and D. Hitchcock. 2005. Houston's Regional Forests. Texas Forest Service.

Solomon, S., D. Qin, and M. Manning (eds). 2007. Climate Change 2007: The Physical Science Basis. Intergovernmental Panel on Climate Change. Geneva, Switzerland.

Söndgerath, D., and B. Schröder. 2002. Population dynamics and habitat connectivity affecting the spatial spread of populations - a simulation study. Landscape ecology 17:57-70.

Soulé, M. E., and J. Terbough. 1999. Continental conservation: scientific foundations of regional reserve networks. Island Press, Washington, DC. 227 pp.

Southeastern Wisconsin Regional Planning Commission (SEWRPC). 1991. Costs of urban nonpoint source water pollution control measures. Southeastern Wisconsin Regional Planning Commission, Waukesha, WI.

Stern, N. 2006. Stern Review on The Economics of Climate Change. HM Treasury, London, UK.

Strebel, D. E. 2002. Carbon sequestration potential in Maryland (draft version). Versar, Inc., prepared for Maryland Dept. Nat. Res., Annapolis, MD.

Thibodeau, F.R. and B.D. Ostro. 1981. An Economic Analysis of Wetland Preservation. Journal of Environmental Management, 12:19-30.

Tilley, D., E. Campbell, T. Weber, P. May, and C. Streb. 2011. Ecosystem based approach to developing, simulating and testing a Maryland ecological investment corporation that pays forest stewards to provide ecosystem services: Final report. Department of Environmental Science & Technology, University of Maryland, College Park, MD.

Trust for Public Land. 2013. Land Conservation in Illinois. http://www.conservationalmanac.org/secure/almanac/midwest/il/index.html. Accessed July 17, 2014.

Tyrväinen, L., and A. Miettinen. 2000. Property Prices and Urban Forest Amenities. Journal of Environmental Economics and Management 39:205-223.

U.S. Army Corps of Engineers (USACE). 2003. Applicability of constructed wetlands for Army installations. Public Works Technical Bulletin 200-1-21. U.S. Army Corps of Engineers, Washington, DC.

U.S. Central Intelligence Agency (CIA). 2006. The World Factbook. Online at http://www.cia.gov/cia/publications/factbook/index.html.

U.S. Environmental Protection Agency (EPA). 2001. Functions and values of wetlands. EPA Publication 843-F-01-002c.

U.S. Environmental Protection Agency (EPA). 2006. Wetlands: protecting life and property from flooding. EPA843-F-06-001.

U.S. Environmental Protection Agency (EPA). 2012. The economic benefits of protecting healthy watersheds. EPA Publication 841-N-12-004.

U.S. Fish and Wildlife Service (USFWS). 2003. 2001 National Survey of Fishing, Hunting, and Wildlife-Associated Recreation: Maryland. FHW/01-MD-Rev.

U.S. Fish and Wildlife Service and U.S. Census Bureau (USFWS and USCB). 2014. 2011 National Survey of Fishing, Hunting, and Wildlife-Associated Recreation. FHW/11-IL (RV).

U.S. Geological Survey (USGS). 1995. Ground water atlas of the United States: Segment 10. Hydrologic Investigations Atlas 730-K. USGS, Reston, VA.

Wang, M. Q., D.J. Santini, and S.A. Warinner. 1994. Methods of valuing air pollution and estimated monetary values of air pollutants in various U.S. regions. Center for Transportation Research, Energy Systems Division, Argonne National Laboratory, Argonne, IL.

Weber, T. 2003. Maryland's green infrastructure assessment: a comprehensive strategy for land conservation and restoration. Maryland Dept. Nat. Res., Annapolis, MD. 246pp. plus appendices.

Weber, T. 2007a. Development and application of a statewide conservation network in Delaware, U.S.A. Journal of Conservation Planning 3:17-46.

Weber, T. 2007b. Ecosystem services in Cecil County's Green Infrastructure: Technical Report for the Cecil County Green Infrastructure Plan. The Conservation Fund, Annapolis, MD.

Weber, T., J. Wolf, P. Blank, R. Aviram, and J. Lister. 2004. Restoration targeting in Maryland's Green Infrastructure. Maryland Dept. Nat. Res., Annapolis, MD.

Woodward, R. T. and Y.-S. Wui. 2001. The economic value of wetland services: a meta-analysis. Ecological Economics 37:257-270.

World Resources Institute. 1998. 1998-99 world resources. World Resources Institute, Washington, DC.

Wossink, A., and B. Hunt. 2003. An evaluation of cost and benefits of structural stormwater best management practices in North Carolina. North Carolina Coop. Ext. Service.