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Ecosystem Based Approach to Developing, Simulating and Testing a Maryland Ecological Investment Corporation that Pays Forest Stewards to Provide Ecosystem Services

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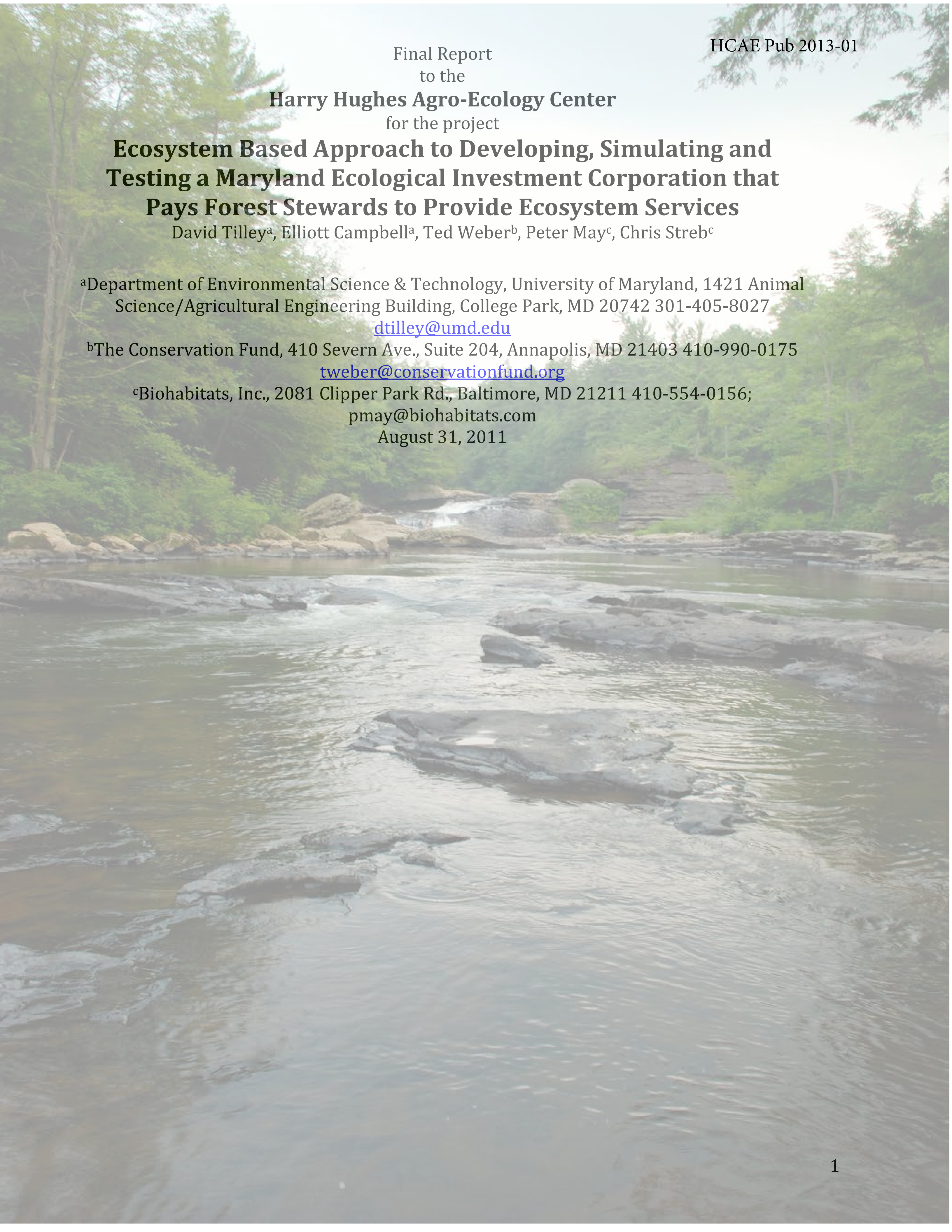


Executive Summary

Forests provide a multitude of vital benefits to the ecosystems, economy and people of Maryland. Forests regulate atmospheric gas exchange, ameliorate micro-climates, stabilize coastlines and riverbanks, provide wildlife habitat, generate and maintain soils, improve water quality, dampen stormwater flows, abate air pollution, and provide food, fiber, and fuel. One of the most dominant economic goods produced by forest is timber, which supplies mulch, fuelwood, lumber, veneer, plywood, paper and other consumer products. People also enjoy hunting, fishing, hiking, camping, birding, horseback riding, and automotive touring in Maryland's forests. While markets exist to set the price for an economic good like timber, many of these ecosystem services are poorly valued, if at all.

Various financial mechanisms and land management programs have been developed by land trusts, and state and federal agencies during the last two decades to increase the preservation and conservation of forests. However, **it is still necessary to financially link the production and consumption of ecosystem services**. Stewards of forested land should be rewarded for producing ecosystem services. In return consumers of ecosystem services should pay to offset their consumption.

The research presented in this report proposes that an **Ecological Investment Corporation (EIC) could be an additional tool for society to achieve better forest land conservation and restoration by directing payments from consumers to land stewards to encourage the production of ecosystem services.** Consumers are defined as people who enjoy the services of ecosystems. The environmental accounting technique known as emergy evaluation was used to determine (1) the value that forest ecosystem services provide to the state's economy and environment (i.e., **<u>public value</u>**) and (2) a fair price that should be paid to land stewards for producing specific ecosystem services (i.e., **<u>fair payment price</u>**). Public value is based on the overall contribution that a resource or energy (e.g., a natural resource, ecosystem service) makes to the state's economy, society and environment. When a resource like freshwater, flows through the economy, it is a form of emergy that is often matched by other forms of emergy, which are often coupled to flows of money. Thus, the use of a resource or consumption of an energy serves as the basis of the economy, society and environment and amplifies the circulation of money, which is often measured macroeconomically as the gross state product. A fair payment price, on the other hand, is the dollar value that should be paid in exchange for the emergy value of an ecosystem service, which should be connected to society's willingness to pay for an ecosystem service.

Emergy evaluation integrates ecosystems, economies and societies by quantifying the flow of solar emergy through their interconnected systems. Solar emergy is defined as the total direct and indirect solar energy used to make a product or provide a service. Emergy evaluation is similar to embodied energy analysis in many ways, but takes a more encompassing perspective to identify the most important energies driving a system. Embodied energy analysis focuses solely on energies derived from fossil fuels and nuclear materials, whereas emergy evaluation includes not only these energies, but also includes the energies provided from the sun directly (e.g., light and shortwave radiation) and indirectly (e.g., wind, waves, and freshwater). Emergy evaluation shares some of the philosophical underpinnings and non-monetary accounting popular in life cycle assessment and ecological footprint analysis.

Emergy evaluation can be used to estimate the public value of ecosystem services based on the flow of solar emergy and the mean ratio of solar emergy consumption to economic production. On average each $1 of economic product in Maryland consumed 2.82 trillion joules of solar emergy in 2000. Thus, the public value of an ecosystem service is estimated by dividing its solar emergy by the state's mean emergy-to-dollar ratio of 2.82 trillion solar-joules per $1 (i.e., 2.82E12 sej/$). The method for estimating a fair payment price to land stewards who produce specific ecosystem services is less clear in the standard methods of emergy evaluation, and therefore it is a subject explored in the research presented here.

Two basic approaches were explored for estimating the fair payment price for ecosystem services. The first used the dollar prices and solar emergy values of commodities, such as gasoline, corn and wool, since they were actively traded on market exchanges, such as the Chicago Mercantile Exchange, to estimate the price of solar emergy of natural resources. This assumed that the solar emergy of ecosystem services and natural commodities have comparable emergy prices and therefore, we could substitute the average emergy per dollar of the commodities for the emergy per dollar of the ecosystem services. The second approach was more complex. It derived a price for the solar emergy of ecosystem services based on existing situations where money was being exchanged for comparable ecosystem services. For example, New York City invested billions of dollars in watershed protection to ensure that it had access to clean drinking water. Several instances similar to New York's watershed protection payments, where ecosystem services were being exchanged for money, were evaluated to determine the amount of solar emergy exchanged per dollar for the various categories of ecosystem services (carbon, water, soil, air, and biodiversity). The amount of money exchanged in relation to the solar emergy value of the ecosystem service was termed an "eco-price". Various estimates of eco-prices were determined and subsequently used to convert the solar emergy value of an ecosystem service occurring in Maryland to dollars.

In 2000 the State of Maryland consumed a total of 508,000 exajoules ($1x10^{18}$) of solar emergy, which produced a gross economic product of $180 billion. Only **3% of the $180 billion (or $4.8 billion) was contributed by renewable environmental energies, such as sun, wind and water.** Another 9% ($15.5 billion) was derived from non-renewable natural resources from within Maryland. The vast majority (88%, or $160 billion) came from imported fuels, electricity and manufactured goods; all with high levels of solar emergy. The 1 million hectares (2.6 million acres) of Maryland's forest consumed $304 million of the renewable energy to produce $309 million of wood. The state harvested the equivalent of two-thirds of that new wood growth as timber, which ultimately added $210 million to the state economy. In addition to producing timber **the forests produced ecosystem services worth $4.4 billion in public value.**

Based on the emergy evaluation of Maryland, **forest land-stewards should receive compensation of $230 to $660 million** in excess of their receipts for timber harvest to continue producing ecosystem services with a public value of $4.4 billion per year. The lower estimate of $230 million assumed that the value of ecosystem services was at least comparable to the market value of commodities. The higher estimate of $660 million was based on the conversion of the solar emergy value of each individual ecosystem service to dollars using the mean price paid for specific services.

On a per capita basis, Maryland residents enjoy $830 worth of ecosystem services from the forest as public value without paying anything to the land steward. If all residents were to contribute to the EIC to generate between $230 and $660 million for land stewards, then each would need pay between $43 and $124 per year (or $3.60 to $10.00 per month).

On an area basis, the typical acre of forest in Maryland generates $1690 of ecosystem services as public value. Based on our compensation estimates for ecosystem services, a land steward should receive a fair payment price of $88 to $254 per year for a typical acre of forest.

The five categories of ecosystem services assessed included **carbon sequestration, hydrologic modification, enhanced soil functioning, air pollution mitigation, and pollination** (Figure ES). By reducing stormwater flows and improving groundwater recharge, forests produced $1200 million of public value for the state economy and environment. Forest stewards should be paid between $62 and $380 million per year for providing these hydrologic services. By preventing soil erosion, taking up nitrogen and phosphorus and building soil carbon, forests produced $2430 million of public value for the state economy and environment. Forest stewards should be paid between $105 and $125 million per year for providing soil-based services. By removing toxic air pollutants, forests produced $481 million of public value for the state economy and environment. Forest stewards should be paid between $25 and $167 million per year for ensuring that air pollution mitigation occurs. By sequestering carbon, forests produced $302 million of public value for the state economy and environment. Forest stewards should be paid between $4 and $16 million per year for ensuring that forests sequester carbon. By assisting with the pollination of agricultural crops, forest added $1.4 million of public value for the state economy and environment. Forest stewards should be paid $70,000 and $300,000 per year for ensuring that pollination occurs.

Taking the ratio of public value to the fair payment price of ecosystem services was defined as the ecological-economic return on private investment (EERPI). Using the highest fair payment market value of $660 million and the public value of $4.4 billion the mean EERPI was 6.7:1. Or using the mid-range estimate of $230 million from the commodity eco-pricing method, the mean EERPI was 19:1. In other words **each $0.05 payment to a forest land steward returns $1 of public value to the economy, society and ecology of the State**.

Sensitivity analysis revealed that the fair payment to land stewards is affected by the forest's net primary productivity and age. On one hand, a young forest that is less than

50 years old would produce ecosystem services annually at about $70 per ha. On the other hand, an old-growth forest that is more than 250 years old, on the other hand, would produce ecosystem services annually at over $350 per ha. Thus, payments should be higher for land stewards that maintain older or more productive forests.

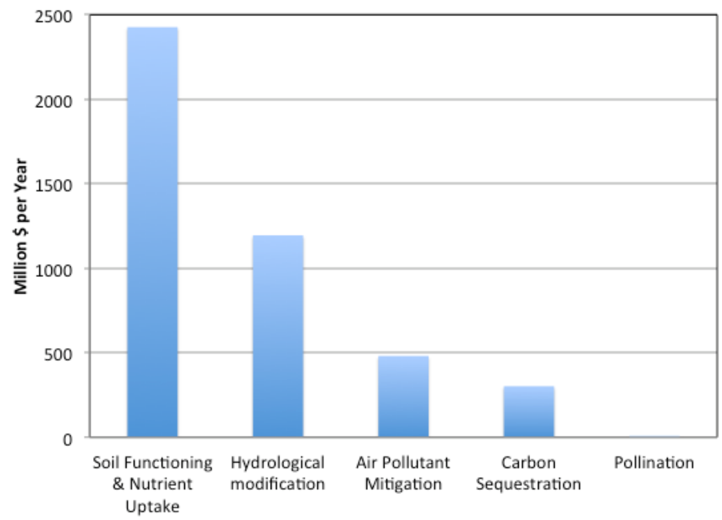
Assuming annual payments of $172/ha/y made over 50 years, the present value would range from $5400/ha to $2100/ha, depending on whether a 2% or 8% discount rate was assumed. With today's historically low interest rates, the 2% discount rate is likely more justified. If the time horizon were shortened to 10 or 30 years, then the present value would be $1500 or $3850/ha, respectively.

Simulation of the *EcoInvestCorp* model, which included revenues from consumers, payments to land stewards, administrative and operational costs, and stockholder dividends, revealed that **if 4% of Maryland's population paid $6.00 per month to the EIC to offset their consumption of ecosystem services, then there would be enough revenue to pay land stewards $241/ha/y (~$100/ac/y)** to maintain 5% of Maryland's forest (50,000 ha, 125,000 ac). This level of participation by consumers and land stewards would generate $19.5 million of revenue for the EIC. From this revenue, land steward income would be $12 million, land steward costs would be $6.5 million, stockholder dividends would be $93,000, administrative costs of the EIC would be $371,000, and EIC net income would be $464,000. The public value generated would be $230 million. Thus, each dollar paid by consumers into the EIC would generate $11.79 of ecosystem services for the economy, the society and environment of Maryland as public value. Assuming stockholders had invested $1 million, then their return on capital would be 9.3%.

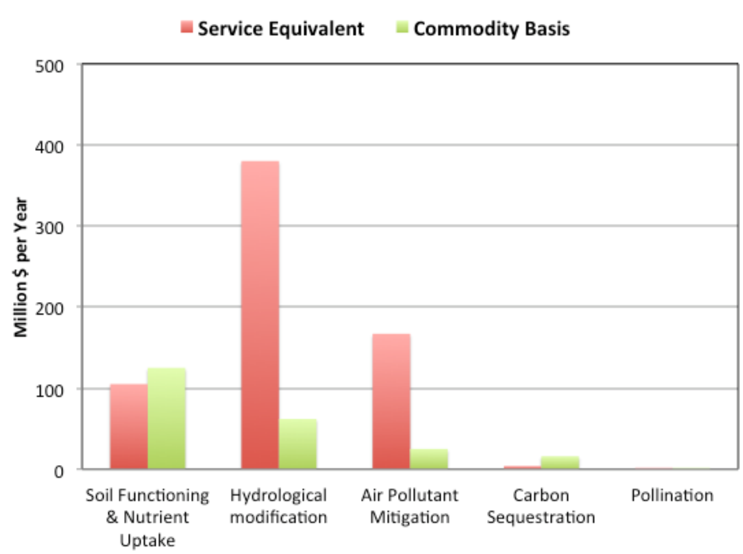
The research completed for this project is a major step toward establishing an Ecological Investment Corporation that can pay forest land stewards to produce ecosystem services and collect payments from consumers who want to encourage the production of ecosystem services. The next steps needed to develop the EIC include pilot-testing it in a region of the state that encompasses a large amount of forested land and developed urban/suburban area. The region should include one major urban/suburban area (Montgomery, Prince Georges or Baltimore Counties) and its surrounding rural counties. Montgomery, Frederick, Washington and Allegany Counties might be a good pilot-testing region since they are contiguous, share political boundaries, watersheds and physiographic provinces. With populations of 925,000, 222,000, 143,000, and 72,000, respectively, as of 2006 (http://www.bea.gov/), the region has over 1.3 million citizens. The rural counties also account for a large portion of the forestland in MD.

The pilot test must include an assessment of how to encourage consumers of ecosystem services to offset their consumption with payments to the EIC and assessment of what will encourage land stewards to participate in the EIC. The former can proceed by working with municipalities and county governments, chambers of commerce and environmental groups to gauge the interest and concerns people would have about offsetting their ecosystem service consumption with payments to the EIC, and how they could be enticed to do so. The latter can proceed by working with University of Maryland Cooperative Extension and local forestry groups to understand what would encourage and discourage participation of land stewards.

The EIC is an innovative and entrepreneurial model for promoting wise environmental stewardship. Its success depends on convincing consumers of ecosystem services that it is in their best interest and the interest of society to pay for their consumption and on convincing producers that participation will enhance their financial situation and benefit society as a whole.



(a)



(b)

Figure. Public value added to the MD state economy and environment (a) and estimated fair payment to land stewards (b) for five ecosystem services generated by Maryland forests in 2000.

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1. Ecosystem Services: Equitable Exchange for Nature's Value

Forests of the world provide a multitude of life-support benefits to ecosystems, economies and societies throughout the world. The ecosystem services provided by forests include: providing wildlife habitat, generating and maintaining soils, improving water quality, dampening stormwater flows, abating air pollution, and reducing the urban heat island effect, regulating climate, stabilizing coastlines and riverbanks, and providing food, fiber, and fuel for humans. Social amenities include: hunting, fishing, hiking & camping, birding, horseback riding, and automotive touring. As human civilization evolved from hunter-gathers to agriculturists to industrialists and now to a knowledge-intensive, global society, the multitude of connections between natural systems and the daily lives of people has become less obvious. This does not mean that nature's services have become less essential, rather the opposite. As human population has expanded across the globe, extracted ancient geologic wealth from the earth, and captured more and more of the world's primary production, nature has played a larger role in protecting humanity from the accumulation of wastes and toxins in the environment that is mostly hidden from the public conscience. Loss of forests and the discharge of pollutants to land, air and water lowers the life-support capabilities that the environment provides for free to humanity.

The most dominant economic good from forest is by far timber, which supplies lumber, veneer, plywood, pulp & paper, and fuelwood. While markets exist to set the price for an economic good like timber, many of the ecosystem services provided by forests are poorly valued if at all. As Antle (2006) put it, "left to their own devices, markets will tend to over-produce market goods and under-produce ecosystem services." If private and public forest lands are to be managed to sustain the delivery of both poorly valued ecosystem services and market-priced economic goods, then novel financial mechanisms need to be developed that encourage forest stewards to produce ecosystem services, social amenities and economic goods.

There are various existing policy instruments offered through private land trusts, state and local governments, and federal agricultural programs that encourage the preservation of open space and working lands, and the conservation of natural capital (e.g., soils, wetlands). While many of these instruments have been hugely successful, they are each limited in different ways.

Private land trusts, such as The Nature Conservancy, which have increased in size and number during the last three decades, rely most heavily on donations from members to purchase lands and easements (e.g., development rights). In 2006 The Nature Conservancy, which operates in the U.S. and globally, received approximately $500 million in contributions (TNC 2006). In 2006 they purchased 120,000 acres throughout the Southeast U.S., paying slightly less than $1400 per acre (TNC 2006). At that purchase price their contributions could cover the cost of over 350,000 acres annually. While nationally land trusts have been able to raise billions of dollars to preserve millions of acres of land, they remain indebted to the continued generosity of donors.

State and local land preservation programs in Maryland and its counties, which purchase development rights from agricultural land owners, are most often financed from real estate and agricultural transfer taxes (i.e., taxes collected when farmland is converted to non-farm use) at the county level (Geoghegan et al. 2006). However, many of these programs have insufficient financial resources to preserve all the parcels that the public wants preserved, so they are searching for innovative funding mechanisms (Geoghegan et al. 2006). In addition, county preservation programs that rely exclusively or mostly on the agricultural transfer tax are in a "catch-22" because the purchase of development rights on existing farmland requires the conversion of farmland to residential, commercial or industrial use somewhere else in the county in order to provide funding. Lynch and Lovell (2002) pointed out that the funds needed to preserve one acre of land in Howard County required the conversion of 22 acres of farmland to non-farm land use. If this were the sole funding mechanism, then obviously more land would be developed than preserved. Programs that rely on real estate transfer taxes are better situated to fund land preservation, but remain beholden to the activity of the real estate market. The American Farmland Trust (2006a) reported that over $2.3 billion had been spent by local and state governments and private land trusts to purchase agricultural conservation easements on 1.1 million acres of farmland.

At the Federal level, payments to farmers for conservation and environmental programs have been offered through a variety of programs, including: the Conservation Reserve Program (CRP), which pays producers to establish field "buffers" that intercept sediment and nutrients and plant cover crops on environmentally sensitive land; the Wetlands Reserve Program (WRP), which provides cost-sharing for wetland restoration on agricultural land; the Wildlife Habitat Incentives Program (WHIP), which cost-shares with landowners to improve wildlife habitat; the Conservation Security Program (CSP), which rewards land stewards for implementing land-based practices on working lands that conserve soil, water, or wildlife; the Farm and Ranch Lands Protection Program, which funds state and local governments and private organizations to purchase development rights to keep productive farmland in agricultural use; and "Swampbuster," which tied the receipt of farm payments to wetlands management. The 2002 Farm Bill increased conservation funding by over 50% to $4.7 billion in fiscal year 2005 (Cattaneo et al., 2005), but remained under funded according the American Farmland Trust (2006b).

Antle (2006) argued that while these federal programs have achieved their intended goals, they are economically inefficient because they fail to maximize the net benefits to farmers *and* society, by not taking into account the value of both marketed commodities and non-market goods and services (i.e., ecosystem services). This inefficiency comes mainly from the fact that federal payments to farmers are based on adopting practices, rather than providing ecosystem services. In addition, these policies are often implemented with politically-minded allocation that does not reflect regional balance.

While it is encouraging that land preservation and conservation practices are increasing in scope due to private land trusts, state and local government land purchase programs and federal agricultural programs, the need remains to financially link the production and consumption of ecosystem services. Stewards need to be rewarded for producing ecosystem services and consumers need to pay for consuming the service.

There is a growing need to develop and test integrative metrics that can value the importance of ecosystem services to human welfare. Economic metrics have been used to value ecological services, but these metrics are determined from the perspective of the receiver of the services (the economy) rather than from the perspective of the donor of the services (the ecosystem). Receiver value is derived from what the receiver of a good or service is willing to pay, while donor value is determined by "what was required to make an item or generate a service" (Odum, 1996). Consumers of ecosystem services need to be more connected to the natural lands on which they depend. Mechanisms that allow consumers to reinforce the capability of ecosystems to provide their unique services need to be developed to strengthen the sustainability of society.

A system of accounting for the energy invested in all studied aspects of a system, called environmental accounting or emergy evaluation, has been developed in order to provide valuation external to the economy and adherent to the fundamental laws of thermodynamics (Odum, 1996). This system of valuation allows the connections between nature's production of ecosystem services (ES) and people's consumption of them to be quantified in the same physical unit and translated into financial terms. The need for an ecological system of valuation was perhaps best stated by Howard and Eugene Odum (Odum and Odum 2000), "When human valuations do not measure the real contributions of natural ecosystems, as is currently the case, ecosystems are not protected, and the larger systems produce less when the natural ecosystems are lost to development."

1.1. Ecosystem Services Defined

Ecosystem services (ES) have been defined differently by a diverse group of organizations and researchers (Farber et al, 2002, Boyd, 2007, EPA, 2010, USFS 2010). A general definition is that they are benefits people receive from ecosystems. The Millennium Ecosystem Assessment categorizes ecosystem services into four classes 1) providing goods to humanity, 2) regulating systems that humanity depends on, 3) supporting systems that provide goods, and 4) enhancing people's intellectual or recreational experiences. This study restricted its analysis to those services that provide a tangible benefit to society (i.e. we did not include aesthetics) and that are not already paid for in some way (i.e. recreation).

1.2. Maryland and It's Forests

Only twenty-nine percent (29%) of Maryland's land area was covered by forest in 2011, which amounted 943,000 ha (Lister and Perdue 2012). Seventy-two percent (72%) of forest land in Maryland is privately owned, while nearly 25% is owned by the State and 3% by the federal government (Lister and Perdue 2012). Maryland's population growth of a half a percent (0.5%) per year lead to a loss of 32,000 ha of forest land to development between 1986 and 1999 (Widmann, 1999). Since 1999 forest land area in Maryland stabilized with reforestation and afforestation balancing land lost to development. Mechanisms to foster restoration of degraded land and mitigation of pollutants in order to restore the environments capacity to produce ecosystem services are sorely lacking. While programs do exist (the Conservation Reserve Enhancement Program (CREP), Maryland Forest Conservation Act) they are not sufficient to ensure provision of ecosystem services. Many forest landowners will sell their land when it is economical, i.e., at the point where they would receive greater economic benefit from selling it for development than keeping it in silviculture or for its preservation value. However, when the land is developed, society as a whole loses the value of its ecological services, which are not considered in the economic decision making process.

The Ecosystem Investment Corporation model (EIC) was developed in order to help reconcile the value invested in ecosystems versus the value received by society from these ecosystems. A better understanding of the situation will provide an additional incentive for forest landowners to keep their land in forest rather than in an alternative land-use that would provide society with fewer ecosystem services and create an additional load on other ecosystems, such as Chesapeake Bay. That is, the EIC strives to simultaneously maximize benefit for the economy, environment and society.

The EIC determines the value of ecosystem services and establishes an organizational structure that will allow consumption to be directly linked to production. This structure will facilitate reinforcement of ecosystem services by allowing those who consume services (the public) to pay the producers of the services (forest landowners) based on the total amount of ecosystem services they either consume or produce.

There are multiple scales at which Maryland's forest operate and interact with the economy, society and other environments. Therefore, the forest will be analyzed at multiple scales to include the forest stand, the regional forest and statewide forest lands. Analyzing the forest at multiple scales allows each individual scale to be more fully understood and the importance of the connections among scales to be recognized. Insight into the context of the system studied is gained when one understands systems larger and smaller than the system of primary interest (Odum, 1996). To fully understand what is going on at the state level the larger system, the country, must be understood as well to give context to the flows entering and exiting the state.

Existing emergy evaluation studies, which analyzed the United States (Tilley 2006) and the National Forest system of the United States (Campbell, 2009), will be referenced to place Maryland into the context of the larger system.

2. Goals and Objectives

The two general goals of this research are 1) to develop the energetic basis for the valuation of key ecosystem services provided by the forests of Maryland and 2) to develop a model that will allow the consumers of ecosystem services to compensate stewards of forest lands that produce ecosystem services. The first goal has the following objectives:

1. Quantify a baseline for the emergy throughput and storage of Maryland's forests to understand their capacity for providing ecosystem services and securing natural capital to support the human economy.
2. Determine the emergy-based value of key ecosystem services to include:
    a. Carbon sequestration
    b. Stormwater runoff avoidance
    c. Groundwater recharge promotion
    d. Air pollutant removal
    e. Soil generation and maintenance
    f. Pollination
    g. Biodiversity protection

The second goal has the following objectives:

3. Develop the EIC as a simulation model that assesses how much consumers should pay into the EIC to offset their consumption of ecosystem services and the value of a fair payment to land stewards for producing these ecosystem services.
4. Develop a tool that can be used to assess the value of the ecosystem services being generated by any particular forest stand within Maryland.

3. Plan of Study

To complete the aims of this project, the following plan of study was followed:

a. An emergy evaluation of Maryland and its forests was conducted to determine the resource basis of the state's economy and the contribution that forests and the environment make to the welfare of its citizens and visitors.
b. The emergy required to produce each key ecosystem service (i.e., carbon sequestration, stormwater runoff, groundwater recharge, excess nutrient removal, soil building and maintenance, air pollutant removal, and biodiversity protection), was determined by developing energy systems mini-models for each service that identify how energies are consumed in the production of each. Furthermore, the value of some ecosystem services was found by comparing the flows of emergy in the forest to an urban system. The emergy flows or differences in emergy flows were then converted to public value and fair payment prices based on various ratios of solar emergy to dollar flow. These ratios, termed eco-prices, were based on three approaches. The first method for estimating eco-prices, termed the specific ecosystem services approach, assessed the amount of money paid in existing markets directly or indirectly for the services of nature, such as stormwater fees, carbon markets, watershed protection fees, air pollutant avoidance costs, and others, relative to the amount of emergy associated with the

service. The second method, termed the mean ecosystem service approach, estimated the eco-price as the weighted mean of the first approach (i.e., the specific ecosystem service approach), which meant that it did not further differentiate between the value of ecosystem services other than their emergy values. The final method, termed the commodity ecosystem service approach, estimated eco-prices based on the market prices and solar emergy of freely traded natural resource commodities like copper, corn, and timber. Like the mean ecosystem service eco-pricing approach, the commodity approach did not further differentiate between the values of the different ecosystem services because we used the mean of a "basket" of natural resources. However, the commodity approach had the distinction of having temporally dynamic eco-prices that were tied to financial markets.

c. Energy Systems Language modeling was used to develop *EcoInvestCorp* as a simulation model of the EIC that incorporated ecosystem service values for the emergy syntheses.
d. The tool for assessing the value that particular forest stands can produce was developed as a standard spreadsheet that assessors could employ to do site valuations.

4. Literature Review

To complete this research we relied on a thorough understanding of forest ecology, ecosystem services, environmental accounting and ecological economics. A thorough exploration of the scientific literature was conducted to achieve this understanding. The following publications were reviewed because of their particular relevance to valuation of ecosystem services and as progenitors of this work.

4.1. Emergy-based work

The publication entitled "Tropical Forest Systems and the Human Economy" by Howard T. Odum (1995) used mini-models and environmental accounting to evaluate tropical forests at different scales. These scales included the forest stand, a landscape with many stands, tropical forests and international trade and tropical forests in the global carbon budget.

Odum stated that "Economic systems are sustainable only by reinforcing their environmental basis". This statement is especially relevant to the EIC. The EIC provides a mechanism for economic systems to reinforce the ecological basis of their economies in a novel way. Odum (1995) also demonstrated the ability of emergy analysis to provide additional insight into the performance of a system that bridges the gap between ecological and economic analysis. Odum (1995) evaluated how the human economy values tropical forests in comparison to the value given by the environment and he suggested an optimum use level that balanced economic gain and the environmental value of the forest. He concluded that realization of this tradeoff was not fully possible if dollar values alone were considered.

The PhD dissertation by Jose-Luis Izursa (2008), entitled "An Ecological Perspective of the Energy Basis of Sustainable Bolivian Natural Resources: Forests and Natural Gas," evaluated the country of Bolivia at multiple scales, using environmental accounting to focus on tropical forests and their management. Izursa (2008) used environmental accounting to demonstrate the benefit that timber certification (e.g., Forest Stewardship Council certification) has on lessening the impact forestry practices have on the environment. He also modeled a variety of forest exploitation options for Bolivia, showing that long term economic sustainability was best achieved through increasing forestry in the country, while using low impact methods. His work serves as a model for how environmental accounting can be applied to evaluate forestry management scenarios and determine a best course of action at multiple scales.

In 1995 Steven Doherty completed his dissertation, entitled "Emergy Evaluations of and Limits to Forest Production", evaluating forests from several locations and under varying land-uses. The locations included Florida, Sweden, Puerto Rico, Thailand and Papua New Guinea. Doherty used environmental accounting to evaluate multiple uses and services such as pulp and paper production, biomass for electricity production, fuel wood production, and services including carbon sequestration, water supply, reforestation and tourism. One of the driving goals of the research was to assess the ability of biomass to compete with, and eventually replace, fossil fuels. Doherty concluded that biomass was not a viable option for replacing fossil fuels at the current global population and global energy demands but will be a part of the future renewable energy resource base. It was also found that the emergy value of carbon stored in Luquillo National Forest was eight times that of the market value and that it would take two years of forest production and water supply to equal the value of the total economic investment in the forest.

4.2. Non-emergy based valuation

The paper "Economic and Ecological Concepts for Valuing Ecosystem Services" by Farber, Costanza, and Wilson, published in 2002 outlines how ecosystem services are defined and categorized by both economics and ecology. They define value as "… the contribution of an action or object to user-specified goals, objectives or conditions (originally from Costanza, 2000). Values exist within value systems, defined as "…intrapsychic constellations of norms and precepts that guide human judgment and action." This is the fundamental difference between emergy valuation and ecological economic valuation. The value system that emergy operates under is that of thermodynamic laws, rather than a system created by human preference. The authors make a distinction between intrinsic and instrumental value, where intrinsic value is something's fundamental right to exist and instrumental value is the benefit that people receive from something.

The authors (Farber et al. 2002) detail the development of economic theory from Aristotle to modern neo-classical economics where utility is the ultimate measure of value, and utility is measured in dollars. When a market exists and a price and quantity are known the marginal value of a good can be determined but in the absence of direct market prices for goods or services value must be estimated and a "psuedomarket" constructed. The authors discuss how value in an ecological system is very different than an economic system. Value in an ecological system could be defined as the contribution something has to an ecological function.

A thermodynamic system of value, as pioneered by H.T. Odum, is acknowledged. Farber et al. (2002) question how the quality of fuels affects the ability to assess a system purely with available energy (or exergy). Emergy evaluation corrects for the different qualities of energy forms with solar transformities.

Farber et al. (2002) also discussed how values can be dependent on the situation. For example, a critical threshold can greatly change the value an ecosystem provides. They provide an example of barrier islands providing shelter from a storm. Once a certain number of barrier islands are gone the cost of a large storm hitting the shore soars. The authors address the fact that economic and ecological values are potentially in conflict but state that as knowledge of the importance and economic linkages of ecosystems increases this gap should decrease. The ultimate conclusion of Farber et al. (2002) is that there is not one correct method or conceptualization of valuation and that the field should continue its evolution. Environmental accounting has the ability to bridge the gap between economic and ecological value that Farber et al. (2002) elucidated very well.

Perhaps one of the most prominent papers on non-emergy based valuation of ecosystem services was published by Robert Costanza et al. (1997) in the journal Nature, entitled "The Value of the World's Ecosystem Services and Natural Capital." As the title suggests, this work estimated the total value of global ecosystem services (on an annual basis) and storages of natural capital. This was done by surveying the ecological economic literature and assessing the willingness-to-pay for ecosystem services of humanity. The authors assessed 17 different ecosystem services including gas regulation, climate regulation, disturbance regulation, water regulation, water supply, erosion control and sediment retention, soil formation, nutrient cycling, waste treatment, pollination, biological control, *refugia*, food production, raw materials, genetic resources, recreation and culture. The total ecosystem service value was estimated between $16 -54 trillion/year, with and average of $33 trillion/year. Costanza et al (1997) included many caveats, predominately due to the rapid nature of the assessment (potential categories omitted) and issues normally associated with non-market valuation (imperfect information known by consumers of these services, price variations).

Wilson and Carpenter (1999) published the article "Economic Valuation of Freshwater Ecosystem Services in the United States: 1971-1997" which synthesized 30 refereed articles over that time period dealing with freshwater ecosystem services. The authors distinguished between non-market and market services and between use and non-use services. Use services include in-stream, withdrawal, aesthetic, and ecosystem services. Non-use services included vicarious consumption, stewardship and option (inherent value, value for future generations, and individual risk aversion) benefits. They detail the methods used to value services, including travel cost, hedonic pricing, and contingent valuation. Their article illustrated the wide variety of values that are found by non-market economic valuation for ecosystem services. Consistent values cannot be found for the same service even when the same method is used, and values vary widely with different methodology. For example, contingent valuation (Gramlich, 1977) found that the willingness to pay (WTP) for the Charles River to be returned to swimmable quality was $81 per household, but the WTP for all rivers to have this water quality was $147 per household (in 1997 dollars). Another study (Carson and Mitchell, 1993) using contingent valuation found that the WTP to return all freshwater bodies to swimmable quality was $298 per household. Using the travel cost method Cameron et al (1996) found that the consumer surplus of visitors to lakes in the Columbia River basin varied from $16 to $125. Hedonic pricing, usually derived from housing prices, values an increase in pH of one unit at $1439 (Lansford and Jones, 1995) per household. The authors concluded that while these values may be imperfect in measuring services from the environment they should still be considered in management as they show that people do give ecosystem services value.

4.2.1. Ecosystem Service Market Development

The state of Oregon has been particularly proactive in initiating a program where payment will be made for ecosystem services. The Oregon Ecosystem Marketplace is currently scheduled for development within the state government by 2014. Similar to the proposed EIC, payments would be made to landowners. Oregon plans to foster existing markets and provide incentives and a mechanism for payments to be made to providers of ecosystem services (i.e., landowners). This would include wetland mitigation banking, water quality trading, carbon trading, conservation banking, voluntary markets as well as the previously stated government incentive programs. Oregon is working on a consistent methodology for assessing ecological value and details of how the marketplace will be implemented.

In the state of Maryland the Pinchot Institute created the Bay Bank, "The Chesapeake's Conservation Marketplace". The Bay Bank is similar to Oregon's Ecosystem Marketplace as it serves as a facilitator between buyers and sellers of ecosystem services. It allows a landowner to see all the programs they are eligible to participate in. The difference is that Oregon is integrating the ecosystem marketplace into its government, and ostensibly will require consumers to participate while the Bay Bank relies on voluntary involvement by consumers.

At the national level, dialogue regarding ecosystem services exists. In the 2008 Farm Bill section 2709 explicitly addresses environmental service markets. However, it does little more than state that technical guidelines should be used to establish marketplaces and that services should be verified but it does not give a plan or timeline for these things to be accomplished. There is a new Office of Environmental Markets (http://www.fs.fed.us/ecosystemservices/OEM/) within the USDA that will work to accomplish these goals.

5. Introduction and Background on Emergy Systems Modeling

5.1. Emergy and Money

The following section is based in large part on Chapter 9 "Energy and Economy" from Odum (2007). Unless otherwise indicated, much of the following text, figures and diagrams can be found in Odum (2007).

5.1.1. Exchange

Money is something that can be exchanged for goods, services, materials, information, or other items of real wealth. Money can take the form of paper money, promises to pay (e.g., a bank check), or material objects (e.g., gems or coins). Money is a basic unit of the financial accounting system that tracks debits and credits. Money circulates among people or institutions as a countercurrent to real wealth (e.g., natural resources, manufactured goods and human services). In systems diagrams money is represented as dashed pathways (see Figure 5.1). Money can flow, it can be stored, and it can be imported or exported to other systems. In the short term, money is conserved, which is a way of saying that the money flowing into a system equals outflows plus the change in storage. However, bank lending and other forms of credit act to increase the availability of money for circulation (Odum 2007). Conversely, defaults on loans removes money from the financial system.

Three forms of exchange are diagrammed in Figure 5.1. The first (Fig. 5.1a) shows moneyless bartering, whereby goods or services are exchanged at some prescribed ratio. In the early part of the 20th Century many small American family farms traded such farm products as eggs for refined products like sugar at an agreed upon ratio. In the second instance (Fig. 5.1b), money has replaced one of the bartered goods in the exchange. Note that money and the good flow in opposite directions. In the third case (Fig. 5.1c), a free (natural) resource drives the economic production whereby money received for selling the resource is used to pay for the human service (e.g., labor) that was required to extract and process the resource into a sellable good.

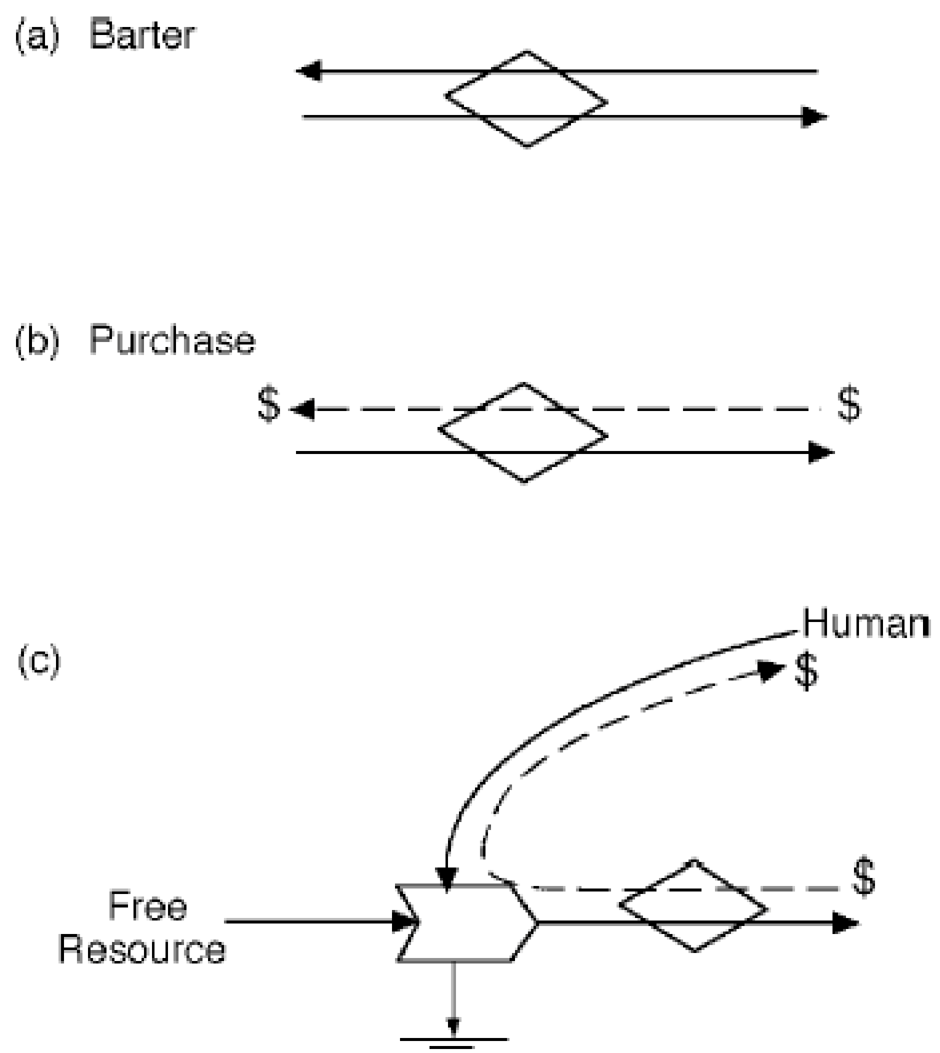


Figure 5.1 Diagrams of various forms of economic exchange (a) without money, (b) with money and (c) money transferring revenue from the sale to pay for costs of production. (Adapted from Odum 2007)

5.1.2. Price and Market Value

The ratio of the money paid to the quantity of the item bought is the price. In the systems diagram in Figure 5.1 price is symbolized by the diamond shape. Prices are typically quoted in currency (e.g., U.S. dollars, $) per count or some other quantity (gallon, ounces, pair). Prices are set in multiple ways. Free markets set the price based on bids (buyers' offer) and asks (seller's offer). This is the ideal of a market economy. Some refer to this as "willingness-to-pay." Another common mechanism for setting prices is government controlled utilities, which do so based on a complex assessment of the utility's costs, fair profit margin, and other factors. In the systems diagrams the price can by controlled from an outside authority (e.g., market, government) or it can be controlled dynamically by the supply and demand of the modeled production/transaction system, like in a market economy.

5.1.3. Money closes system loops for production reinforcement

Figure 5.2 shows various arrangements where feedback from the consumer reinforces the producer's rate of production. In Figure 5.2A a simple loop system reinforces production in direct proportion to consumption. There is no money involved. An example would be children working on a family farm. The children work to be fed and meet the family's needs. The moneyless system is appropriate for small-scale systems that are poorly connected to larger scale economic systems. Sometimes these agricultural systems are referred to as subsistence farms.

In an ecosystem production and consumption are balanced by reinforcement that occurs without money flow (Figure 5.2B). Materials often accompany the reinforcement feedback action that promotes production. For example, herbivorous animals are attracted to plants for a meal, defecate near the plant and thereby recycle valuable materials that increase the plants production.

Figure 5. 2C shows exchange controlled by barter arrangement. Older, subsistence farming provides a prototypical example of bartering, like eggs for sugar, or wool for spices.

In Figure 5.2D money flows in the opposite direction of the product and the feedback to complete a local circulation between consumer and producer, thereby smoothing the linkage between production and consumption. Not shown in the diagram is the property that the money system is more useful when it is connected to a larger economic system. The production and consumption linkage are not hard wired when money is used. Outside resources can be purchased to reinforce production.

In economic systems, money keeps people engaged in reinforcing production. When money is paid for useful reinforcement (i.e., work), the reinforcement to a worker is immediate. A higher price for wages stimulates people to produce more; a lower price for the product signals to consumers to use more. Thus, price and its associated human behavior patterns are self-regulating to keep the availability of commodities optimal. In this way, money helps maximize power and empower (Odum 2007).

Arrangements of coupled production and consumption systems that have reinforcing feedback can be optimized so that over-production and under-consumption are regulated. In moneyed systems prices can be manipulated by markets or other large-scale controlling agents (eg., governments, utilities) to optimize the balance.

The production of ecosystem services, while providing life support to consumers of those services, is presently poorly connected to the consumers because of the lack of pathways designed to regulate and maintain consumption. The EIC's main remedy for this disconnect is to offer the capability to connect consumers with producers via a circulation of money that flows as a countercurrent to the flow of ecosystem services and reinforcing actions like restoration and forest auditing. If the multitude of ecosystem services are measured in emergy, then a representative "price of emergy" can be used to stipulate how much should be paid for the production of an ecosystem service. The EIC will work to manage and encourage the reinforcing feedback from the consumer to the producers (i.e., the forest land stewards).

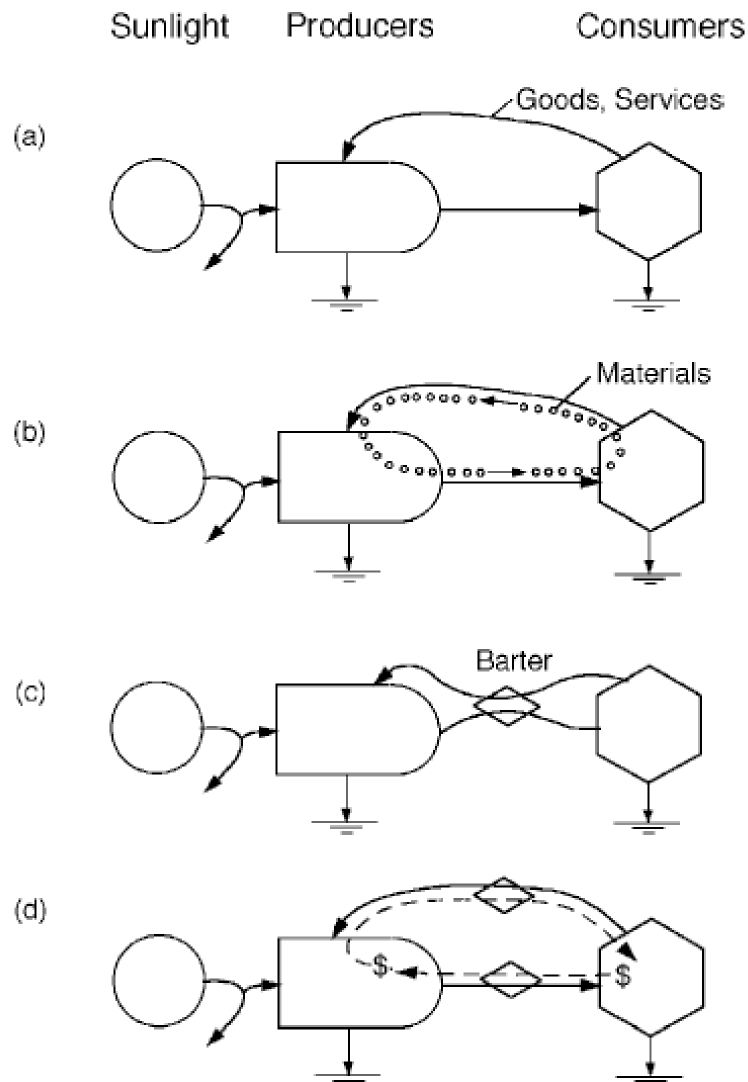


Figure 5.2. Various arrangements for consumption and feedback reinforcement to production. (A) Simple loop system reinforces production in direct proportion to consumption. There is no money involved. An example would be children working on a family farm. (B) In ecosystems materials often accompany the reinforcement feedback to promote production. No money is involved. For example, herbivorous animals are attracted to plants, defecate near the plants and thereby recycle valuable materials that increase the plants production without a counter-current of money. (C) Exchange controlled by barter arrangement. Older, subsistence farming provides a prototypical example of bartering, like eggs for sugar, or wool for spices. (D) Money flows in the opposite direction of the product and the feedback to complete a local circulation from consumer to producer, thereby easing the restrictions on linking production to consumption and vice versa. Not shown in the diagram is the property that the money system is more useful when it is connected to a larger economic system. *Source: Odum (2007)*

5.2. The Price of Emergy and the Energy Hierarchy

A macroscale, energetic perspective of the global economy of society and nature shows that money circulation is limited to a portion of the system (Figure 5.3). If money is a basic numeraire for decision-making, then poor decisions about nature (and public information see Figure 5.3) will be made because nature's importance to overall energy flow is not reflected by money.

Whereas emergy measures the real wealth produced and consumed, money circulates as it is exchanged for the emergy. The buying power of the money depends on the "price" of the emergy. Here the price of emergy is defined as the ratio of the emergy flowing to the money paid. At the macroeconomic scale the ratio of total money circulation to total emergy flow consumed for a nation or state describes the average ability of money to buy real wealth (i.e., emergy). This ratio of a nation's average emergy-to-dollar ratio can then be used to estimate the dollar value that a flow of emergy from an ecosystem adds to the economy. That is, dividing a flow of emergy emanating from an ecosystem by a nation's average emergy-to-dollar ratio indicates the amount of money circulating in the economy due to that flow of emergy. For example, if hypothetically a wetland produced 140E12 sej/ha/y of clean water and the mean emergy-to-money ratio was 2E12 sej/$ for the nation, then the wetland added $70/ha/y as clean water to the ecological-economic welfare of the country.

The average emergy-to-dollar ratio for a nation is but one ratio or "price" of emergy. The price of emergy varies along the energy transformation hierarchy (Figure 5.4). As a natural resource goes from its source (e.g., forest, mine, fishery) along its processing chain, the emergy value of the resulting product increases slowly while the market value (i.e., price) increases rapidly. This results in the price of emergy growing quickly as a resource is transformed to a final product.

Tilley (1999) showed that the emergy-to-dollar ratio of wood products in the U.S. was higher for the unprocessed natural resource (i.e., 11E12 sej/$ for logs) than for finished products (e.g., 3.8E12 sej/$ for paper) (Figure 5.5a). By comparison the average emergy-to-dollar ratio for the U.S. during this same period was 1.1E12 sej/$. The emergy-to-dollar ratio fell as the wood was processed along the various industrial pathways. The emergy-to-dollar ratio of wood on the stump (i.e., in the forest) was assumed to be undefined because there was no money paid for the wood while it was in the forest. Thus, there exists a gradient for the ratio of emergy flow to dollar flow for natural resources as they are processed and consumed economically (Fig. 5.5b).

In this report we build on this concept of the emergy-to-dollar gradient to distinguish between the *public value* and a *fair payment price* for ecosystem services.

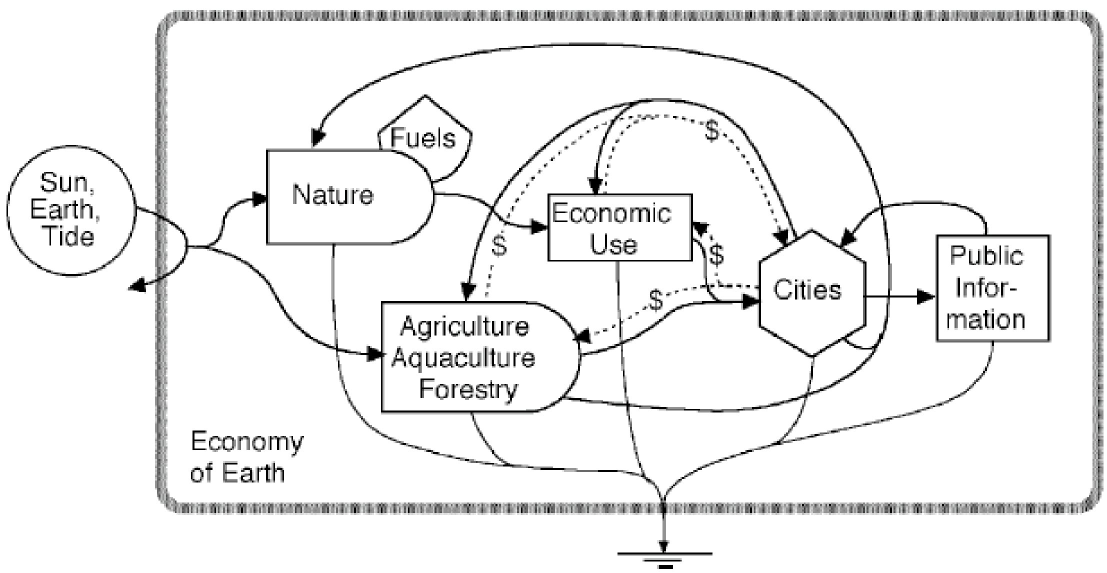


Figure 5.3. Macroscale, energetic view of the global economy of society and nature which shows that money circulation is limited to a portion of the system. *Source: Odum (2007)*

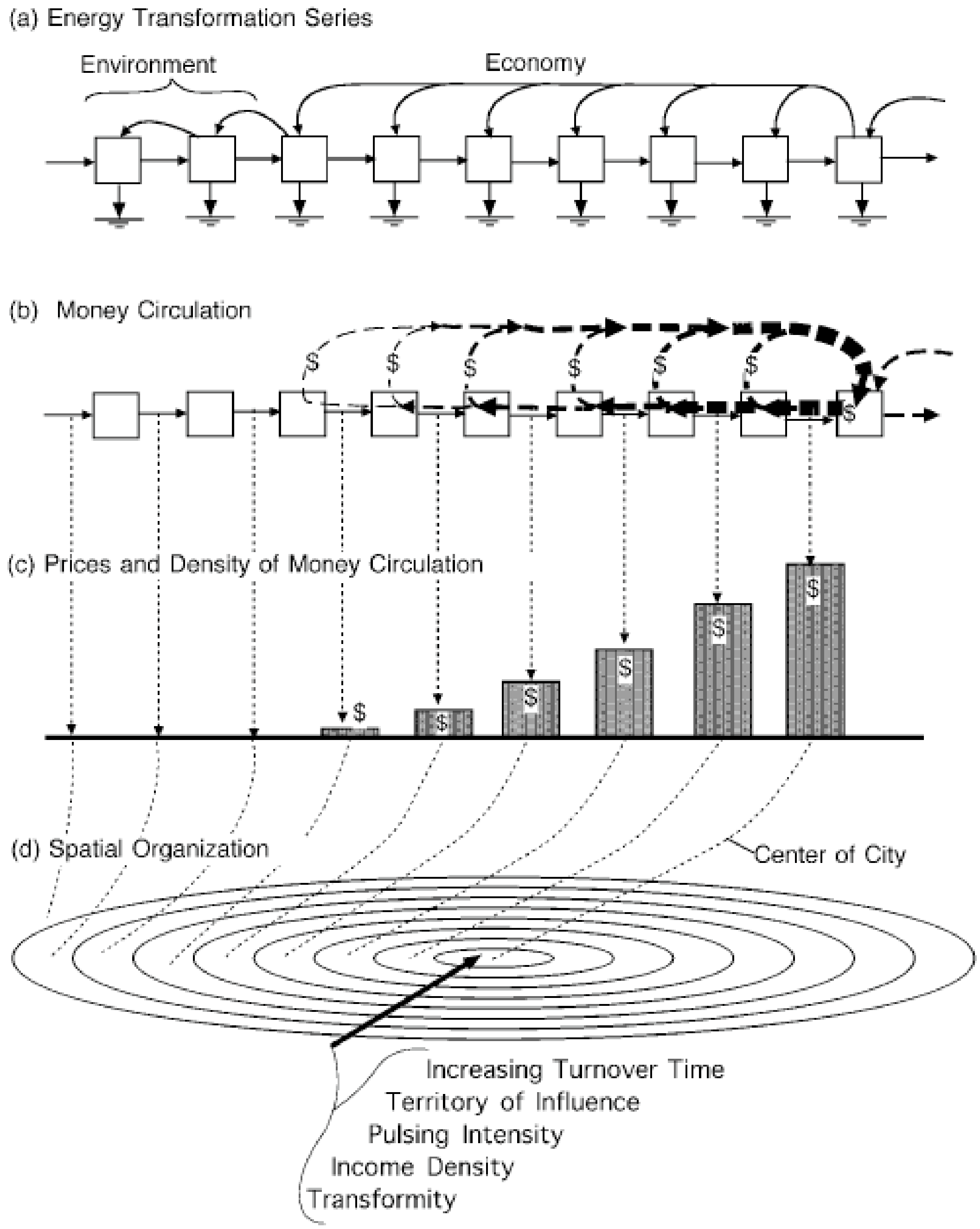
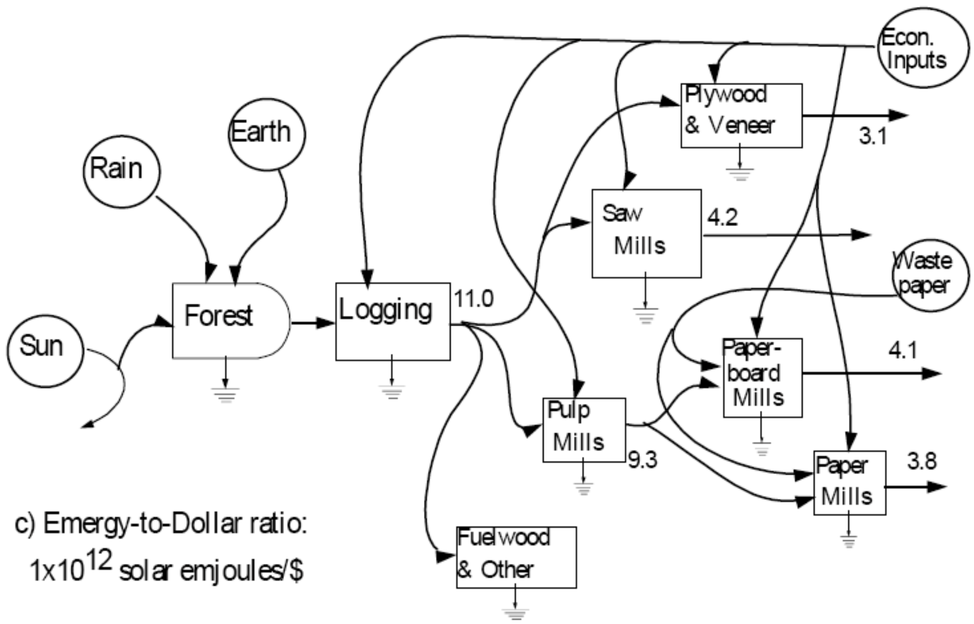
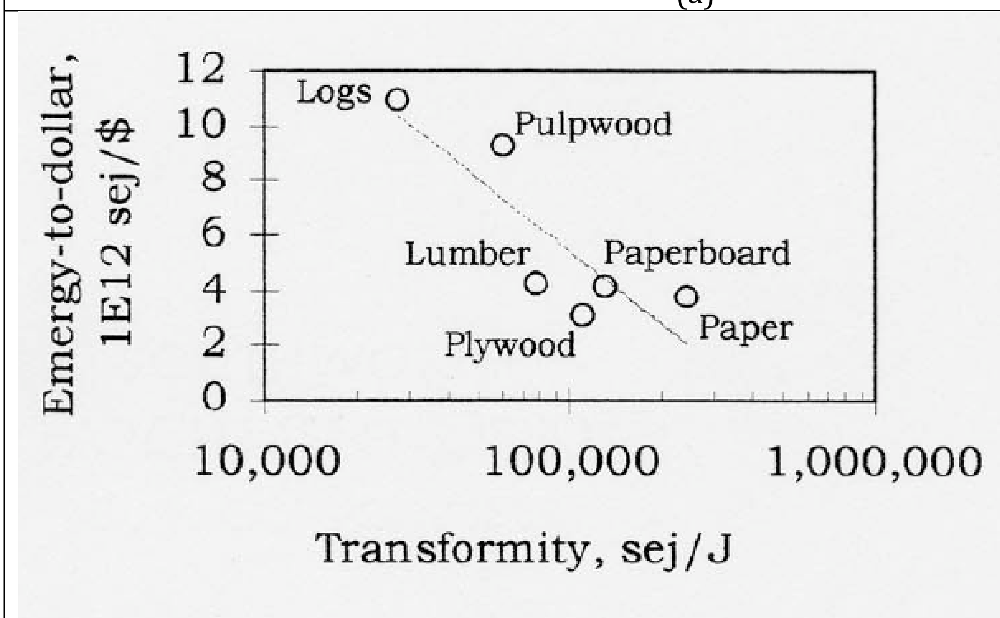


Figure 5.4. Circulation of money in the energy transformation hierarchy. (a) Aggregated view of the series of energy transformations necessary to process emergy from the natural environment to an economic center such as a city; (b) the circulation of money is non-existent in the environment on the left, but accelerates in intensity as energy is transformed towards the right; thus money flow grows fast while emergy increases slowly, resulting the ratio of money/emergy growing exponentially (i.e., rapidly) as shown in (c) where money is concentrated on the right in the highly developed parts of the economy like city centers; (d) shows the zonal distribution of the coupled energy-money processes. *Source: Odum (2007)*



(a)



(b)

Figure 5.5. The U.S. wood products industry typifies the relationship between emergy and money for an industry directly dependent on a natural resource. (A) The systems diagram characterizes the flow of emergy from sun, rain and earth to the forests, logging sector, saw mills, plywood mills, pulp mills, and paper mills to become finished products for consumption. (B) The emprice (sej/$) for the major products declined as the emergy flowed through the industrial sectors, which is quantified by the increasing transformity (Tilley 1999)

5.2.1. Public Value of Ecosystem Services

The public value of an ecosystem service indicates how much total economic welfare it generates for the entire public. Public value is the ecosystem services' large-scale value that benefits the vitality of many. The "tragedy of the commons" is that while public value benefits and sustains many people, there is no requirement that people pay for the value received. Thus, public value is not indicative of the willingness of consumers and producers of ecosystem services to exchange money. Therefore, for goods and services with public value, a fair exchange rate between consumers and producers needs to be determined.

In this study once the solar emergy of an ecosystem service was determined, its public value was found by dividing the solar emergy flow by Maryland's mean *solar emergy-to-dollar ratio*. This gives an estimate of the public value in dollars. We propose a similar method for estimating a fair exchange rate between consumers and producers, i.e., an amount that consumers will be willing to pay and that producers will be willing to accept. The proposed method would use a different emergy-to-dollar ratio to convert the solar emergy flow to dollar value reflective of a fair payment price.

5.2.2. Fair Payment Prices for Ecosystem Service

One way to estimate a fair payment price for ecosystem services that is based on emergy evaluation is to find prices that people are currently paying for solar emergy. As shown in Section 5.2 above, people and corporations pay for solar emergy when they buy wood products. Buenfil (2001) showed beautifully how the money paid for the solar emergy of freshwater behaved similarly to what Tilley (1999) demonstrated for wood products. Namely, that as water was extracted from nature, treated to drinking water standards and delivered to consumers, the solar emergy per dollar paid decreased. Doubtless many other instances exist where the amount of money paid for solar emergy decreases as a natural resource is transformed into a product through various economic sub-systems.

Commodity markets, like the New York Mercantile Exchange or Chicago Board of Trade, are constantly adjusting the rate at which money is exchanged for natural resources. Since natural resources and ecosystem services are derived directly from natural systems, we propose that the market-set price for natural resource commodities is an appropriate price to use to estimate the solar emergy per dollar (i.e., a price of emergy or eco-price) that can be used to convert the solar emergy of ecosystem services to a fair payment price.

In addition to financial commodity markets, there are other financial transactions that could be used to estimate eco-prices (i.e., the price of emergy) for transforming solar emergy to a fair payment price. Appropriate financial transactions would include cases such as a municipality or water supply corporation that collects a fee that is dedicated to preserving the ecological integrity of the supply watershed to maintain high quality water, or where people voluntarily pay to offset their carbon footprint. The use of eco-prices determined from these types of exchanges of money for solar emergy is justified because it is based on payments that the public is already making to protect or conserve ecosystems and the services they produce.

Therefore, to obtain fair payment prices for ecosystem services produced by Maryland forests we developed three methods for estimating eco-prices: 1) Natural Resource Commodity Market eco-price 2) Specific Ecosystem Service eco-price, and 3) Mean Ecosystem Service eco-price. The Commodity eco-price method (1) estimated eco-prices based on the market prices set for a group of natural resources traded on the NY Mercantile Exchange. The Specific Ecosystem Service eco-price method (2) estimated eco-prices based on cases where money was being spent to secure a specific ecosystem function (i.e., service). In this method the use of an eco-price was restricted to a similar ecosystem service (e.g., the eco-price of watershed protection was used to convert the solar emergy of stormwater mitigation to its fair payment price). Finally, the Mean Ecosystem Service eco-price method (3) used a single eco-price (i.e., the mean of the specific ecosystem service prices) to translate the solar emergy of each type of ecosystem service to a fair payment price.

6. Methods

6.1. Description of State of Maryland's Economy and Ecology

Maryland is the eighth smallest state in the United States, comprised of 2.5 million ha (9,772 square miles) but has the 15th largest economy with a state domestic product of

$273 billion dollars in 2008 (Table 6.1). During the recent economic recession (2008-09) Maryland was one of the few states to maintain economic growth, due to a strong reliance on high tech industry and trade. Farming contributed $2.38 billion to the Maryland economy in 2007. The forestry industry in Maryland is the 5th largest industry in the state, employing 14,000 people and generating $2.2 billion dollars annually (Rider, 2010). Maryland is known for its diversity and is referred to as Little America or America in Miniature due to the high variability in climate, geology, elevation, and ecology. Ecologically, Maryland has five distinct terrestrial eco-regions, and several aquatic systems, the largest of which is the Chesapeake Bay, the largest estuary in North America.

6.2. Geology

Maryland is located in the Mid-Atlantic region of the United States and is comprised of five physiographic regions. Going from west to east the physiographic regions are the Coastal Plain Province, the Piedmont Plateau Province, the Blue Ridge Province, the Ridge and Valley Province, and the Appalachian Plateau Province. The highest elevations in Maryland are in the west with the highest point being Backbone Mountain at 1024 m above sea level (msl) but the majority of the state is at a much lower elevation, as evidenced by the fact that the average elevation is only 106 above msl. The Coastal Plain Province is comprised of deep unconsolidated sediment, ranging from 2,400 to 12,000 meters. These sediments support several deep aquifers in this region. In contrast, the Piedmont Province is composed primarily of igneous and metamorphic bedrock such as schist, gneiss, gabbro, phyllite, slate, and marble. This hard substrate does not support large aquifers. The Blue Ridge, Ridge and Valley and Appalachian Provinces are somewhat similar geologically. They are all underlain by folded and faulted sedimentary rock; minerals commonly occurring in these regions are quartzite, limestone, shale, sandstone, and dolomite.

6.3. Climate

Maryland is diverse climatically considering that it is a small state. The western portion of the state has lower average temperatures and less precipitation (average of 9° C and 0.91 m/y at the extremes) than the eastern part of the state (with state high averages of 15° C and 1.24 m/y). The Chesapeake Bay and Atlantic Ocean play a major part in ameliorating temperatures and promoting rainfall in the eastern portion of the state while the higher elevations of the Appalachian Mountains in the west create lower temperatures.

Table 6.1. Physical, demographic and economic attributes for Maryland 2000.

Attribute	Value	units
Land area	2.53	million ha
Continental shelf and bay area	11.40	million ha
Bay area	0.45	million ha
Land + bay	2.98	million ha
Shoreline, ocean	0.16	million m
Shoreline, waves	12.9	million m
Population, 2000	5.30	million ind
Per capita income, 1999	25,614	$/ind

6.4. Methodology for Conducting an Emergy evaluation

6.4.1. Determine Boundary with Systems Diagram

The first step in conducting an emergy evaluation is to define the boundary of the study. This step is important because the flows accounted for are those that enter and exit the boundary. When studying a state, country or a well-bounded ecosystem (e.g. a national park), the boundary is often easy to define. However, if one is evaluating a natural ecosystem such as an urban forest or a manufacturing industry in an economy, the boundary definition is more nebulous. In the more nebulous cases care must be taken to establish exactly what is being studied so accurate accounting of flows and storages can be made. In this step an energy systems language diagram should be drawn. This represents, pictorially, the flows and storages of the system to be analyzed and helps the researcher to inventory the components of the system and see the connections between them. The temporal boundary is also determined in this step. The typical time period is one year, but this can vary with the goal of the study or the system under study.

6.4.2. Construct Standard Emergy Table

Once the systems diagram is made the next step is to construct the Standard Emergy Table (Table 6.2), which contains all of the input and output flows of energy and materials, their solar transformities or specific solar emergies, and total solar emergy. See the footnotes to Table 6.2 for a detailed explanation of the Standard Emergy Table.

Table 6.2. The Standard Emergy Evaluation Table is used to inventory energy and material inputs, and weight them according to their solar transformity or specific emergy, respectively, to determine solar emergy of individual inputs as well as the total. The table is also used to show how the solar transformity of an output energy is estimated.

A	B	C	D	E	F
Note	Item	Energy or Material	Units (J or g)	Solar Transformity or Specific Emergy (sej/J or sej/g)	Solar Emergy (sej/y)
1	Energy i	e_i	joules	t_i	$M_i = t_i \times e_i$
2	Mass j	a_j	grams	s_j	$M_j = s_j \times a_j$
3	Total Emergy	n/a	n/a		$M_T = M_i + M_j$
4	Output k	e_k	joules	$t_k = M_T/e_k$	

Column A is the line item number, which is also the number for the footnote found in the appendices where raw data sources are cited and equations are shown.

Column B is the name of the input item, whether it is energy or material.

Column C is the value for the input item (e_i or a_j, in joules or grams, respectively) or the output (i.e., yield) energy (e_k).

Column D has the units for Column C.

Column E has the solar transformity of input energy i (t_i, in units of solar emergy joules per joule) or the specific solar emergy (s_j, in units of sej/g). Solar Transformities for input items may be obtained from multiple literature sources or the Emergy Society transformity database (ISAER www.emergydatabase.org) or calculated for the specific system under investigation as shown for the Output k, which has a solar transformity of $t_k = M_T/e_k$.

Column F is the solar emergy (M) of a given flow, calculated as energy or material times solar transformity or specific solar emergy, respectively (Column C x Column E) for individual inputs. The total emergy input (M_T) is the sum of individual input emergies.

Column G (not shown) is sometimes added to the standard emergy table to show the public value in dollars for each input and the total. As mentioned previously, the public value indicates the total equivalent flow in the larger-scale economic production system (e.g., the portion of gross domestic product for a nation or state). It is found by dividing the solar emergy of Column F by the mean *solar emergy-to-dollar ratio*.

6.4.3. Expressing Public Value in Dollars

When an emergy analyst wants to express the solar emergy as dollars of public value, the standard practice (Odum 1996) has been to divide the solar emergy (sej) by the mean *solar* *emergy-to-dollar ratio* (sej/$) of the economy that encompasses the flow of solar emergy. The mean *solar emergy-to-dollar ratio* used in this study was determined for the State of Maryland*. It has been common practice in emergy evaluation to* show the public value as a Column G in Table 6.2. However, since we were not only interested in public value, but also in the fair payment price (see section 5.2.2), we show the public value and three estimates of the fair payment prices in separate tables structured like those in Table 6.3 and 6.4.

Table 6.3 Template for showing Public Value of Ecosystem Services based on Mean Statewide Emergy-to-Dollar ratio.

Ecosystem Service	Units	Quantity	Unit Emergy Values (sej/unit)	Solar Emergy (1E18sej)	State-wide Emergy to Dollar Ratio (1E12 sej/$)	Public Value ($ million)
Ecosystem Service i	J	e_i	t_i	$M_i = t_i \times e_i$	P_{pv}	$PV_i = M_i/P_{pv}$
Ecosystem Service j	g	a_j	s_j	$M_j = s_j \times a_j$	P_{pv}	$PV_j = M_j/P_{pv}$
Total Public Value						$PV_T = PV_i + PV_j$

Notes: P_{pv} is mean statewide solar emergy-to-dollar ratio for Maryland; PV_i and PV_j are public values for ecosystem services i and j, respectively; PV_T is total public value of all ecosystem services evaluated.

Table 6.4. Template for showing Fair Payment Price of Ecosystem Services based on one of three Eco-prices (Commodities, Specific Ecosystem Service or Mean Ecosystem Service).

Ecosystem Service	Units	Energy or Material	Unit Emergy Values (sej/unit)	Solar Emergy (1E18 sej)	Eco-price (1E12 sej/$)	Fair Payment Price ($ million)
Ecosystem Service i	J	e_i	t_i	$M_i = t_i \times e_i$	P_{eco}	$FP_i = M_i/P_{eco}$
Ecosystem Service j	g	a_j	s_j	$M_j = s_j \times a_j$	P_{eco}	$FP_j = M_j/P_{eco}$
Total Public Value						$FP_T = FP_i+FP_j$

Notes: P_{eco} is the eco-price (Commodities, Specific Ecosystem Service or Mean Ecosystem Service; FP_i and FP_j are the fair payment prices for ecosystem services i and j, respectively; FP_T is total amount paid to land stewards as fair payment.

Table 6.5. Template for displaying the *public value* and three estimates of the *fair payment price*

	Total Dollar flow in Maryland ($ million per yr)	Mean Dollar flow per Forested Area ($ per ha per yr)
Public Value	PV	PV/a
Commodity Price	FP_{cp}	FP_{cp} /a
Specific Ecosystem Service Eco-price	FP_{SESP}	FP_{SESP} /a
Mean Ecosystem Service Eco-price	FP_{MESP}	FP_{MESP}/a

Notes: PV and PV/a are total and per unit area Public Value to Maryland, respectively; FP_{cp} and FP_{cp}/a are total and per unit area value, respectively, of the Fair Payments to Maryland land stewards based on the Commodity Price model; FP_{MESP} and FP_{MESP}/a are total and per unit area value, respectively, of the Fair Payments to Maryland land stewards based on the Mean Ecosystem Service Price model; FP_{SESP} and FP_{SESP}/a are total and per unit area value, respectively, of the Fair Payments to Maryland land stewards based on the Specific Ecosystem Service Price model.

6.4.4. Estimating Fair Payment Price in Dollars

The fair payment price is the number of dollars that should be paid to a land steward for producing a given quantity of ecosystem services. The fair payment price better reflects the dollars that producers and consumers are willing to exchange for ecosystem services than the public value.

The three methods for estimating the fair payment price (see section 5.2.2) were based on 1) Commodity Price 2) Specific Ecosystem Service Price, and 3) Mean Ecosystem Service Price. Fair payment prices used eco-prices (or the emergy per dollar ratios) to translate solar emergy flows to dollar payments. Table 6.3 shows the tabular template for displaying the fair payment price based on the three eco-price models.

6.4.5. Public value versus Fair Payment Price

For each class of ecosystem service a table similar to Table 6.5 was developed to contrast the public value with the fair payment price. The tables will show the total and per unit area value to the state.

6.5. Definitions of emergy terms and indices:

The following list defines key terms used in emergy evaluations and describes typical indices developed from aggregating resource flows (Figure 6.6). Emergy indices are calculated from the data aggregated from the emergy analysis table. These indices, which relate economic and environmental flows, are used to quantify investment intensity, net yield, environmental loading, and sustainability. The utility of a particular index depends on the specific goal or question of concern.

Emergy: the available energy (i.e., exergy) of one form that is used in past transformations directly and indirectly to make a product or service. Emergy is measured as the accumulative number of joules (J) used in the past transformations. The amount of energy of one form required to make any other form, such as sunlight, fuel, electricity, human service or a material resource becomes the common basis for expressing the value (i.e., emergy) of each form. Since solar energy is the basic energy form that ultimately supports the creation of all other forms, it is common practice to refer to the solar emergy of an energy form and to express the value in solar emjoules (sej). Other units, such as coal emjoules, have been used the past (Odum 2007), but it seems most appropriate to use solar energy as the basis of ecosystem services.

Transformity: the ratio of emergy input to available energy (exergy) output. For example, the solar transformity of wood is 4000 solar emjoules per joule (sej/J) because 4000 solar emjoules of environmental inputs were required to generate a joule of wood as output. The solar transformity of sunlight absorbed by the earth is defined as 1 sej/J. Transformities have been calculated for a wide variety of resources, commodities, and renewable energies, and can be found in past publications (e.g., Odum 1996), and a series of emergy folios (Odum 2000, Odum et al. 2000, Brown and Bardi 2002, Brandt-Williams 2002, Kangas 2002).

Specific emergy: the emergy per unit mass output. This is usually expressed as solar emergy per gram (sej/g).

Eco-price (sej/$): the solar emergy associated with an exchange of money for a product or service. It has the same units as emprice, but is estimated at the micro-economic scale. (This was a new index developed for this report).

Emprice (sej/$): the emergy supporting the generation of one unit of economic product (expressed as currency), thus it the mean macroeconomic relationship between solar emergy and money. The average emergy/money ratio (sej/$) of an economy is found by dividing the total emergy use of the economy by its gross economic product (e.g., GDP).

Empower: the flow of emergy per unit of time. Emergy flows are usually expressed in units of solar empower (i.e. sej/yr).

Emergy Yield Ratio (EYR=Y/F): emergy yield produced (Y, where Y can be R+N+F or energy of yield times solar transformity of yield) per unit of emergy contributed from the economy (F) (sej/sej)

Public value ($): the dollar value of an ecosystem service determined by dividing its solar emergy by the emprice.

Fair Payment Price ($): the dollar value that a land steward should be paid for producing ecosystem services. It is found by dividing the solar emergy of the ecosystem service by the eco-price. (This was a new index developed for this report).

Ecological-Economic Return on Private Investment (EERPI, sej/sej): the ratio of public value generated from an ecosystem service to a fair payment made to a land steward for producing that ecosystem service. (This was a new index developed for this report).

Environmental Loading Ratio (ELR=(N+F)/R): emergy contributed from non-renewable and economic sources per unit of emergy contributed from renewable resources (sej/sej) It is an indicator of the pressure of agricultural systems on the environment and may be considered a measure of ecosystem stress (Ulgiati and Brown, 1998).

Emergy Sustainability Index (ESI=EYR/ELR): is the ratio of yield to environmental load, which measures system production relative to environmental pressure (Ulgiati and Brown, 1998).

Emergy Investment Ratio (EIR=F/(N+R)): emergy purchased and contributed from the economy (F) per unit of emergy contributed free from the environment whether renewable or non-renewable (R+N)

Emdollar (Em$) or dollar value: links emergy directly to dollars by signifying how much money circulated in an economy due to a flow of emergy. It is calculated by dividing solar emergy by the mean emergy-to-dollar ratio of the encompassing economy (Em$=sej/sej/$). Historically, emergy analysts followed Odum's convention to call this quantity emdollars to distinguish it from market-based dollars. However, this convention was not adopted for this report because the authors felt it was unnecessarily confusing to non-emergy analysts to use emdollars, when dollars could suffice.

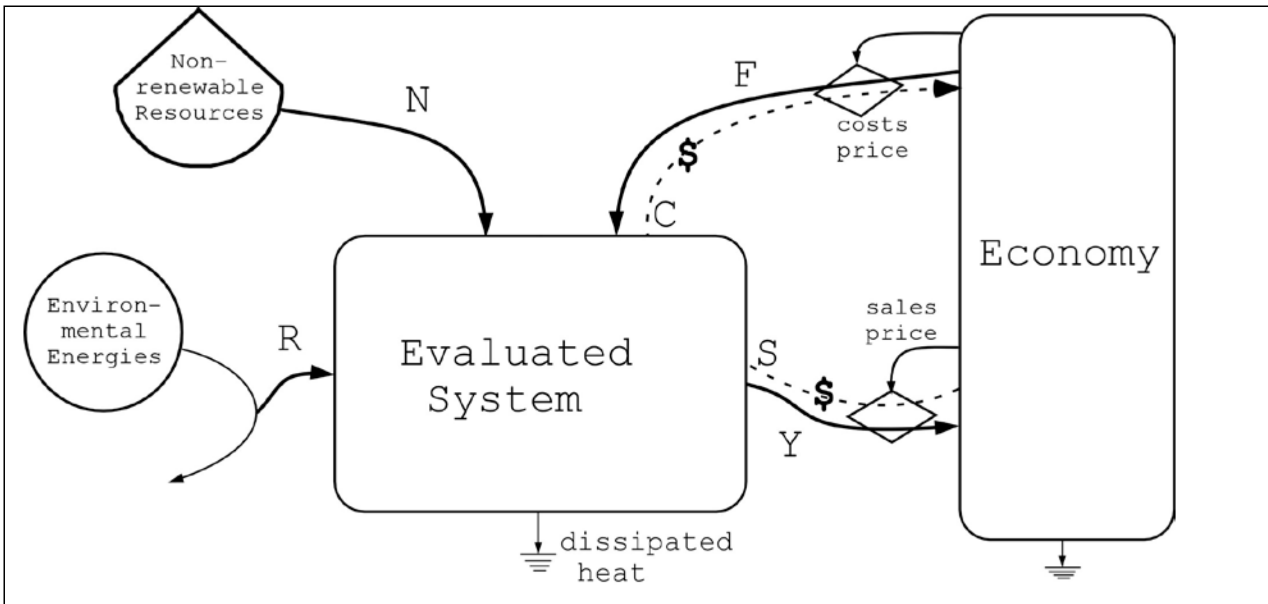


Figure 6.6. Energy systems diagram of the aggregated inputs (R, N, and F) to an evaluated system that produces a yield (Y) to the economy and generate sales revenue (S) which pays for purchased costs (C).

7. Estimates of the relationship of emergy to money: Eco-Prices

Historically, emergy values (sej) have been converted to dollar values by dividing by the mean emergy–to-dollar ratio which is based on the total emergy flow and gross economic product of the economic system being evaluated. For Maryland the mean emergy-to-dollar ratio was found by dividing the total annual emergy flow for 2000 by the Gross State Product for 2000; it was 2.82E12 sej/$ in 2000 (Table 8.2). This conversion of emergy to money provides an estimate of the ultimate public value that a flow of emergy provides to the entire economic welfare of the state. If the total emergy flow of Maryland's forest were divided by the Maryland State emergy-to-dollar ratio, then the value would be the total value that the forests provide to the state. It is not a value equivalent to a market price that someone would be willing to pay. This perspective on public valuation of ecosystem services is analogous to the notion that manufacturing jobs have an economic multiplier effect on the economy, whereby, historically, there were 3 to 5 non-manufacturing jobs for every one manufacturing job.

One important objective of the EIC would be to estimate a dollar value that consumers could pay to the EIC to compensate land stewards for producing forest ecosystem services. The traditional way of estimating public value using emergy provides a very large value that does not necessarily represent what a producer deserves for their efforts nor what a consumer should pay. Therefore, we developed methods for developing a fair payment price that consumers could pay to land stewards.

Rather than use the state's mean emergy-to-dollar ratio, we developed estimates of the eco-price (i.e., sej/$) of various ecosystem services and marketed natural resources that could be used to convert ecosystem emergy flows to dollar payments. Using an eco-price to make the equivalency between the emergy of the service and dollars to be paid gives a fair payment value that citizens and institutions "could pay" for ecosystem services. One should note that the fair payment value is less than the public value that the ecosystem service provides to the economy and society.

To estimate the fair payment price for ecosystem services, cases were evaluated where ecosystem services, or goods closely associated with ecosystem services (e.g., timber), were paid for either in a market, through a tax or via government regulation. The emergy of the ecosystem service or good was divided by the dollars exchanged, which generated an eco-price.

7.1. Public Value

The emergy-to-dollar ratio for the State in 2000 (2.82E12 sej/$, Table 8.2) was used to convert emergy flows of ecosystem services to public value. By comparison the mean for the nation during the same year was 1.07E12 sej/$.

7.2. Specific Ecosystem Service Eco-prices

The following section describes the basis for the eco-prices estimated for carbon sequestration, water quality and quantity, soil genesis, air quality, pollination and biodiversity. These eco-prices were used to convert the solar emergy of each forest ecosystem service to a fair payment price.

7.2.1. Carbon Sequestration Eco-price

Eco-prices for carbon sequestration were estimated based on 1) the average price of carbon on the European Carbon Exchange during 2010, which was $15 per ton, 2) the average price of carbon on the Chicago Carbon Exchange, which was $2 per ton and 3) the average price of log timber in Maryland in 2010, $138 per ton of wood. The energy content of a ton of wood was multiplied by a transformity of 36,200 sej/J to get the emergy value of the wood. This value was then divided by the dollar value of the ton of wood to arrive at the eco-price (emergy per dollar) for carbon.

7.2.2. Water Quality and Quantity Eco-price

Five estimates of the eco-price for hydrologic and hydrologically-related ecosystem services were developed to estimate the fair payment price for hydrological ecosystem services.

An estimate of the eco-price of stormwater mitigation was based on the $1.5 billion investment New York made to protect the watersheds supplying water to New York City. The ratio of the emergy of the clean water supplied since the beginning of the program to the dollars spent was the estimate of the eco-price for stormwater mitigation.

Groundwater recharge was the second estimated eco-price for water, which was found as the ratio of solar emergy of groundwater pumped per dollar spent by municipalities in Maryland.

Three programs enacted to spur a reduction in nutrients discharged to the Chesapeake Bay were used to estimate the eco-price of services directly related to water. One was based on the money spent to support the Chesapeake Bay Clean Water Act, the second on the nutrient trading in the Chesapeake watershed, and third was based on the Water Quality Best Management Practices Cost Share Program. The solar emergy of the nutrient inputs avoided through the implementation of water quality management was divided by the dollar cost of the program.

The mean eco-price for water-related ecosystem services was 7.26E12 sej/$ (Table 7.1). The minimum water-related estimate was from nutrient trading in the Chesapeake Bay watershed giving a value of 0.49E12 sej/$, while the maximum was 10.9E12 sej/$ for BMP cost-sharing (Table 7.1).) The average reciprocal of water's eco-price was $501.1/quad-sej (Table 7.1, one quad = 1E15). Nutrient trading had a reciprocal eco-price of $2049/quad-sej, which was the highest of all eco-prices estimated. The high price may indicate that too much is being paid for the small amount of nutrients removed.

7.2.3. Soil Eco-price

The eco-price of soil was estimated from two direct market exchanges for soil products. The first estimate was based on the market price of "fill-dirt" (from www.earthproducts.com) and its solar emergy content. Fill-dirt is mostly purchased in bulk for landscaping and land development. Fill-dirt has a low price and is largely inorganic; we assume that the eco-price of fill-dirt best represents the inorganic fraction of soil. The eco-price for fill-dirt was 153E12 sej/$, or a reciprocal eco-price of $8.6/quad-sej (Table 7.1).

The second estimate to obtain a soil eco-price was based on the market price for bark mulch (average of several prices at online stores), which was considered to be representative of the organic fraction of soil. The organic content of soil is one of its most important characteristics because it is indicative of many of its physical, chemical and biological properties. The generation of soil organic matter is also directly tied to the main solar emergy flows of the forest ecosystem, making the energy flows easily traceable to soil. The eco-price of mulch was 7.54E12 sej/$, or a reciprocal eco-price of $101.5/qual-sej (Table 7.1).

7.2.4. Air Quality Eco-price

Maryland estimated that air pollution cost it $400 million per year from 2000 to 2010 due to increased medical care and lost environmental and agricultural productivity (Maryland.gov, 2011). We estimated the eco-price of air quality based on Maryland's share of the national costs of air pollution in 1970, plus the extra costs of ozone pollution. Ozone was chosen as the best indicator of air quality in Maryland because it was most often designated the air pollutant of concern in Maryland (Improving Maryland's Air Quality, MDE, 2009). The emergy of ozone was determined by multiplying the mass of ozone generated to force the air quality standards to be exceeded by the specific emergy of ozone. The mass of ozone was the concentration that exceeded the standards times the volume of the urban air-shed in Maryland (see Appendix 4 for details). The eco-price was estimated by dividing the solar emergy by the dollar cost associated with air pollution.

In addition, the Clear Skies Act of 2003 was used to estimate an eco-price of air pollution. The program was estimated to cost $4 billion over 15 years, and reduce SO_2, NOx, and Hg by 8.2, 3.4 and 0.000033 million tons, respectively. The total emergy of the pollutants was estimated by multiplying SO_2, NOx and Hg by transformities found in the literature. Then the total emergy was divided by the estimated cost of the program.

The eco-price of air pollution based on ozone in Maryland was 3.88E12 sej/$, or the reciprocal was $257.6/quad-sej (Table 7.1). The eco-price of air pollution based on the Clear Skies program was 11.4E12 sej/$, or the reciprocal eco-price was $87.7/quad-sej.

7.2.5. Pollination Eco-price

Pollinators promote biodiversity in general, but especially effect plant diversity (Tepedino, V.J. 1979). Pollinators also play important roles in supporting many agricultural crops (Ingram, 1996) and increasing economic productivity of farms. The ecosystem services provided by forest dwelling pollinators to agricultural production was the basis for valuing pollination.

Losey and Vaughn (2006) estimated a dollar value for the contribution that native pollinators made to US agriculture. We adapted their estimate to Maryland based on the percentages of crops pollinated by native pollinators. We also relied on USDA National Agricultural Statistics Services for data on pollination-sensitive crops produced in Maryland (www.nass.usda.gov, 2011). The emergy of the crops produced was derived by multiplying the mass of crops produced by a weighted average of the solar transformities for vegetables produced in Maryland (see Appendix 2 for details).

The eco-price of pollination in Maryland was 13.0E12 sej/$, or the reciprocal was $77/quad-sej (Table 7.1).

7.2.6. Biodiversity Eco-price

We estimated the eco-price of biodiversity, but did not use it to estimate a fair payment price because we lacked a model that estimated the decrease in emergy flows due to the loss of biodiversity in Maryland's forests. However, we acknowledge that biodiversity is an important ecosystem service provided by Maryland forests. The eco-price for biodiversity can be used in the future when an emergy model is available for assessing the decreased emergy flow associated with altered forest biodiversity in Maryland.

The eco-price for biodiversity was estimated based on the price paid for the long-term conservation of land. Two organizations, Maryland Environmental Trust (MET) and The Conservation Fund Mid-Atlantic (CFMA) were the source of information used to determine the eco-price. Both organizations purchased land in Maryland to place it in long-term conservation. MET purchased nearly 3,000 acres in 2009 and the CFMA has purchased 155,000 acres since 1985. The organizations' goals are to purchase land with the greatest ecological and cultural values. The solar emergy of the purchased land was based on the flow of renewable emergy for an average year. The eco-price was the solar emergy divided by the cost to acquire the land in 2009.

Placing sensitive lands into land trusts such as these not only promotes biodiversity, it also helps secure other ecosystem services such as water quality, soil genesis and air quality. Thus, this estimate of the eco-price of biodiversity encompasses many features and may lead to double counting values. More work is needed to consider how well this eco-price represents the fair payment price for biodiversity.

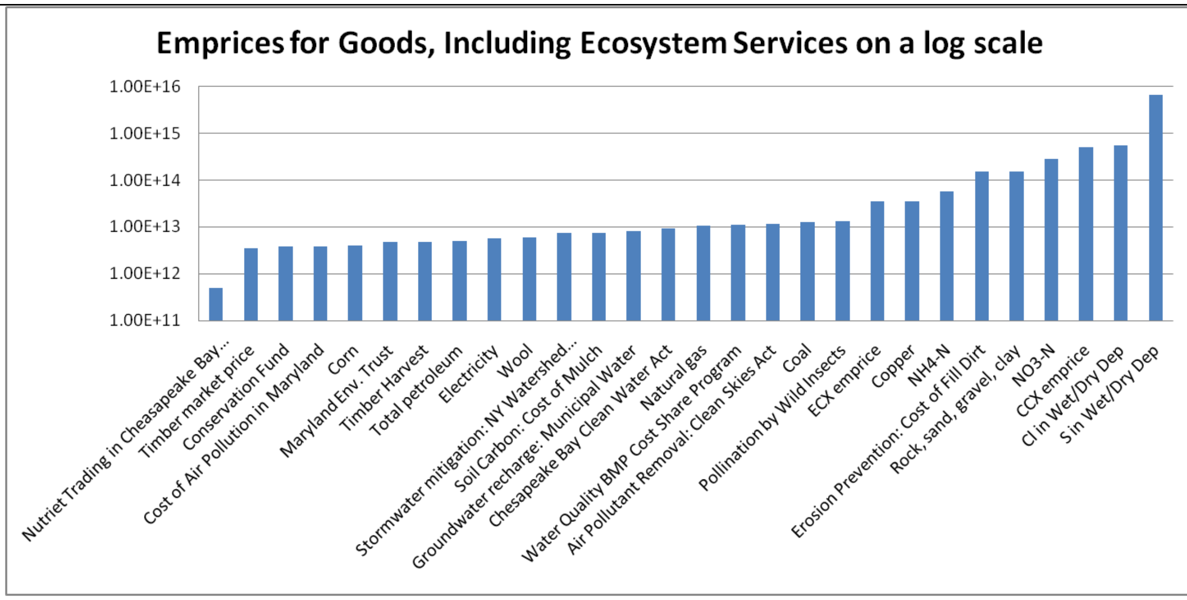
The mean eco-price of biodiversity in Maryland was 4.26E12 sej/$, or the reciprocal was $279/quad-sej (Table 7.1).

Table 7.1. Specific Ecosystem Service Eco-prices

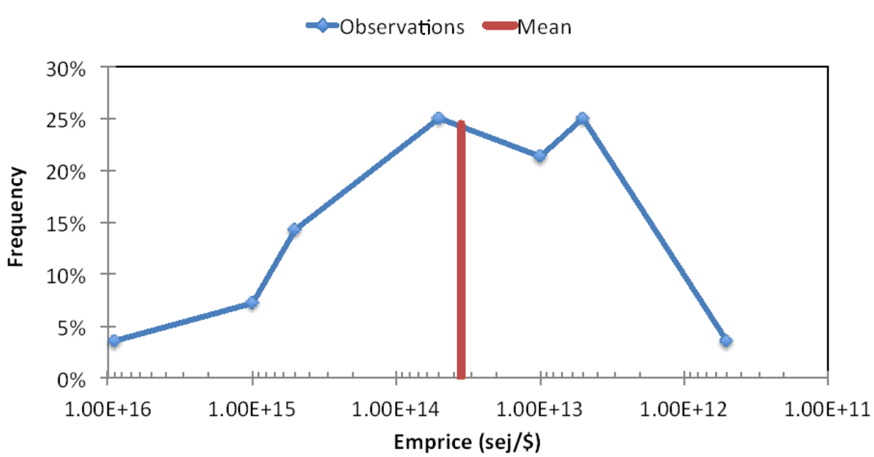
Note	Item	Eco-price (sej/$)	Reciprocal of Eco-price ($ per quadrillion solar emjoules)
	Carbon Sequestration		
1	European Carbon Ex. emprice	3.54E+13	18.9
2	Chicago Carbon Ex. emprice	5.06E+14	2.5
3	Timber market price	3.50E+12	285.6
	Average for Carbon	**1.82E+14**	**102.3**
	Water Quality & Quantity		
4	Stormwater mitigation: NY Watershed Protection	7.34E+12	136.3
5	Groundwater recharge: Municipal Water	8.23E+12	121.5
6	Chesapeake Bay Clean Water Act	9.32E+12	107.3
7	Nutrient Trading in Chesapeake Bay Watershed	4.88E+11	2048.7
8	Water Quality BMP Cost Share Program	1.09E+13	91.7
	Average for Water	**7.26E+12**	**501.1**
	Soil Genesis		
9	Erosion Prevention: Cost of Fill Dirt	1.53E+14	8.6
10	Soil Carbon: Cost of Mulch	7.54E+12	101.5
	Average Soil	**8.01E+13**	**55.0**
	Air Quality		
11	Air Pollutant Removal: Clean Skies Act	1.14E+13	87.7
12	Medical and Environmental Cost of Air Pollution in Maryland	3.88E+12	257.6
	West Virginia Tax on Air Pollutants		
13	NO3-N	2.83E+14	3.5
14	NH4-N	5.83E+13	17.1
15	S in Wet/Dry Dep	6.58E+15	0.2
16	Cl in Wet/Dry Dep	5.46E+14	1.8
	Average Air Quality	**7.64E+12**	**172.6**
	Pollination		
17	Pollination by Wild Insects	1.30E+13	77.0
	Biodiversity		
18	Maryland Environmental Trust	4.71E+12	212.3
19	Conservation Fund	3.80E+12	345.1
	Average Biodiversity	**4.26E+12**	**279.0**

Weighted Average for Specific Eco-prices	**8.75E+13**	**82.4**
Average of All Eco-prices	**3.06E+14**	**177.8**

See Appendix 2 for footnotes to estimates



(A)



(B)

Figure 7.1. Rank order (a) and frequency distribution (b) of the eco-prices (sej/$) evaluated. The mean (3.5E13 sej/$) was based on the log transformed eco-price.

7.3. Mean Eco-prices from Specific Ecosystem Service Approach

The eco-prices ranged from 0.49E12 sej/$ for nutrient trading to 6500E12 sej/$ for sulfur deposition, which is a range of 13,000 or over four orders of magnitude (Figure 7.1a). Due to the wide range and skewed distribution of the eco-prices (Figure 7.1a), we log transformed the data to create a frequency distribution (Figure 7.1b). The frequency distribution was nearly bell-shaped with a mean of 35E12 sej/$. Due to the hierarchical property of energy flow through energy chains (see Tilley's 1999 example for wood products in the section above), a logarithmic distribution was expected for eco-prices. There were a few very large eco-prices associated with air quality and soils with the majority of them falling within the range of 1E12 to 10E12 sej/$ (Figure 7.1a). The mean of the log transformed distribution gives an expected eco-price for ecosystem services in general. The mean can be useful when more specific eco-prices cannot be estimated for lack of data or a proper model.

7.4. Natural Resource Commodity Markets for Dynamic Eco-Prices of Ecosystem Services

The EIC concept might enjoy more popularity if the eco-prices for the ecosystem services were more dynamic than is possible with the specific ecosystem service approach given in Table 7.1. The specific ecosystem service pricing explained above does not have a mechanism for correcting the eco-prices of services on an hourly, daily, weekly, or monthly basis. Likely, changes to the specific ecosystem service eco-prices would require an expert committee to meet to discuss and agree on changes. Thus, this is a shortcoming of employing the specific ecosystem service method for eco-pricing.

Table 7.2. Natural Resource Commodity Market-based Ecosystem Service Eco-prices

Note	Item	Eco-price (sej/$)	Reciprocal of Eco-price ($ per quadrillion solar emjoules)
20	Coal	1.29E+13	77.5
21	Rock, sand, gravel, clay	1.53E+14	8.6
22	Timber Harvest	4.82E+12	207.5
23	Natural gas	1.06E+13	94.8
24	Total petroleum	5.00E+12	200.0
25	Electricity	5.59E+12	17.6
26	Copper	3.54E+13	28.3
27	Corn	3.96E+12	252.4
28	Wool	6.03E+12	165.9
	Arithmetic mean	2.64E+13	37.9
	Log-transformed mean [10^(mean of the log)]	1.10E+13	90.8

See Appendix 2 for footnotes to estimates

One way to overcome the limitation of non-dynamic pricing would be to tie the eco-price to actively-traded, allied resources or goods. The Natural Resource Commodity Market eco-pricing (henceforth, Commodity eco-pricing) estimates eco-prices based on the emergy-to-dollar ratio of ubiquitous and frequently traded commodities, such as electricity, gasoline, crude oil, natural gas, copper, timber, corn and wool. The mean eco-price of this "basket" can then be used to translate the solar emergy flow of ecosystem services to fair payment prices that can be paid to land stewards.

If eco-prices were tied to actively traded market commodities then the eco-prices could be adjusted on a more timely basis and without a top-down approach required by the specific ecosystem service method. A disadvantage may be that eco-prices would fluctuate so much that land stewards could not be guaranteed a stable or minimum price.

The justification for Commodity eco-pricing is that both ecosystem services and natural resource commodities are generated from nature. When natural resources are extracted from the earth that is their first step into the economic system and the first time that money is exchanged for them, which sets a market price. Since ecosystem services are generally not traded and thus do not have market prices, the Commodity eco-pricing provides a proxy pricing mechanism.

7.4.1. Eco-prices for Natural Resource Commodity Market method

The basic construction materials of rock, sand, gravel and clay had the highest eco-price of the natural resources used in the Commodity approach (Table 7.2). Their eco-price was 153E12 sej/$ or a reciprocal eco-price of $8.6/quad-sej, which was equivalent to the eco-price for erosion prevention (Table 7.1).

Copper had the second highest eco-price. The commodity trading value of copper was $4.09 per lb on June 2, 2011, which provided an eco-price of 35.4E12 sej/$, which equaled the mean eco-price of ecosystem services derived according to the specific ecosystem service approach.

Timber had one of the lowest eco-prices of the natural resources used in Commodity approach (Figure 7.2). The commodity trading value of timber was $235 per 1000 board feet on June 2, 2011, which provided an eco-price of 4.8E12 sej/$, or reciprocal of eco-price of $207.5/quad-sej. Arguably, the fair payment price form most forest ecosystem services should be priced using this eco-price of timber.

Corn had the lowest eco-price of all the natural resources used in the Commodity approach (Figure 7.2). The futures contract for corn delivered in May 2012 was $7.66 per bushel on April 10, 2012, which provided an eco-price of 3.96E12 sej/$, or reciprocal of eco-price of $252.4/quad-sej.

The majority of the Commodity-based eco-prices fell within the range of 4E12 to 11E12 sej/$ (Figure 7.2). However, due to the skewness of the eco-prices, the arithmetic mean was 26.4E12 sej/$. Rather than use the arithmetic mean, we took the log-transformed mean 11E12 sej/$ as the best estimate of the Commodity eco-price. This was lower than the log-transformed mean of the Specific Ecosystem Service method of 35E12 sej/$. Since the fair payment price is found by dividing the solar emergy (sej) by the eco-price (sej/$), a lower eco-price gives a higher fair payment price than a higher one.

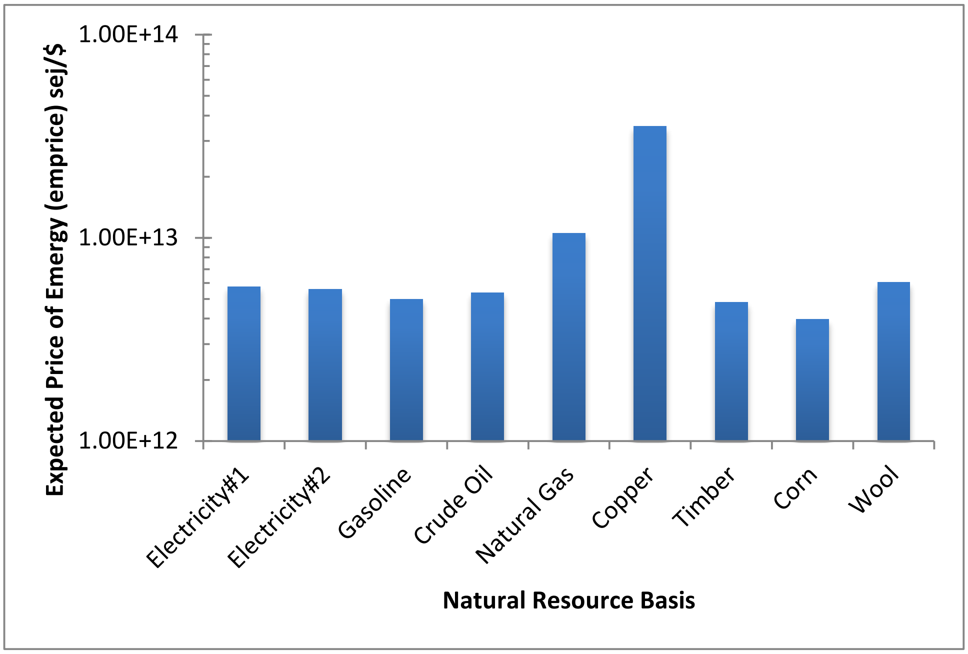


Figure 7. 2. Expected eco-prices (sej/$) for various commodities (June 2011) used in the Natural Resources Commodity Market approach.

8. Emergy Analysis of the State of Maryland

The emergy analysis of Maryland provided an overview of the value of the various inputs that drive the state's ecology and economy (Figure 8.1). This quantitative context is necessary to better understand the values of the individual ecosystem services presented in the report.

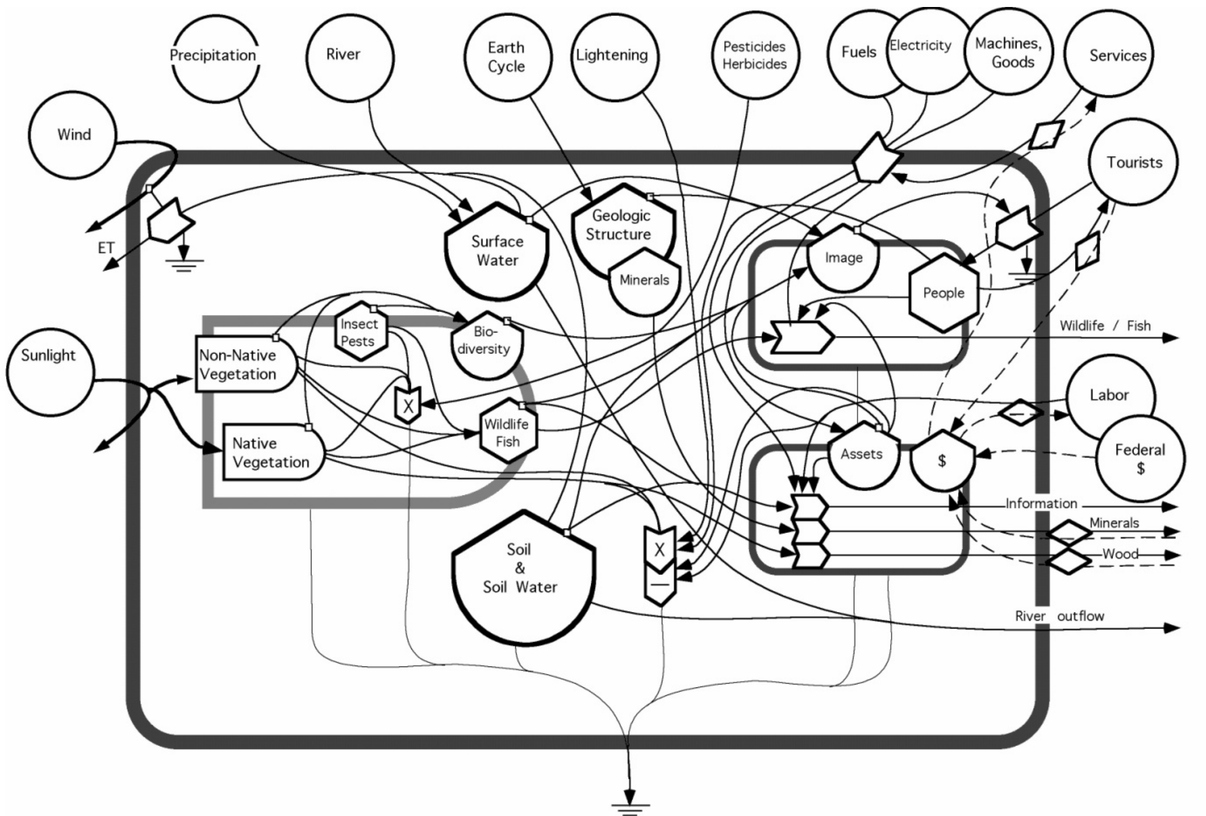


Figure 8.1. Energy Systems Language Diagram of Maryland showing the environmental and economic flows into, out of, and within the system. Flow labels correspond to expressions in Table 8.2.

The emergy analysis of Maryland started by Sherry Brandt-Williams, Erika Felix and Daniel Campbell of the US Environmental Protection Agency in 2002 was completed as part of this project. The USEPA has conducted emergy analyses of West Virginia and Minnesota as part of its effort to better understand the ecological economics of resource rich states (Campbell et al. 2005, Campbell and Ohrt 2009). A state emergy analysis serves to characterize the state, its economic flows, non-renewable consumption and its renewable energy base.

Maryland's emergy flows for 2000 are summarized in Table 8.1. The State had $13 billion of ecological value flow through that was derived from renewable resources such as rain, wind, waves, tides and rivers. However, the State only captured $10.5 billion of the total throughflow. These values were based on the US emergy-to-dollar ratio of 1.07E12 sej/$, which means the values are the mean contribution these ecological resources would make to the nation. Later, the contribution of various emergy flows in Maryland to the State's well-being are given in Table 8.2 by using the emergy-to-dollar ratio of 2.82E12 sej/$, which was Maryland's average for 2000.

Indices that describe some of the most important relationships between then environment and economy in Maryland are summarized in Table 8.2. Renewable resource consumption added $4.9 billion to the state economy in 2000, while non-renewable resources imported into the state ($160 billion) added much more. Non-renewable resources from within the State added another $15.5 billion (Table 8.2). Maryland derived 11.3% of its annual wealth from its in-state emergy flows. Only 2.7% of the total emergy was from renewable flows. Without importing vast amounts of energy and resources from around the world, Maryland would be forced to support itself on $20.4 billion per year.

In 2000, the Environmental Loading Ratio was 33:1, which meant that by importing a tremendous amount of solar emergy, Maryland added a heavy environmental load to its natural environment.

The footnotes for the calculations in Tables 8.1 and 8.2 are given in Appendix 1.

Table 8.1: Emergy evaluation of Maryland in 2000.

Note	Description	Data	units/yr	Emergy E19 sej/yr	Public Benefit to US Billion $ 2000
	Renewables				
1	Solar irradiance	1.93E+19	J	2	0.02
2	Wind	1.67E+18	J	246	2.23
3	Tides	1.10E+17	J	266	2.42
4	Rain, Chemical Potential	4.11E+17	J	743	6.76
5	Transpiration (ET)	7.56E+16	J	212	1.93
6	Rivers used, Chemical potential	1.88E+17	J	343	3.12
7	Rain received, Geopotential	4.57E+16	J	47	0.43
8	Rain used, Geopotential	2.59E+16	J	71	0.64
9	Runoff	1.98E+16	J	54	0.49
10	Rivers, Geopotential	6.41E+16	J	174	
11	Waves	4.28E+16	J	128	1.17
12	Earth Cycle	4.00E+16	J	135	1.23
	Renewables received (Rain chemical + tides + waves + River chemical)			1389	13.0
	Renewables, total used (ET + River chemical + River geo + waves + tides)			1124	10.5
	Economic and non-renewables, produced or extracted				
13	Waste treatment	7.44E+12	g	29	0.26
14	Soils	2.79E+15	J	20	0.18
15	Coal	1.21E+17	J	475	4.32
16	Rock, sand, gravel, clay	-	g	2059	18.72
18	Timber	7.99E+17	J	535	4.87
19	Natural gas	3.74E+13	J	0	0
22	Building materials	5.54E+12	g	<0.01	<1
23	Grains, fruits, vegetables	5.88E+16	J	1545	14.04
24	Paper products	0.00E+00		-	-
25	Electricity	1.75E+17	J	2799	25.45
26	Synthetic chemicals, plastics	3.23E+08	g	<0.01	<1
27	Textiles	1.03E+12		0.45	0.0
28	Aquaculture, fishing	6.45E+13	J	28	0.26
29	Meat, Dairy, Eggs	6.42E+14	J	41	0.37
30	Heavy Machinery	2.59E+11		173	1.58
					70.5

Table 8.2 Emergy Analysis Summary Table for Maryland in 2000

Item	Name of Index	Expression	Maryland	units	Maryland Public Value Billions $
1	Renewable Use	R	1.39E+22	sej/yr	4.9
2	In-state Non-renewable	N0 + N1	4.38E+22	sej/yr	15.5
3	Imported Emergy	F + G + PI	4.51E+23	sej/yr	159.9
4	Total Emergy Inflows	R + F + G + PI	4.64E+23	sej/yr	164.5
5	Total emergy used U=R+N0+F2+G+PI	U	5.08E+23	sej/yr	180.1
6	Total exported emergy	B+PE3	3.27E+23	sej/yr	116.0
7	Emergy used from home sources	(N0+F3+R)/U	11.3%		
8	Imports-Exports	(F+G+PI)-(B+PE3+N2)	1.23E+23	sej/yr	43.6
9	Ratio of export to imports	(B+PE3+N2)/(F+G+PI)	0.73		
10	Fraction used, locally renewable	R/U	2.7%		
11	Fraction of use purchased outside	(F + G + PI)/U	0.89		
12	Fraction used, imported service	PI/U	0.18		
13	Fraction of use that is free	(R+N0)/U	0.0273		
14	Ratio of purchased to free	(F2+G+PI)/(R+N0)	35.7		
15	Use per unit area	U/Area	1.58E+13	sej/m^2	
16	Use per person	U/Population	9.59E+16	sej/person	
17	Renewable Carrying Capacity at present standard of Living	(R/U)(Population)	1.42E+05	people	
18	Developed Carrying Capacity at same living standard	8(R/U)(Population)	1.14E+06	people	
19	State Econ. Product	GSP	1.80E+11	$/yr	
19	Ratio of emergy use to GSP	U/GSP	2.82E+12	sej/$	
20	Ratio of emergy use to GNP US	U/GNP	1.07E+12	sej/$	
21	Ratio of Electricity to Emergy Use	el/U	0.0587		
22	Fuel Use per Person	F2/Population	1.61E+16	sej/person	
23	System Environmental Loading Ratio		33		
24	System EYR		1.13		
25	Emergy Sustainability Ratio		0.034		
26	Investment Ratio		4.55		
27	Area		3.21E+10	m^2	
28	Population		5.30E+06	individuals	

9. Ecosystem Services of Maryland's Forests

Figure 9.1 captures some of the complexity associated with how the ecological functions of the forests of Maryland support economic and social activities as well as the quality of the human and natural environment. The biologically diverse vegetation and wildlife of the forest work together to process dilute planetary energies to build rich moist soils. The economic and social activities operate on huge amounts of imported fuels, electricity, goods, services and tourism which are matched with the multiple flows of energy from the forest. Many types of waste are recycled unintentionally from the economy to the forest where they are often processed and made benign. In addition to enjoying many indirect benefits of the forest's ecological functions, a portion of Maryland's economy is directly tied to forestry and forested lands.

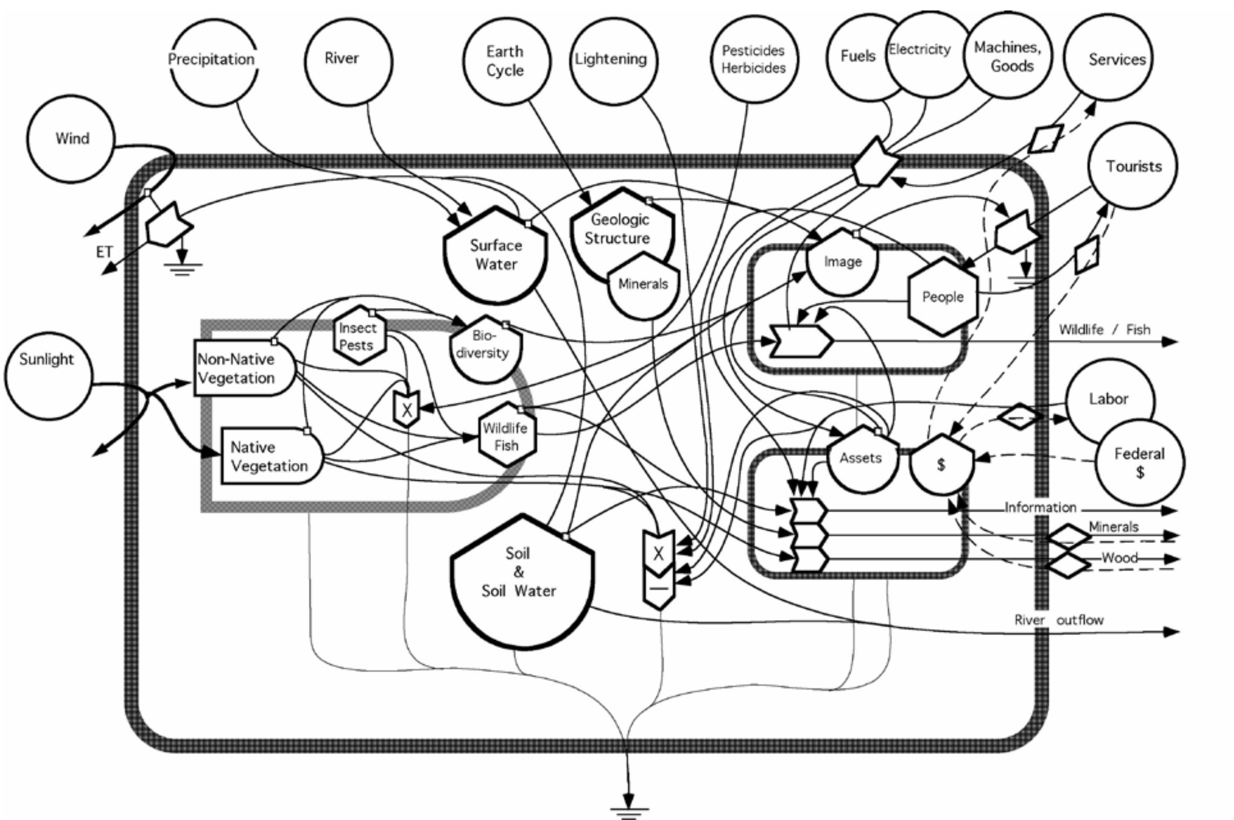


Figure 9.1. Overview systems diagram of the multiple ecosystem services provided by the forests of Maryland.

10. Carbon sequestration Model

The importance of carbon sequestration and the role that forests play in the global carbon cycle has become evident in the last 30 years as climate change research has progressed. Expanding global forests is one of the easiest ways to mitigate CO_2 emissions.

The systems diagram in Figure 10.1 represents how carbon is stored in a forest ecosystem, its movement through the ecosystem, and the energy sources that drive this process. Carbon is removed from the air through photosynthesis, a process driven both by sun and wind (which contributes to transpiration). Carbon can either be returned to the atmosphere through respiration or stored within the biomass of the plant, either in the body of the plant or the roots. Carbon moves from the plant to the soil either through death of the body of the plant or its roots either by natural causes, disease/pests or soil erosion. Pruning of limbs through wind or natural death and leaf fall also moves carbon from the plant to the soil. Within the soil, carbon can be respired and put back into the atmosphere through the activity of the soil microbial community, taken back up by the plant community, or lost to the system through soil erosion. Long-term storage of carbon occurs in wood, roots, and soils of the forest (Figure 10.1).

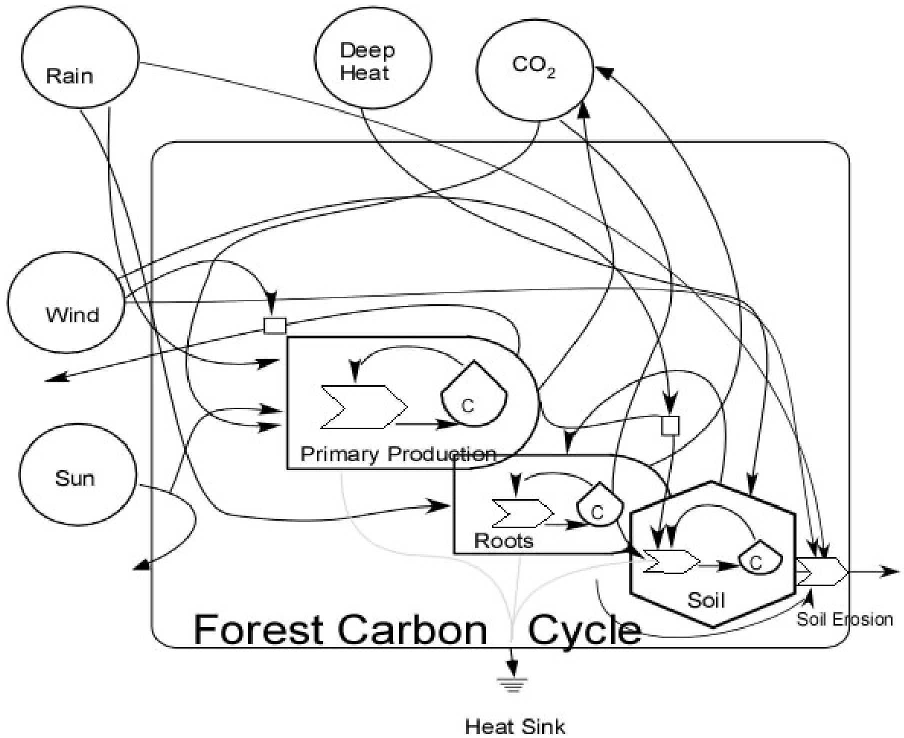


Fig. 10.1. Energy Systems Diagram detailing Carbon storages and energy flow-through in a typical Maryland Forest.

10.1. Data Collection

Data from the USFS Forest Inventory Analysis database suggested that during an average year 1.5 MT of carbon was sequestered on an average hectare of forested land in Maryland. While this number certainly varies by dominant tree species, soil quality, and climate, making a fine scale calculation of this variability was beyond the scope of this study. However, a field study was conducted to determine how carbon stocks varied in Maryland according to their physiographic region and surrounding land-use.

Field work was conducted during the summer of 2009 for five forest sites located in three physiographic regions of Maryland (i.e., Appalachian, Piedmont and Coastal Plain). The sites also represented natural forest, urban forest, and restored forest. Standard forestry methodology was used at 15 randomly generated 1/10th acre plots in each study area to assess tree species and diameter at breast height (dbh). The sample location within a forest was randomly generated using ArcMap. Soil samples of the top 10 cm were taken at each plot. The organic content of the soil sample was estimated using the loss on ignition method (Schumaker, 2002). Collected field data was used in the Maryland Forest emergy evaluation to estimate the value of the ecosystem service of carbon sequestration.

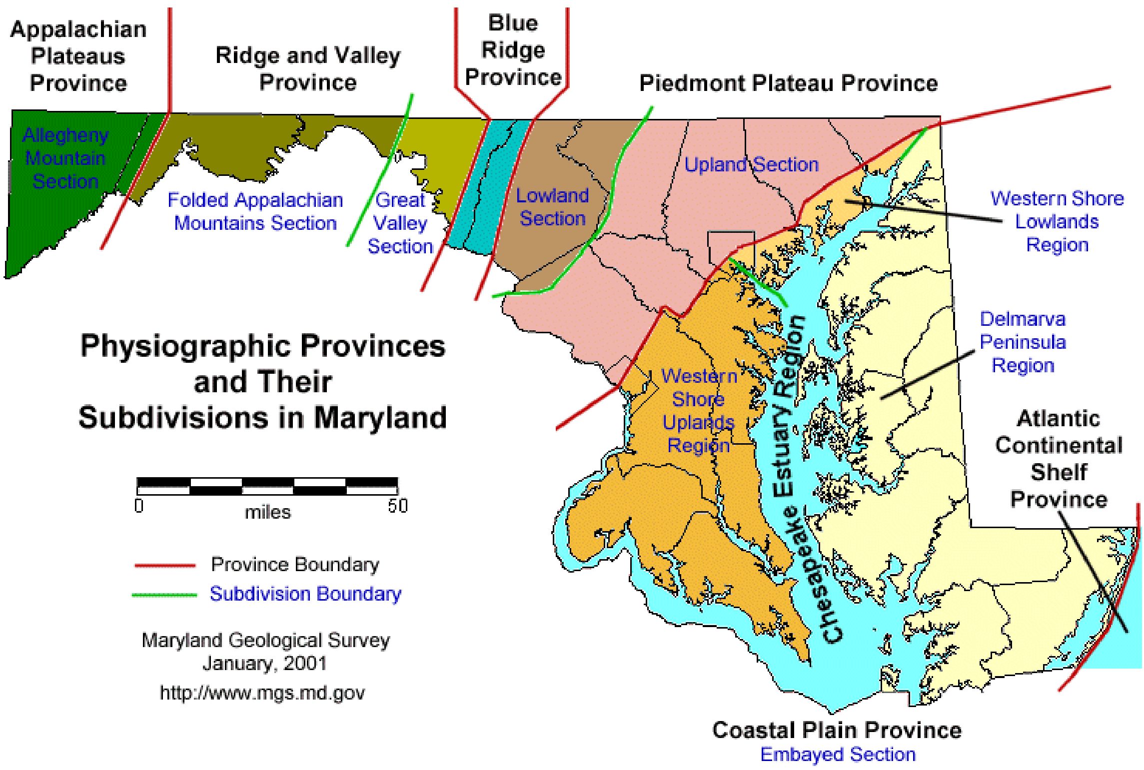


Figure 10.2. Map of Maryland's physiographic regions.

10.2. Parameter Estimate

Allometric equations (Jenkins et al., 2003) were used to calculate the carbon stored in each tree measured in the field. A conservative estimate of 1.5 MT/ha was used to assess the amount of carbon sequestered each year. USFS Forest Inventory Analysis (FIA) data and the Carbon Online Estimator (COLE, NCASI and USFS, 2010) were used to obtain carbon sequestration estimates for Maryland as a whole. COLE estimated carbon sequestration by forest type in all 50 states. Data on the forest types in Maryland was taken from the USFS FIA.

Carbon values were found by assuming that 50% of the total biomass was made of carbon (Lamlom and Savidge, 2003). The mass of carbon was converted to emergy units by converting the mass unit to its energy content (joules), and then multiplying the joules by the transformity of forest carbon (sej/J). Average wood density of 540 kg/m^3 and an energy content of 3.5 kcal/g were used to convert volume to mass and mass to energy.

10.3. Carbon and biomass in Maryland Forests

The field survey of three Maryland State Forests and two restored riparian forests found that the Appalachian Region had a higher density of biomass than the Coastal Plain or Piedmont (Table 10.1). The restored riparian forest had the least biomass, which was because it had only been restored 12 years before sampling. The values found in this survey were similar to values previously found for biomass in Maryland (USFS FIA, 2006). The Appalachian forest had more biomass and carbon than either the coastal plain or Piedmont forests (Table 10.1). The lower biomass found for Elvaton can be explained by the fact it was restored more recently.

Table 10.1. Biomass and carbon stored in aboveground biomass in sample forests of Maryland.

Physiographic Region	Forest	Condition	Observed Biomass MT ha^{-1}	USFS FIA Modeled Biomass MT ha^{-1}	Observed Carbon MT ha^{-1}	USFS FIA Modeled Carbon MT ha^{-1}
Appalachian	Savage River SF	Natural	233	124	117	62
Coastal Plain	Spring Branch	Restored Riparian	126		63	
Coastal Plain	Cedarville State Forest	Natural	153	180	76	90
Piedmont	Green Ridge SF	Natural	154	167	77	83
Piedmont	Elvaton	Restored Riparian	86		43	

10.4. Values of Carbon Sequestration

Forest sequestration of carbon provided $303 million of *public value* to the state's economic product each year. Recall that public value is based on the translation of the solar emergy joules (sej) of carbon sequestered to dollar value by dividing by the state's mean emergy-to-dollar ratio. On an area basis the forests' sequestration of carbon added the equivalent of \$300 ha^{-1} yr^{-1} (\$121 $acre^{-1}$ yr^{-1}) to the state economic product (Table 10.2).

Estimates of the *fair payment price* to be paid to land stewards ranged from \$4 ha-$forest^{-1}$ yr^{-1} to \$15.8 ha-$forest^{-1}$ yr^{-1} (\$1.62 acre $forest^{-1}$ yr^{-1} to \$6.39 acre $forest^{-1}$ yr^{-1}), depending on which eco-price was used (Table 10.2). The Commodity method gave the highest payment price, while the Mean Ecosystem Service Equivalency gave a middle value of \$9.2 ha-$forest^{-1}$ yr^{-1} (\$3.7 acre $forest^{-1}$ yr^{-1}) and the Specific Ecosystem Service Equivalency gave the lower value of \$4 ha-$forest^{-1}$ yr^{-1}.

Table 10.2. Public value and fair payment prices for forest sequestration of carbon (multiply \$/ac/y by 2.5 to determine \$/ha/y).

Carbon Sequestration	Maryland (million \$ per yr)	Per Area (\$ per ac per yr)
Public Value	\$300.0	\$121.41
Commodity Price	\$15.8	\$6.39
Mean Ecosystem Service Price	\$9.2	\$3.72
Specific Ecosystem Service Price	\$4.0	\$1.62

10.5. Tree diversity in Maryland Forests

The highest average species richness and Shannon-Wiener Diversity Index was found at the Elvaton sites, a restored riparian forest (Table 10.3). The lowest species richness and Shannon-Wiener Diversity Index was found at Spring Branch, also a restored riparian forest. Spring branch was restored 12 years prior to sampling, while Elvaton had been restored 2 to 5 years before sampling. On average there were 8.3 tree species per site, which were of equal area (Table 10.3).

Table 10.3. Tree diversity at sampled forests (1000 m^2).

Physiographic Region	Forest	Condition	Mean Tree Species Richness (#)	Shannon-Weiner Diversity Index
Appalachian	Savage River SF	Natural	7.7	1.44
Coastal Plain	Spring Branch	Restored Riparian	6.3	1.38
Coastal Plain	Cedarville State Forest	Natural	8.7	1.65
Piedmont	Green Ridge SF	Natural	8.5	1.61
Piedmont	Elvaton	Restored Riparian	10.5	2.10
Mean			8.3	

10.6. Discussion

The public value is natural wealth that is created for the entire state and all of its citizens and visitors to enjoy. The estimate of the public value of carbon sequestration assumed that the amount of solar emergy consumed by a forest as it grew and took up carbon dioxide had a dollar value equivalent to the mean dollar value of solar emergy for the entire Maryland economy.

Land stewards should not be paid the full public value because there would be no value differential between the public value and the fair payment price. As described in the Introduction and Background on Emergy and Money above, the energy hierarchy of ecological economic systems produces a situation whereby a small amount of money circulates as a countercurrent to a resource as it is taken from the environment and enters the economic system. By the time the resource has been processed through its various agricultural, mining, refining, manufacturing, and wholesale and retail transactions to reach final consumption, there is much more money circulating in the countercurrent and therefore a higher dollar price for its emergy. For example, a mineral such as copper will undergo increases in its dollar value (i.e., $/gram) as it is mined, refined and made into a commercial product, such as copper pipe. The mining corporation is paid based on the price of copper in the Earth, not on its price as pipe. By analogy the ecosystem service should have a final consumption value, similar to the value of a commodity like copper pipe (i.e., its public value), and its "primary value" like copper in a mineral deposit.

The three techniques developed here for estimating the "primary value" of ecosystem services gave the amount of money that should be paid to land stewards who produce ecosystem services, which serve as the "primary" sources of emergy for the ecological-economic system. We call this the fair payment price.

The Ecological-Economic Return on Private Investment (EERPI) indicates how well the investment in the EIC creates public value. For carbon sequestration the EERPI ranged from 75 to 19, indicating that the EIC investors create a lot of public value for their investment.

11. Hydrologic Ecosystem Services

Forest lands provide a benefit to the coupled systems of man and nature in the form of market services, societal services and ecosystem services. A large portion of this benefit comes from the positive impact that forests have on water quality and quantity, which are the hydrologic ecosystem services. Three important hydrologic ecosystem services are 1) nutrient/pollutant removal, 2) stormwater runoff mitigation, and 3) groundwater recharge. This research focused on the hydrologic systems of the Piedmont and Coastal Plain regions in Maryland, which had either forested or urban land-uses. The urban land-use was defined as areas with greater than 40% impervious cover, which is typical of urban/suburban conditions in Maryland.

The forest services of groundwater recharge, stormwater mitigation and nutrient removal were valued as the difference between the rates of emergy flow in a forested watershed and an urban watershed.

11.1. Emergy-hydrologic Model (SoilAqDyn)

The emergy-hydrologic model SoilAqDyn was developed to simulate the emergy associated with groundwater flows and stormwater runoff in forested and urban systems in either the Piedmont or Coastal Plain physiographic regions (Figure 11.1). The emergy value of water associated with each part of the surface and sub-surface was given solar transformities according to the residence time of water. The solar transformity increased as the residence time of the water increased from the surface to the sub-surface (Buenfil 2000).

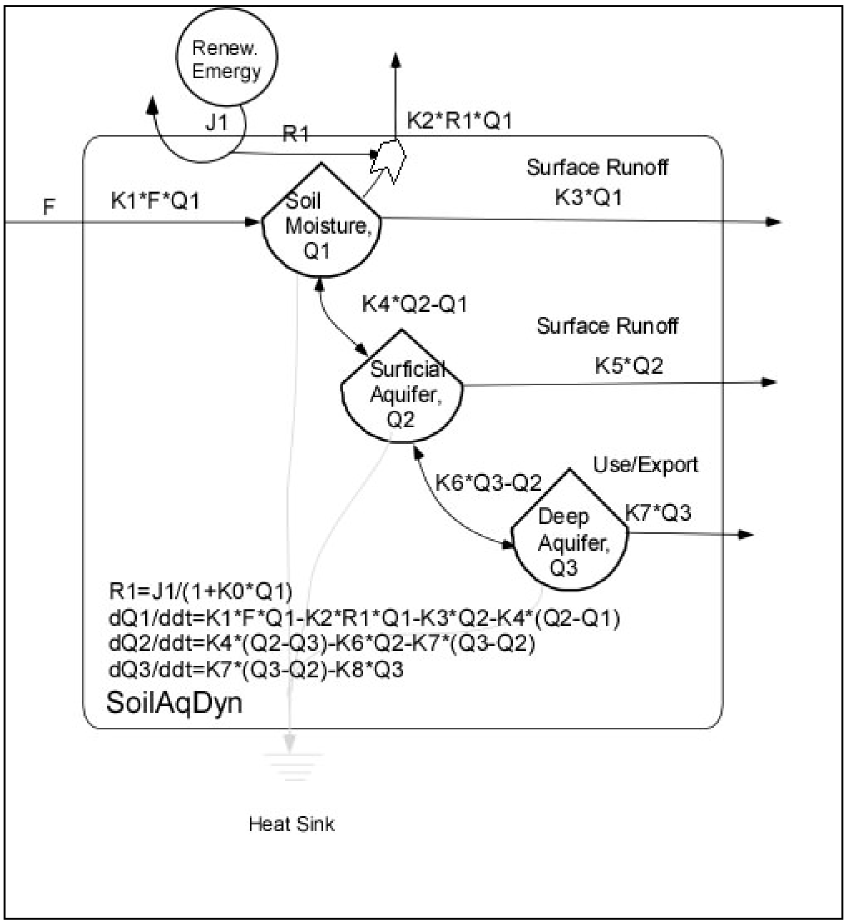


Figure 11.1. Energy Systems Language diagram of the SoilAqDyn with the equations used to simulate it. Parameter values are given in Table 11.1.

11.1.1. Data collection and Parameter estimates

SoilAqDyn was simulated in Microsoft Excel™. Data for SoilAqDyn was taken from two USGS weather stations, in the Piedmont and Coastal Plain Provinces of Maryland. When up-scaling the ecosystem services for the state as a whole rainfall data was obtained from NOAA.

Table 11.1. Initial Conditions and parameter estimates for *SoilAqDyn* in Figure 11.1.

Initial Conditions	Piedmont		Coastal Plain	
	Forest	Urban	Forest	Urban
Q1=	16	12	16	12
Q2=	375	375	308	308
Q3=	45	45	2000	2000
F=	variable	variable	variable	variable
J1=	0.2	0.2	0.2	0.2
Parameters				
K0=	0.625	0.625	0.625	0.625
K1=	0.0625	0.3	0.0625	0.1
K2=	0.625	0.483333	0.625	0.491667
K3=	0.25	0.5	0.2	0.491667
K4=	2.79E-05	1.38E-05	3.42E-05	1.68E-05
K5=	0.0001	0.0001	0.0001	0.0001
K6=	2.53E-05	2.53E-05	3.08E-05	3.08E-05
K7=	-1.5E-05	-1.5E-05	2.96E-06	2.96E-06
K8=	0.000111	0.000122	2.5E-06	0.00008

Parameters for SoilAqDyn, such as rate of runoff, infiltration and transpiration were estimated using the existing literature, particularly the USGS groundwater atlas (USGS 2009) and a forest hydrology textbook (Chang 2006) (Table 11.1). Rainfall rate (F) was taken from USGS weather station data for the calendar year of 2009.

The hydrologic outputs of SoilAqDyn were transformed to solar emergy to value the hydrologic ecosystem services that forests provide. The ecosystem service was defined as the difference between the solar emergy of the hydrologic flow (i.e., groundwater recharge or stormwater runoff) in the urban and forest systems.

11.1.2. Stormwater Mitigation

SoilAqDyn was also used to model the runoff from a single storm event in forested and urban watersheds (Figure 11.2). Only the surface and near-surface storages were needed to model storm runoff, otherwise SoilAqDyn was not altered. However, the time step for SoilAqDyn had to be shortened to an hourly basis, whereas daily rainfall data had been used to model groundwater.

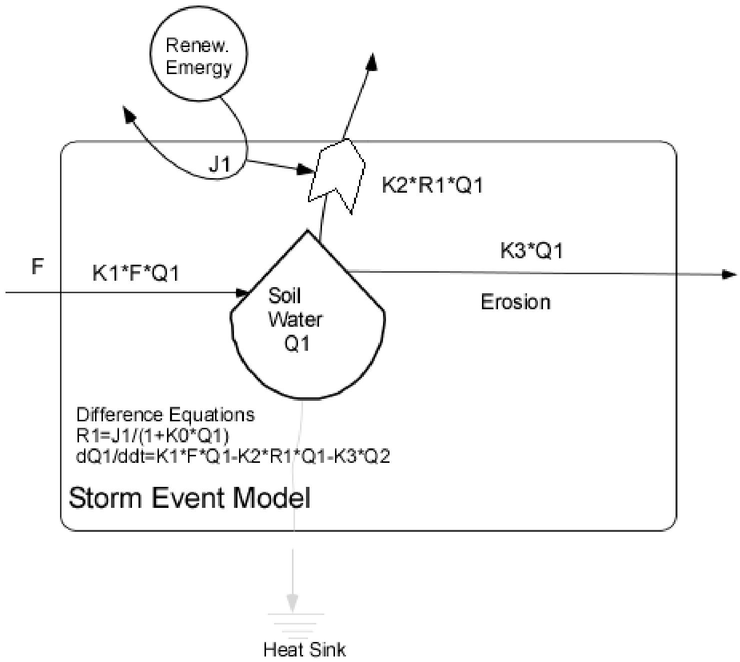


Figure 11.2. Energy systems language model of a 48 hour storm even with difference equations.

11.1.3. Validation of SoilAqDyn

The hydrology of SoilAqDyn was validated by comparing modeled water storage with observed water levels at a USGS station in Baltimore County, which is in the Piedmont region (Figure 11.3). While SoilAqDyn did not match perfectly with observed values, the general trend and minimum observed during April (i.e., ~Day 125) corresponded.

11.2. Groundwater storage and suppressed storm runoff

SoilAqDyn was used to simulate daily water storage in forested Piedmont, urban Piedmont, forested Coastal Plain and urban Coastal Plain watersheds (Figure 11.3a). More water accumulated in the forested soils than in the urban ones (1.59 cm vs. 0.87 cm). Forest lands were found to store 50% more water than urban lands and allow for 34% more ground water recharge. Land use was more important in determining sub-surface water storage than physiographic region (Figure 11.3a). Given the same land use, however, the Piedmont tended to store more water than the Coastal Plain.

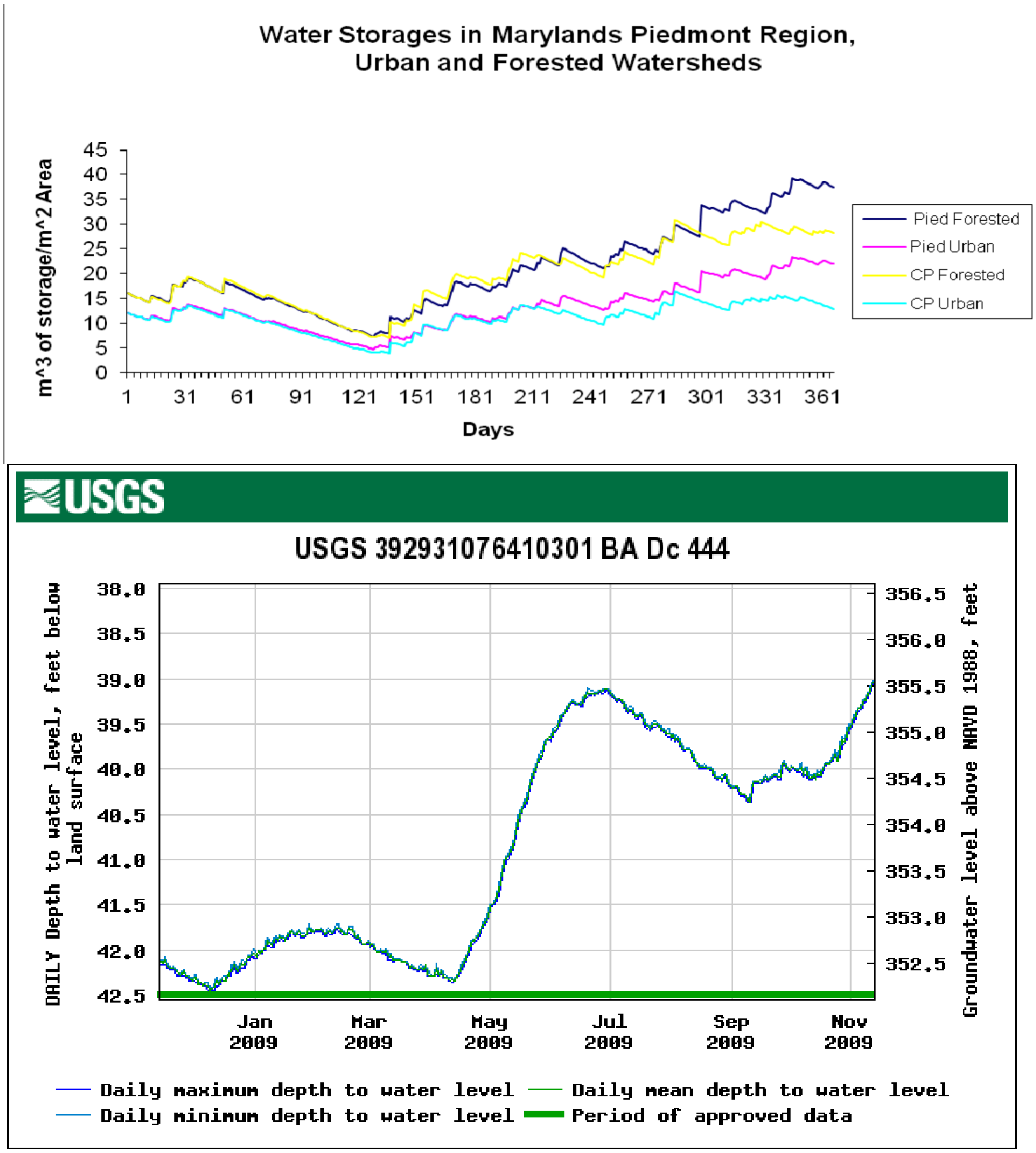


Figure 11.3. Modeled (a) and observed (b) groundwater storage for Maryland piedmont regions. Monitoring station is in Baltimore County.

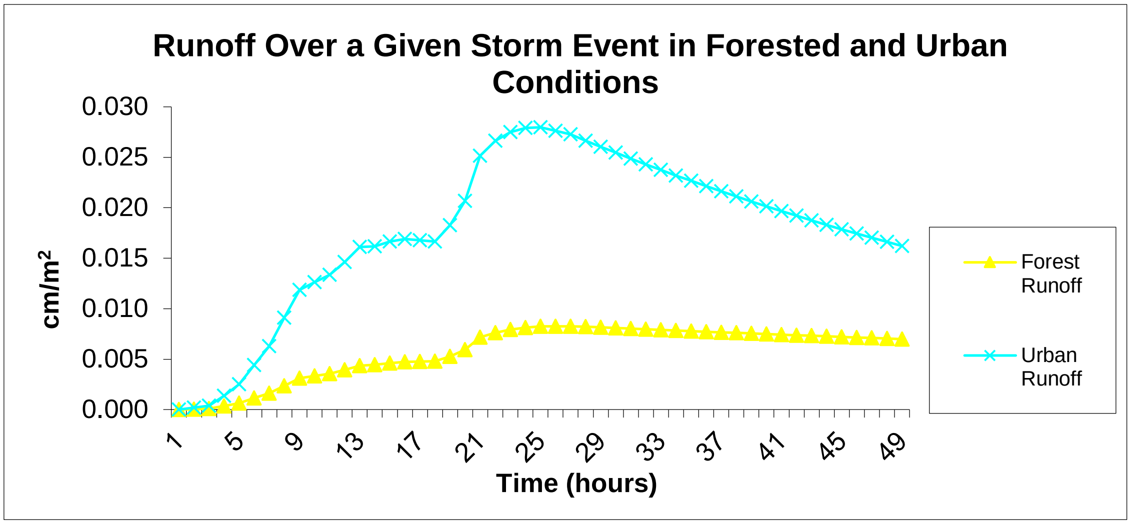


Figure 11.4. Prediction of storm runoff from forested and urban watersheds using SoilAqDyn and assuming a 48-hour storm event.

Less runoff was generated from the forested watershed than the urban watershed (Figure 11.4). Thus, the forests, by dampening the discharge from a storm, lessened the negative effects of high storm flows, like accelerated erosion, and the need for larger public works.

11.3. Nutrient Removal Model

Nutrient uptake was calculated using literature values for the amount of nitrogen and phosphorus removed by forests on a yearly basis. Goodale et al. (2002) used USFS FIA data to estimate nitrogen uptake in the watersheds of the eastern United States. We used this data to obtain an average for Maryland of 11 kg N/ha/yr. Yanai (1992) found that typical Northeastern hardwood forest took up 9.6 kg P/ha/yr; this number was assumed to be consistent with Maryland forests. We assumed that urban lands had a net zero nutrient balance, but realize that due to fertilizer application they would be sources of nutrients. Since the nutrient removal service was the difference in solar emergy of nutrient outputs from forest and urban systems, our estimates for the ecosystem service of nutrient uptake by forests are conservative estimates.

11.4. Value of Hydrologic Services

Table 11.2 summarizes the public value and fair payment prices for groundwater recharge in Maryland forest based on simulating SoilAqDyn. The groundwater recharge service was based on the additional water that recharged the aquifer due to forest cover rather than urban land cover. The greater recharge is affected by the greater permeability of forest soils compared to urban soils.

The public value of groundwater recharge by forests was $478 million in the State in 2000. The three estimates of the fair payment price ranged from $14.6 to $142 million per year assuming payments were made to all forest land stewards. On an area basis, the fair payment price ranged from $5.9 to $57.5 per acre per year. The specific ecosystem service price method gave the highest fair payment price. The EERPI was greater than three, indicating that investment in the EIC would benefit the public three times more than the cost of the payment.

Table 11.2. Public value and fair payment prices for the hydrologic ecosystem service of groundwater recharge (multiply $/ac/y by 2.5 to determine $/ha/y).

Value	Maryland (million $ per yr)	$ per Forested Acre ($ per acre per yr)
Public Value	$478.6	$193.7
Commodity Price	$25.0	$10.1
Mean Ecosystem Service Price	$14.6	$5.9
Specific Ecosystem Service Price	$142.0	$57.5

Table 11.3 summarizes the public value and fair payment prices for stormwater mitigation in Maryland forest based on simulating a single storm event in SoilAqDyn. The stormwater mitigation service was based on the reduction in surface runoff due to forest cover compared to urban land cover.

The public value of stormwater mitigation by forests was $717 million in the State in 2000 (Table 11.3). The three estimates of the fair payment price ranged from $21.8 to $238 million per year assuming payments were made to all forest land stewards. On an area basis, the fair payment price ranged from $8.8 to $96.3 per acre per year. The specific ecosystem service price method gave the highest fair payment price. The EERPI was greater than three, indicating that investment in the EIC to pay stewards for stormwater mitigation would benefit the public three times more than the cost of the payment.

Table 11.3. Public value and fair payment price for the hydrologic ecosystem service of stormwater mitigation (multiply $/ac/y by 2.5 to determine $/ha/y).

Value	Maryland (million $ per yr)	$ per Forested Acre ($ per acre per yr)
Public Value	$717.40	$290.3
Commodity Price	$37.40	$15.1
Mean Ecosystem Service Price	$21.80	$8.8
Specific Ecosystem Service Price	$238.00	$96.3

12. Soil Ecosystem Services

The soil ecosystems of forests play an important role in providing ecosystem services. They are the foundation for growth of primary producers, provide habitat for fauna, recycle nutrients, and sequester carbon, which is the building block for forest productivity. The properties of nutrient cycling and habitat provision are accounted for in other ecosystem service categories, so this section focuses on how forests build soil organic matter and reduce soil erosion.

12.1. Soil Carbon Model: ForSoilCarbon

The model *ForSoilCarbon* was constructed in order to simulate the carbon dynamics in forest and suburban soils (Figure 12.1). Vegetation is built up as flora, which feeds carbon to soil storage. Soil carbon can be eroded while flora can be lost from the system, bypassing soil.

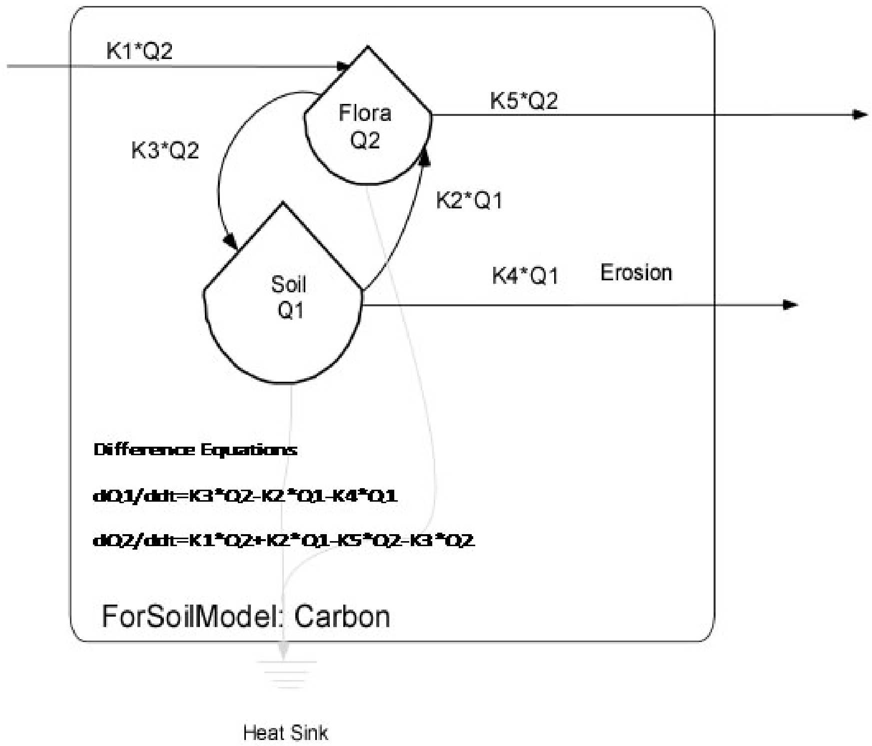


Figure 12.1. Model *ForSoilCarbon* for simulating soil carbon dynamics.

Table 12.1 Initial Conditions and parameters for F*orSoilCarbon*.

	Forest	Urban
Initial Conditions		
Q1	65	39
Q2	75	15
Parameters		
K1	0.0200	0.0188
K2	0.0067	0.0083
K3	0.0085	0.0110
K4	0.0001	0.0026
K5	0.0053	0.0125

12.1.1. Data Collection and Parameter Estimate

Table 12.1 gives the initial conditions and parameter values for *ForSoilCarbon*. Valuation of soil building relied on literature values for rates of organic matter accumulation on the forest floor in different forest types and how impervious surface cover affected the rate of organic matter accumulation. The COLE (Carbon Online Estimator) from the USFS was used to estimate storages and rates of carbon accumulation in different forest types.

The initial conditions in the *ForSoilCarbon* were derived from the COLE model for different forest types in Maryland. Initial conditions for ForSoilCarbon considered 1 ha of land and a 1 m depth of soil with a bulk density of 1.25 g cm^{-3}. Calibration to urban conditions assumed an impervious cover of 40% and 16% tree canopy, which were consistent with assumptions in i-tree Vue (2011).

12.2. Soil Erosion Model: ForSoilMineral

ForSoilMineral (Fig. 12.2) assumed that the accretion of soil comes from two emergy sources: forest productivity labeled as Renewable Emergy, and the mineral contribution from Parent Material. Erosion of soil was assumed to follow a first order rate process driven by the stock of soil mineral (Q1). Thus, the amount of emergy stored in soil is the balance of the two inputs and one output.

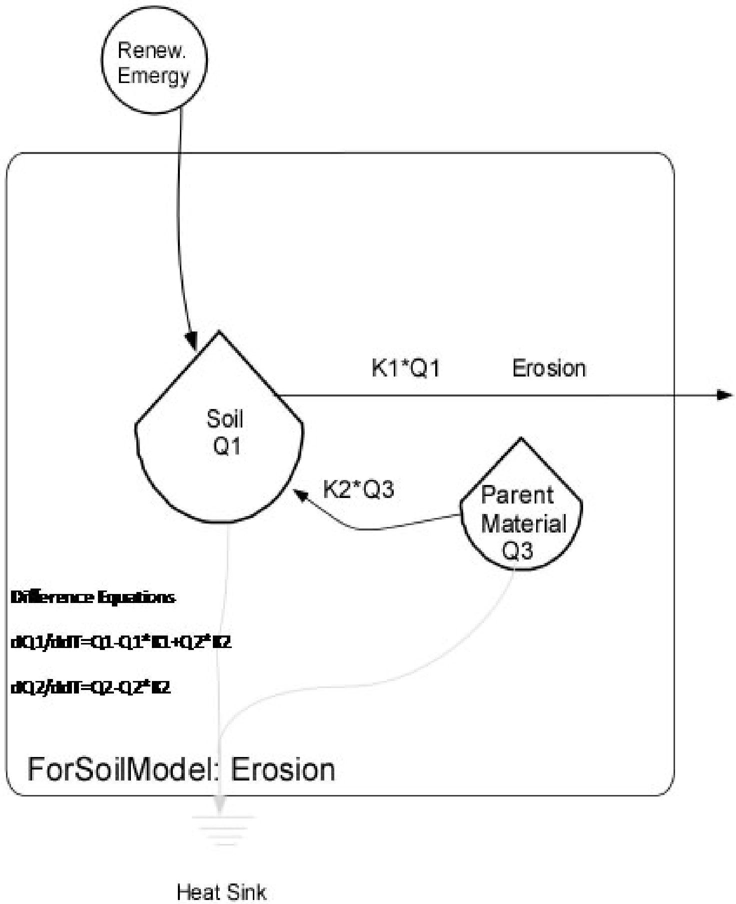


Figure 12.2. Model *ForSoilMineral* for simulating soil erosion in forest and urban areas.

12.2.1. Data Collection and Parameter Estimate

Erosion rates for *ForSoilMineral* for forest and suburban conditions were derived from the literature. The document *A Summary Report of Sediment Processes in Chesapeake Bay and Watershed* (Gellis et al., 2003), was research conducted and published by the USGS and a primary resource for determining erosion rates in Maryland.

Table 12.2 gives the initial conditions and parameter values for *ForSoilMineral*.

Table 12.2 Initial Conditions and parameters for ForSoilMineral.

	Forest	Urban
Initial Conditions		
Q1	12500	7500
Q2	100000	100000
Parameters		
K1	0.0000096	0.0004587
K2	0.0000005	0.0000003

12.3. Results

12.3.1. ForSoilCarbon

When soil carbon was simulated for a forested ecosystem it was shown to increase, while for an urban system soil carbon decreased over time (Figure 12.3). Over the 100 year period simulated soil carbon increased from 65 to 92 MT/ha in the forest, while urban soil carbon decreased from 39 to 34 MT/ha.

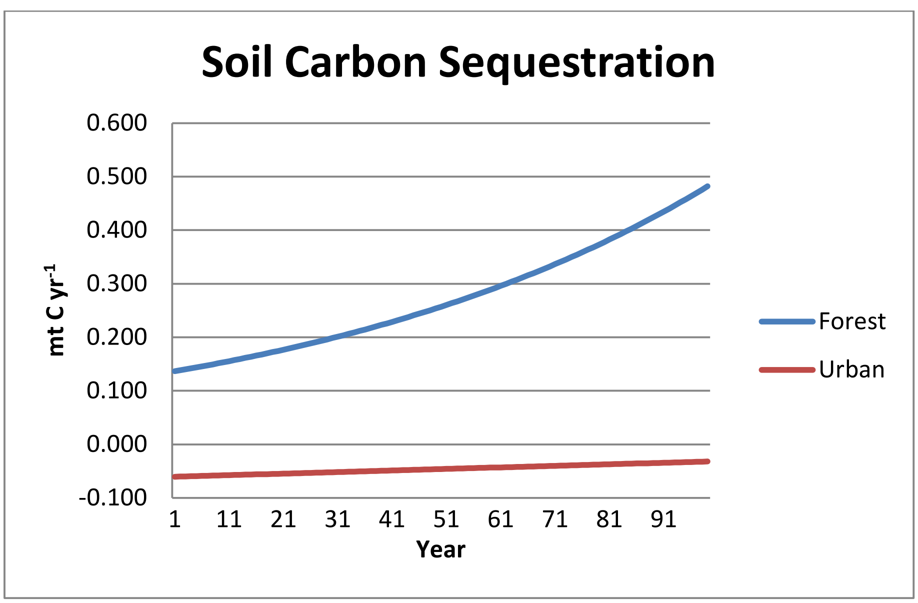


Figure 12.3. Simulated values of soil carbon using *ForSoilCarbon*.

12.3.2. ForSoilMineral

The annual rate of soil erosion in the urban system decreased from 3.4 to 3.26 MT-soil/ha/y over the 100-year simulation period (Figure 12.4). Soil erosion in the forest was nearly zero and remain unchanged during the 100-year simulation (Figure 12.4).

The storage of soil in the forest system went from 12500 to 12493 MT/ha in the 100-year simulation period while the urban soil storage decreased from 7500 to 7170 MT/ha. Thus, the urban landscape lost a much higher percentage of its soil.

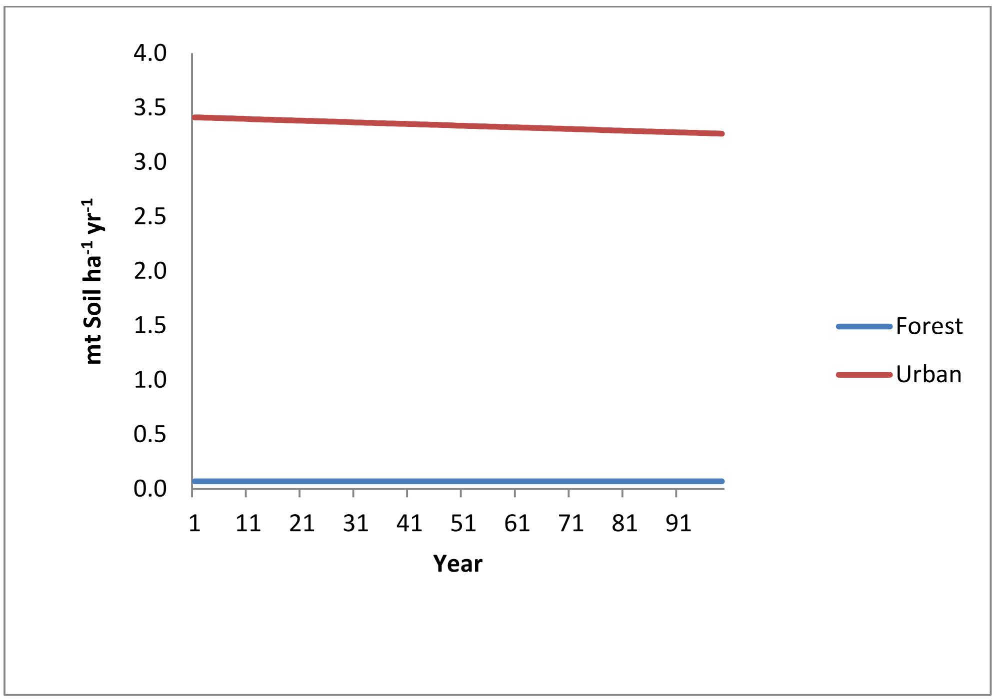


Figure 12.4. Simulated soil erosion in forest and urban systems. In the urban system soil erosion decreased but from a much higher level than in the forest system.

12.3.3. Valuing the Service

The ecosystem services of Soil Building and Erosion Prevention were both based on the difference in solar emergy flows between the completely forested soils and urban forest soils. Soil building was derived from the carbon build up in the ForSoilCarbon model. Erosion prevention was derived from the total mineral loss estimated by the ForSoilMineral model. The difference in solar emergy was multiplied by the appropriate eco-price of soil building or erosion prevention to derive the public value and three estimates of fair payment price.

The annual public value generated by all Maryland forests for soil building was estimated to be $219 million, while the public value for preventing soil erosion was nearly 10 times as much at $2112 (Table 12.3). On an area basis, these two values translated to a mean of $89/ac/y and $854/ac/y, respectively (Table 12.3).

Three fair payment values were estimated for each of the two soil-based ecosystem services. For soil building the payments ranged form $2.7 to $4.6/ac/y (Table 12.3). The Commodity Eco-price method gave the highest fair payment value, while both the Mean and Specific Ecosystem Service Eco-prices gave lower estimates. Preventing soil erosion was a much more valuable service than building soil. The range of fair payment prices was $26 to $44.6/ac/y for preventing soil erosion (Table 12.3).

Table 12.3 Public value and fair payment price for forest soil services (multiply $/ac/y by 2.5 to determine $/ha/y)**.**

Soil Ecosystem Service	All Forest Land in Maryland ($ millions per y)	Mean per Area Per Forested Acre ($ per acre per y)
Soil Building		
Public Value	$219	$89
Fair Payment Estimates		
Commodity Equivalency Eco-price	$11	$5
Mean Ecosystem Service Eco-price	$7	$3
Specific Ecosystem Service Eco-price	$7	$3
Erosion Prevention		
Public Value	$2,112	$855
Fair Payment Estimates		
Commodity Equivalency Eco-price	$110	$45
Mean Ecosystem Service Eco-price	$64	$26
Specific Ecosystem Service Eco-price	$70	$29

12.4. Discussion

The annual public value of preventing soil erosion was nearly 10 times as much as soil building. Preventing soil erosion was one of the most valuable ecosystem services provided to society with a public value of $855/ac/y (Table 12.2). Preventing soil erosion with reforestation is one of the most important ecosystem services that land stewards can perform. Reducing the transport of suspended particles to receiving waters, such as Chesapeake Bay, is one of the highest priorities for restoration projects.

The ecosystem service of soil building was found to add $219 million of public value annually to Maryland (Table 12.2). The process of generating soil and sequestering carbon is a much slower process than soil erosion in terms of MT/ha/y. While a 100 year-old forest was found to build soil at 0.5 MT-C/ha/y, urban systems were found to lose it at 3.23 MT-C/ha/y. That means that loss is six times faster than generation. Our estimates of soil carbon dynamics and erosion were largely consistent with the recent literature (Scheyer, 2005; Dissmeyer, 1985; Gellis et al., 2003). Herbivory was not included in ForSoilCarbon, so its estimate of carbon accumulation was probably slightly higher than it should have been. However, herbivory would not have a large effect on yearly carbon sequestration.

ForSoilCarbon and ForSoilMineral were intentionally kept simple so that non-technical professionals could understand it. However, as simple as it was in its construction, its ability to predict carbon dynamics of the soil were on target. Both models were heavily dependent on initial conditions, so it is important to parameterize them appropriately to produce accurate results.

In an effort to keep erosion estimate simple, ForSoilMineral did not include several factors that are included in well-established models of soil erosion like USLE, RUSLE or MUSLE (Chang, 2006). These traditional soil loss models take into account physical properties of the soil, like texture, topography, and climate. These types of models could be used in the future by the EIC to develop more precise estimates of erosion. Since our main purpose was to generalize forest soils and to be able to compare soil ecosystem services to other forest services, our assumptions were sufficient.

13. Air Quality Ecosystem Service

The forests of Maryland play an important role in improving air quality by removing air pollutants (Nowak, 2006; MDNR, 2011). Mechanisms for trees removing pollutants from the air include absorption through leaf stomata and interception by leaves (Landsberg and Sands, 2011). The forest soil is also a large and important sink for many air pollutants (Landsberg and Sands, 2011). This ecosystem service is especially important because of the widespread detriment that poor air quality has on the health of all humans (Mazzeo, 2011).

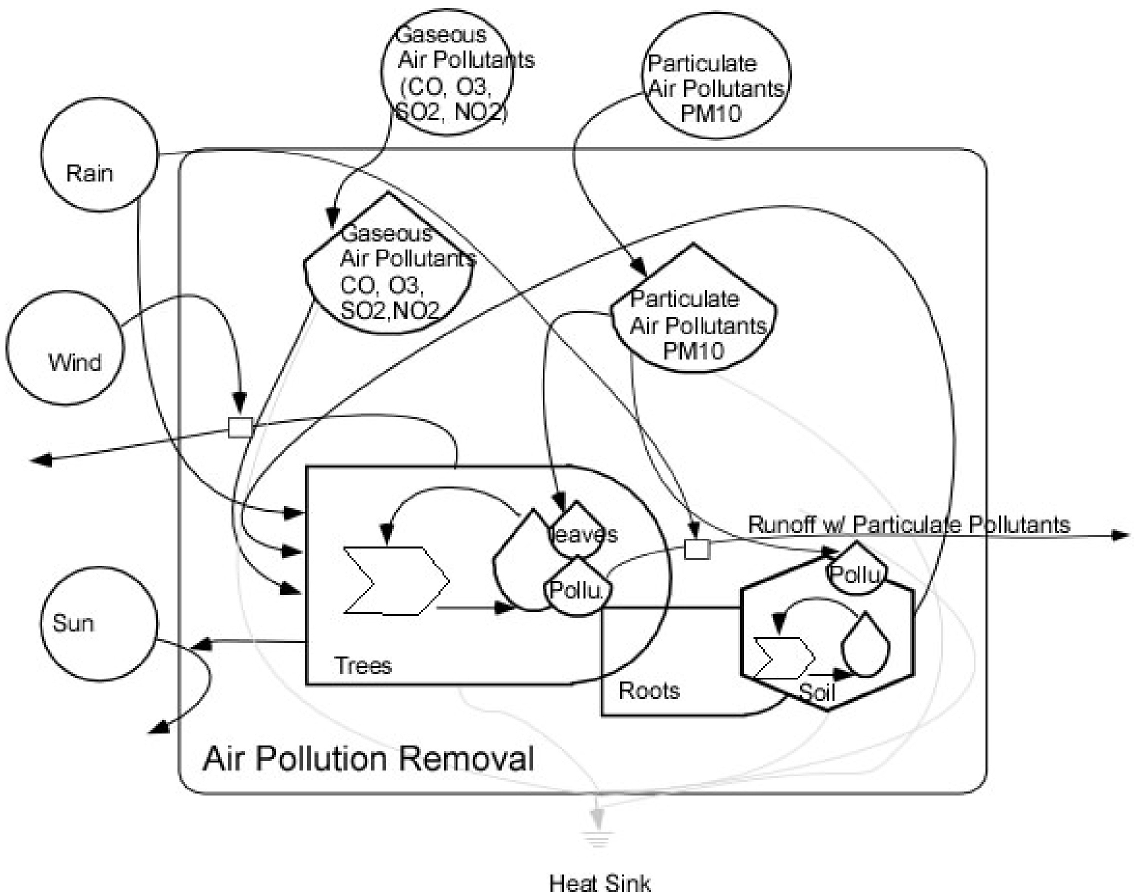


Figure 13.1. Energy systems language diagram showing how forests remove air pollutants from the atmosphere.

13.1. Air Quality Model

The air quality ecosystem service was based on estimates of the mass of pollutants (CO_2, CO, O_3, SO_2, NO_2, and PM10) removed from the atmosphere by forests. The mass removed was estimated using the UFORE model developed by the USFS (Nowak et al., 2006). UFORE is a widely accepted biophysical model used to determine the role of forests in ameliorating air pollution (Nowak et al. 2009). The UFORE model was run for Maryland using I-tree VUE, which is free software available from the USFS ((www.i-tree.org)).

The solar emergy associated with each pollutant removed was found by simply multiplying the mass removed by the appropriate solar transformity of the air pollutant. Existing solar transformities were available from the literature for most of the pollutants, but there were no previous estimates for ozone or PM10. Therefore, we estimated new transformities for these two air pollutants (see Appendix 4).

13.1.1. Data Collection and Parameter Estimate

The i-tree VUE software contains estimates of removal rates for CO_2, CO, O_3, SO_2, NO_2, and PM 10 according to geographic location (Table 13.1). We chose removal rates specific to Maryland's state boundary, which was found using ArcMap software (ESRI, 2010). UFORE requires GIS files for land-use and land-cover, impervious surface, and leaf area of the analyzed land. These files were obtained from the United States Geology Survey National Land Cover Database, which is an online database. The state boundary was then used to clip the land area needed using ArcMap.

Table 13.1. Sequestration values assumed by the UFORE Model (MT/ha/y).

Air Pollutant	Value
Carbon sequestered	3
CO removed	0.00152
NO_2 removed	0.00744708
O_3 removed	0.017443348
SO_2 removed	0.004159442
PM_{10} removed	0.008190064

13.2. Results for air pollutant removal

The the ecosystem service of air pollution removal totaled $112 million annually for the state of Maryland, with the majority, ($80 million), made up by the ozone removal ecosystem service (see Figure 13.2, calculation in Appendix 1). The same specific eco-price was used to calculate the dollar value for all pollutants.

Table 13.2 summarizes the public value and fair payment prices for air quality improvement in Maryland forests. The public value of air quality was determined for each pollutant evaluated with UFORE. Removal of ozone had the highest public value at $342.8 million per year in the State in 2000 (Table 13.2). Sulfur dioxide removal had the second highest at $69.0 million, while PM10 removal was close behind at $52.6 million. Nitrogen dioxide and carbon monoxide had the lowest public values at $16.1 million and $0.58 million, respectively.

Table 13.2 also gives three estimates of the fair payment price for each of the five main air pollutants. The average piece of forested land in Maryland could generate up to $48.12 per acre per year for ozone removal, which was the highest valued pollutant. The specific ecosystem service eco-pricing method gave the highest estimates for the fair payment prices. The mean ecosystem service eco-pricing method gave the lowest fair payment prices, while the commodity method was between the two methods. The minimum fair payment price for ozone removal was $4.22/ac/y (Table 13.2).

Based on the specific ecosystem service eco-pricing method, the fair payment prices ranged from $0.08 for CO to $48.12 for O_3 per acre per year (Table 13.2). Based on the commodity eco-pricing method, the fair payment prices ranged from $0.01 for CO to $7.23 for O_3 per acre per year (Table 13.2).

The EERPI was greater than three, indicating that investment in the EIC to pay land stewards for improving air quality would benefit the public three times more than the cost of the payment.

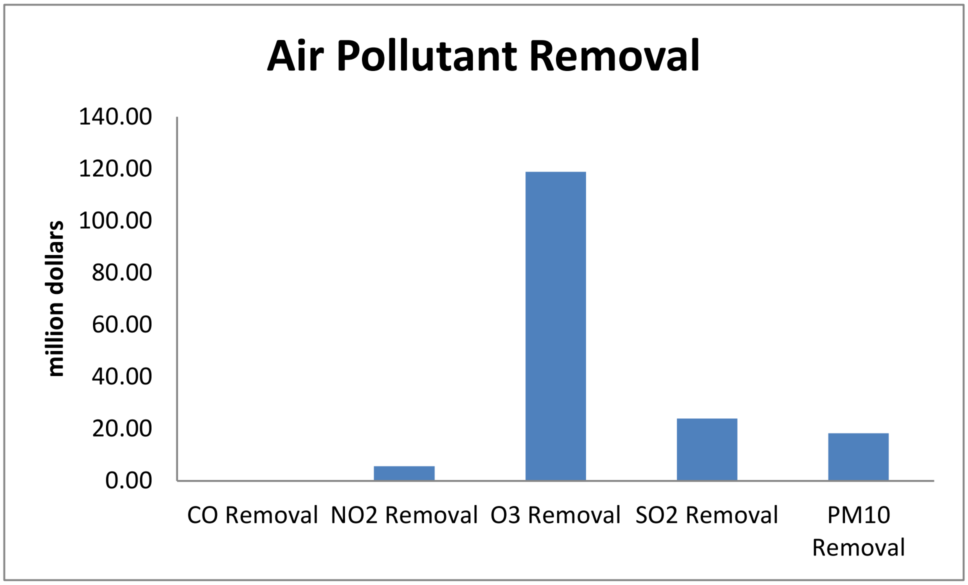


Figure 13.2. Annual value of fair payment price paid to land stewards for air pollutant removal by forests based on Specific Ecosystem Service Eco-price.

13.3. Discussion

The public value and fair payment prices for air quality ecosystem services were determined for five main types of air pollutants. Ozone removal had the highest public value and fair payment prices. This was because forests removed a larger mass of ozone compared to other pollutants (see Table 13.1) and ozone had a relatively high transformity. Since ozone is the primary air pollutant of concern for public health in Maryland (MDE, 2010) its higher payment price is also justified based on public health concerns.

Table 13.2 Public value and fair payment price for air quality ecosystem service (multiply $/ac/y by 2.5 to determine $/ha/y**).**

	Maryland (million $ per yr)	Value per Area ($ per acre per yr)
CO Removal		
Public Value	$ 0.58	$ 0.23
Commodity Price	$ 0.03	$ 0.01
Mean Ecosystem Service Price	$ 0.02	$ 0.01
Specific Ecosystem Service Price	$ 0.20	$ 0.08
NO_2 Removal		
Public Value	$ 16.1	$ 6.50
Commodity Price	$ 0.84	$ 0.34
Mean Ecosystem Service Price	$ 0.49	$ 0.20
Specific Ecosystem Service Price	$ 5.6	$ 2.25
O_3 Removal		
Public Value	$ 342.8	$ 138.73
Commodity Price	$ 17.9	$ 7.23
Mean Ecosystem Service Price	$ 10.4	$ 4.22
Specific Ecosystem Service Price	$ 118.9	$ 48.12
SO_2 Removal		
Public Value	$ 69.0	$ 27.91
Commodity Price	$ 3.6	$ 1.46
Mean Ecosystem Service Price	$ 2.1	$ 0.85
Specific Ecosystem Service Price	$ 23.9	$ 9.68
PM10 Removal		
Public Value	$ 52.6	$ 21.29
Commodity Price	$ 2.7	$ 1.11
Mean Ecosystem Service Price	$ 1.6	$ 0.65
Specific Ecosystem Service Price	$ 18.2	$ 7.38

14. Pollination Ecosystem Service

Wild bees are estimated to pollinate between 15 and 30% of all crops produced in the United States (Losey and Vaughn, 2006). However, most of the major crops produced in Maryland are either self-pollinated (soy beans) or wind-pollinated (corn). In addition, a portion of crops pollinated by insects are pollinated by domesticated bees. To assess the pollination ecosystem service of Maryland forests we focused solely on the wild pollinators.

14.1. Emergy-Pollination model

The emergy value of pollination was estimated by calculating the number of acres of cropland supported by native bees and the number of native bees necessary to pollinate that cropland. In Maryland, there are 20,662 ha of crops supported by the native pollination of approximately 4 billion bees. The emergy of the pollen generated by crops was necessary to support the bee population, and thus the transformity of the bee population was the emergy of the pollen divided by the joules of the population of native bees.

14.2. Data Collection and Parameter Estimate

Data for the crops produced in Maryland in 2010 was taken from the USDA, National Agricultural Statistics Service. The calculation of the percentage of crops pollinated by wild pollinators was adapted from the calculations in Losey and Vaughn, 2006. Data from www.extension.org was used to estimate the number of hives necessary to support 1 ha of crops and the number of bees in a hive.

14.3. Results

Pollination is a relatively minor ecosystem service in Maryland. It had one of the smallest public values ($1.43 million in Table 14.1) of all ecosystem services evaluated in this study. Only CO removal was smaller. This was not unexpected, since most major crops in Maryland are not insect-pollinated, but rather self-pollinated or wind-pollinated.

The highest per acre fair payment price for pollination was $0.12 per ac per year (Table 14.1). The EERPI was 5:1, indicating that the value returned to the public for each dollar paid to land stewards was $5.

Table 14.1 Public value and fair payment price for Pollination by wild insects (multiply $/ac/y by 2.5 to determine $/ha/y**).**

	Maryland (million $ per yr)	Value per Area ($ per acre per yr)
Public Value	$1.43	$0.58
Commodity Price	$0.07	$0.03
Mean Ecosystem Service Price	$0.04	$0.02
Specific Ecosystem Service Price	$0.30	$0.12

14.4. Discussion

The public value of the pollination ecosystem service was the lowest of all ecosystem services considered in this research. If this study was done in a different state with crops reliant on wild pollinators the value would likely be much higher. Losey and Vaughn (2006) estimated that wild pollinators contributed over $3 billion to the United States economy. Two limitations of our estimate of public value were that the role of pollinators in homeowner or community supported agriculture vegetable gardens was not considered, nor was pollination of non-agricultural plants (i.e., wild plants) considered. Future studies should more fully consider the role of pollination in ecosystems.

15. Summary of Ecosystem Service Values

In their current condition and spatial extent the forests of MD provide $4.4 billion of public value to the economy, society and ecology of the State each year (Table 15.1). If the entire 2.5 million acres (1.0 million ha) of Maryland forest participated in the EIC so that land stewards could be paid for producing ecosystem services, we estimate that the fair payment market would be at least $134 million (Table 15.3) but could be as much as $657 million per year (Table 15.2), depending on which method is used to estimate the solar emergy-based eco-prices. The specific ecosystem service eco-pricing method generated the greatest fair market value.

Since this method coupled the eco-price to each specific ecosystem service type, it may the best choice. However, the other two methods, commodity and mean ecosystem service eco-price, which were averages of broad categories of ecosystem services, have their advantages. The mean ecosystem service eco-pricing method has the advantage that it is not dependent on one service, but rather a bundle of services. The commodity eco-pricing method also has the advantage of being based on a bundle of services. In addition it is dynamic and directly tied to the market prices of natural resources, which means that eco-prices could be adjusted in real-time. The two non-commodity methods were largely dependent on the pricing associated with government programs and policies or long-term assessments of health costs. Thus, they would change much more slowly, which has the advantage of providing a stable price, which could be desirable for the EIC.

Taking the ratio of public value to the fair payment price of ecosystem services gives the ecological-economic return on private investment (EERPI). Using the highest fair payment market value of $657 million and the public value of $4.4 billion the mean EERPI would be 6.7:1. Or using the mid-range estimate from the commodity eco-pricing method of $230 million, the mean EERPI would be 19:1. **In other terms a roughly $0.05 payment to a land steward to hold his land in forest for one year returns $1 of public value to the economy, society and ecology of the State**.

Table 15.2 gives a synthesis of fair payment prices for ecosystem service based on the **specific ecosystem service eco-pricing method**. The highest value ecosystem services were stormwater mitigation ($238 million per year), groundwater recharge ($142 million) and ozone removal ($119 million) (Figure 15.1). Together these make up over 75% of the total value. On average, each acre of forest in Maryland could generate $263/yr in fair payments for ecosystem services.

Table 15.3 gives a synthesis of fair payment prices for ecosystem service based on the **mean ecosystem service eco-pricing method**. The highest value ecosystem services were erosion prevention ($64 million per year), stormwater mitigation ($21.8 million), groundwater recharge ($14.6 million) and ozone removal ($10.4 million). Together these made up over 82% of the total value. On average, each acre of forest in Maryland could generate $54/yr in fair payments for ecosystem services.

Table 15.4 gives a synthesis of fair payment prices for ecosystem service based on the **commodity eco-pricing method**. The highest value ecosystem services were erosion prevention ($110 million per year), stormwater mitigation ($37.4 million), groundwater recharge ($25 million) and ozone removal ($17.9 million). Together these made up over 83% of the total value. On average, each acre of forest in Maryland could generate $92/yr in fair payments for ecosystem services.

If each acre of Maryland forest that was in the EIC, received an average payment of $263/y and every citizen of the State contributed equally to the payments, then the average annual per capita payment would be $109 or $9/month (Table 15.2).

15.1. Comparison of the Valuation Methodologies

An advantage of using weighted averages is that it mitigates the effect that any one eco-price could have on the overall estimate of the annual value of ecosystem services. The downside of using weighted averages is that information is lost. When weighted averages are used ecosystem services with high eco-prices are not valued as highly. By our estimate, use of the weighted average (i.e., Mean Ecosystem Service Eco-price) decreased the annual value of ecosystem services by 79%. Ecosystem services like stormwater mitigation and ozone mitigation had the greatest drops in value because their eco-prices were some of the highest we found. Society places a high value on controlling stormwater. It is costly for society to replicate a forest's hydrological capabilities. Using the weighted average loses the high value of hydrological services implied by these distinctive properties. Thus, the Specific Ecosystem Service approach may be the best of the three approaches for converting solar emergy to dollars of payment. However, it suffers by not being dynamic. Future research should explore how the Specific Ecosystem Service approach can be combine with the Commodity-based approach to take advantage of their respective strengths, specificity and timeliness.

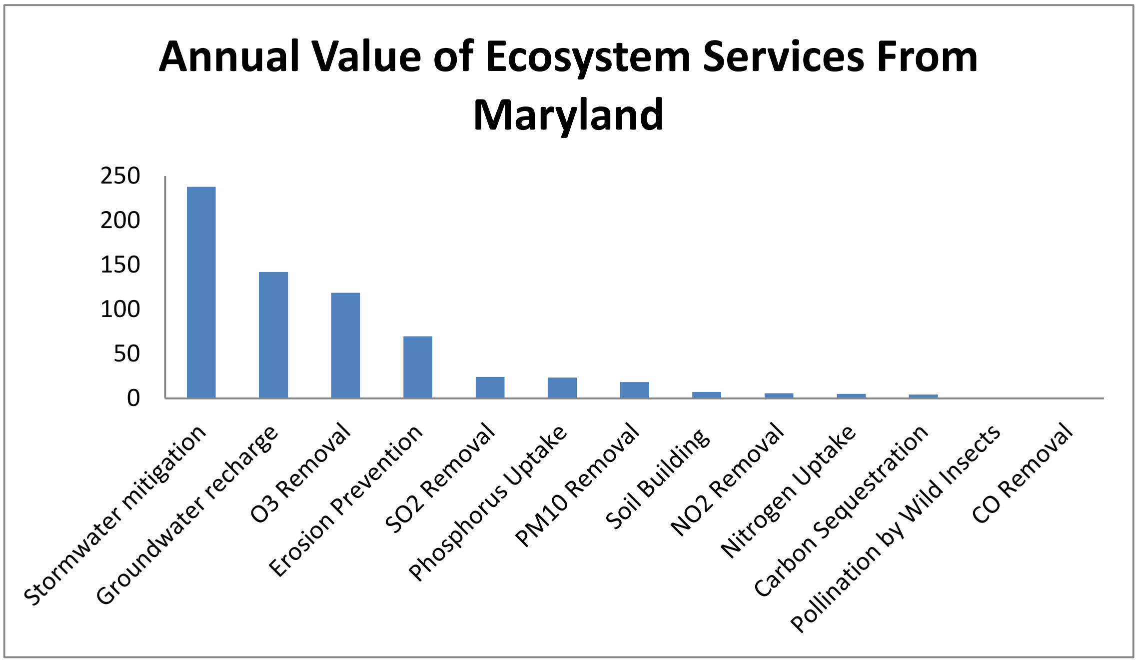


Figure 15.1. Fair Payment Value of Forest Ecosystem Services in Maryland based on Service Specific Eco-price Approach. (million $ per year)

Table 15.1 Public value of forest ecosystem services (annual) in Maryland based on the State's average emergy-to-dollar ratio (i.e., Mean State Eco-price).

Item	Units	Quantity	Unit Emergy Values (sej/unit)	Solar Emergy (1E18 sej/y)	Eco-price (1E12 sej/$)	Public Value ($ million)
Carbon Sequestration	J	2.22E+16	3.62E+04	802.3	2.82	303
Stormwater mitigation	J	1.53E+16	1.24E+05	1901	2.82	717
Groundwater recharge	J	8.99E+14	1.41E+06	1268.2	2.82	479
Nitrogen Uptake	g	1.10E+10	4.10E+09	45.2	2.82	17
Phosphorus Uptake	g	9.68E+09	2.16E+10	209.2	2.82	79
Soil Building	J	4.06E+15	1.43E+05	580.6	2.82	219
Erosion Prevention	g	3.33E+12	1.68E+09	5596.8	2.82	2112
CO Removal	g	1.27E+09	1.20E+09	1.5	2.82	1
NO2 Removal	g	6.22E+09	6.84E+09	42.6	2.82	16
O3 Removal	g	1.46E+10	6.23E+10	908.5	2.82	343
SO2 Removal	g	3.48E+09	5.26E+10	182.8	2.82	69
PM10 Removal	g	6.84E+09	2.04E+10	139.4	2.82	53
Pollination	ha	2.07E+04	1.84E+14	3.8	2.82	1
Total Value for Fair Payments to Land Stewards						4408

See Appendix 1 for Maryland Emergy evaluation from which the mean eco-price for Maryland was calculated

Table 15.2. Fair Payment Value (annual) of forest ecosystem services in Maryland based on Specific Ecosystem Service Eco-pricing Approach.

Note	Item	Units	Quantity	Unit Emergy Values. (sej/unit)	Solar Emergy ($x10^{18}$ sej)	Eco-price (1E12 sej/$)	Fair Payment Value (million $)
1	Carbon Sequestration	J	2.22E+16	3.62E+04	802	182	4
	Stormwater mitigation						
2	Piedmont Region	J	7.96E+15	1.24E+05	978	8.9	110
3	Coastal Plain Region	J	7.37E+15	1.55E+05	1140	8.9	128
	Groundwater recharge						
4	Piedmont Region	J	4.64E+14	1.50E+06	696	8.9	78
5	Coastal Plain Region	J	4.35E+14	1.32E+06	575	8.9	64
	Nutrient Uptake	J					
6	Nitrogen	g	1.10E+10	4.10E+09	45	8.9	5
7	Phosphorus	g	9.68E+09	2.16E+10	209	8.9	23
8	Soil Building	J	4.06E+15	1.43E+05	581	80	7
9	Erosion Prevention	g	3.33E+12	1.68E+09	5600	80	70
	Air Pollutant Removal						
10	CO Removal	g	1.27E+09	1.20E+09	2	7.6	0.2
11	NO_2 Removal	g	6.22E+09	6.84E+09	43	7.6	6
12	O_3 Removal	g	1.46E+10	6.23E+10	908	7.6	119
13	SO_2 Removal	g	3.48E+09	5.26E+10	183	7.6	24
14	PM10 Removal	g	6.84E+09	2.04E+10	139	7.6	18
15	**Pollination by Insects**	ha	2.07E+04	1.84E+14	4	13	0.3
	Total						657
	Ecosystem Service per Acre of Forest						263
	Ecosystem Service per Capita in Maryland						115

See Appendix 3 for footnotes detailing calculations

Table 15.3. Fair Payment Value of ecosystem services (annual) in Maryland based on Mean Ecosystem Services Eco-pricing Approach.

Item	Units	Quantity	Unit Emergy Values (sej/unit)	Solar Emergy ($x10^{18}$sej)	Eco-price (1E12 sej/$)	Fair Payment Value (Million $)
Carbon Sequestration	J	2.22E+16	3.62E+04	802.3	87.1	9.2
Stormwater mitigation	J	1.53E+16	1.24E+05	1901	87.1	21.8
Groundwater recharge	J	8.99E+14	1.41E+06	1268.2	87.1	14.6
Nitrogen Uptake	g	1.10E+10	4.10E+09	45.2	87.1	0.5
Phosphorus Uptake	g	9.68E+09	2.16E+10	209.2	87.1	2.4
Soil Building	J	4.06E+15	1.43E+05	580.6	87.1	6.7
Erosion Prevention	g	3.33E+12	1.68E+09	5596.8	87.1	64.3
CO Removal	g	1.27E+09	1.20E+09	1.5	87.1	0.02
NO2 Removal	g	6.22E+09	6.84E+09	42.6	87.1	0.5
O3 Removal	g	1.46E+10	6.23E+10	908.5	87.1	10.4
SO2 Removal	g	3.48E+09	5.26E+10	182.8	87.1	2.1
PM10 Removal	g	6.84E+09	2.04E+10	139.4	87.1	1.6
Pollination	ha	2.07E+04	1.84E+14	3.8	87.1	0.04
Total Value for Fair Payments to Land Stewards						134

Table 15.4. Fair Payment Value of ecosystem services (annual) in Maryland based on Commodity Eco-pricing Approach.

Item	Units	Quantity	Unit Emergy Values (sej/unit)	Solar Emergy (10^{18}sej)	Eco-price (1E12 sej/$)	Fair Payment Value (million $)
Carbon Sequestration	J	2.22E+16	3.62E+04	802.3	50.8	15.8
Stormwater mitigation	J	1.53E+16	1.24E+05	1901	50.8	37.4
Groundwater recharge	J	8.99E+14	1.41E+06	1268.2	50.8	25.0
Nitrogen Uptake	g	1.10E+10	4.10E+09	45.2	50.8	0.9
Phosphorus Uptake	g	9.68E+09	2.16E+10	209.2	50.8	4.1
Soil Building	J	4.06E+15	1.43E+05	580.6	50.8	11.4
Erosion Prevention	g	3.33E+12	1.68E+09	5596.8	50.8	110.1
CO Removal	g	1.27E+09	1.20E+09	1.5	50.8	0.03
NO2 Removal	g	6.22E+09	6.84E+09	42.6	50.8	0.8
O3 Removal	g	1.46E+10	6.23E+10	908.5	50.8	17.9
SO2 Removal	g	3.48E+09	5.26E+10	182.8	50.8	3.6
PM10 Removal	g	6.84E+09	2.04E+10	139.4	50.8	2.7
Pollination	ha	2.07E+04	1.84E+14	3.8	50.8	0.07
Total Value for Fair Payments to Land Stewards						230

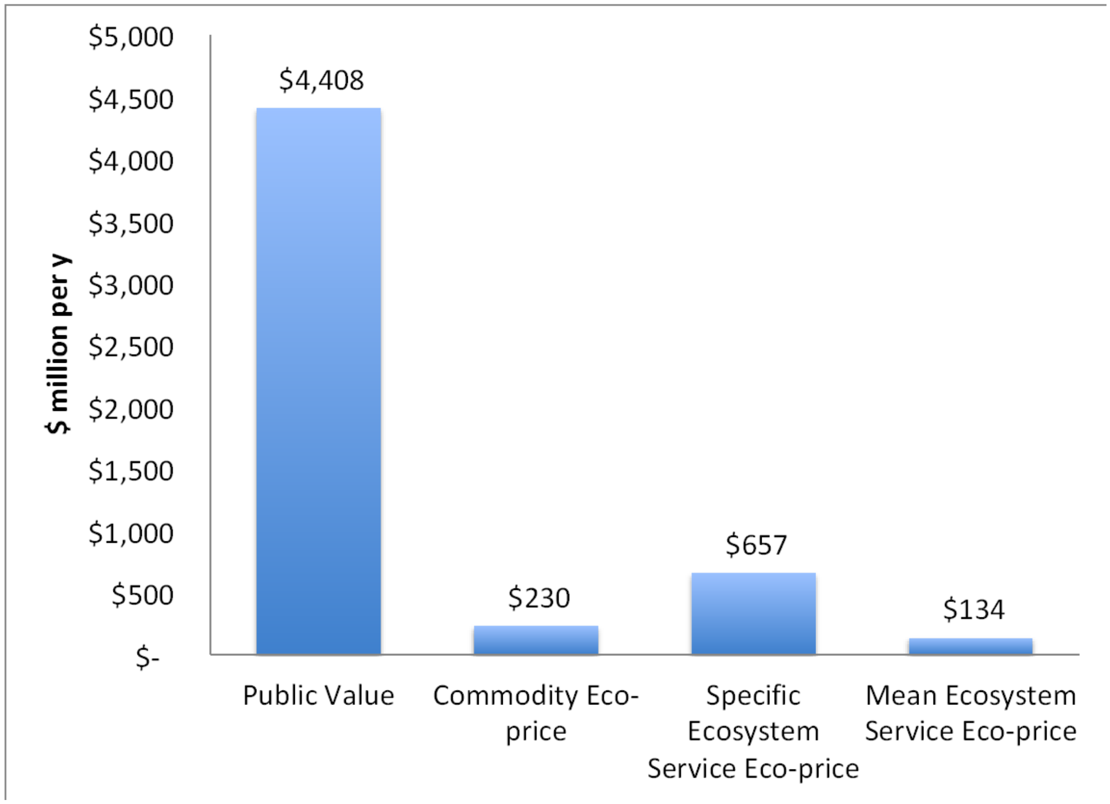


Fig. 15.2. Public value and fair payment estimates of ecosystem services provided by the forests of Maryland in 2000.

15.2. Exploration of the Value of Forest Productivity based on Commodity Eco-price

In this section we explore the value of forest productivity based on various Commodity Eco-prices to understand the effect of commodity choice on the fair payment price. Forest productivity (i.e., net primary production) was chosen for the exploration because it is arguably the basis for most other forest ecosystem services.

Assuming that forest productivity was 4 MT/ha/y, its annual fair payment price was estimated to be between $27 and $199 per ha (Figure 15.3). The various commodity eco-prices were based mostly on June 2nd, 2011 market exchange prices of gasoline, crude oil, natural gas, copper, timber, corn and wool. The price of electricity was the mean national price paid in 2006. The trading prices change by the minute every business day.

The copper-based eco-price gave the lowest fair payment price ($27/ha/y), while corn gave the highest price ($242/ha/y) (Figure 15.3). The majority of the fair payment prices were between $150 and $200/ha/y.

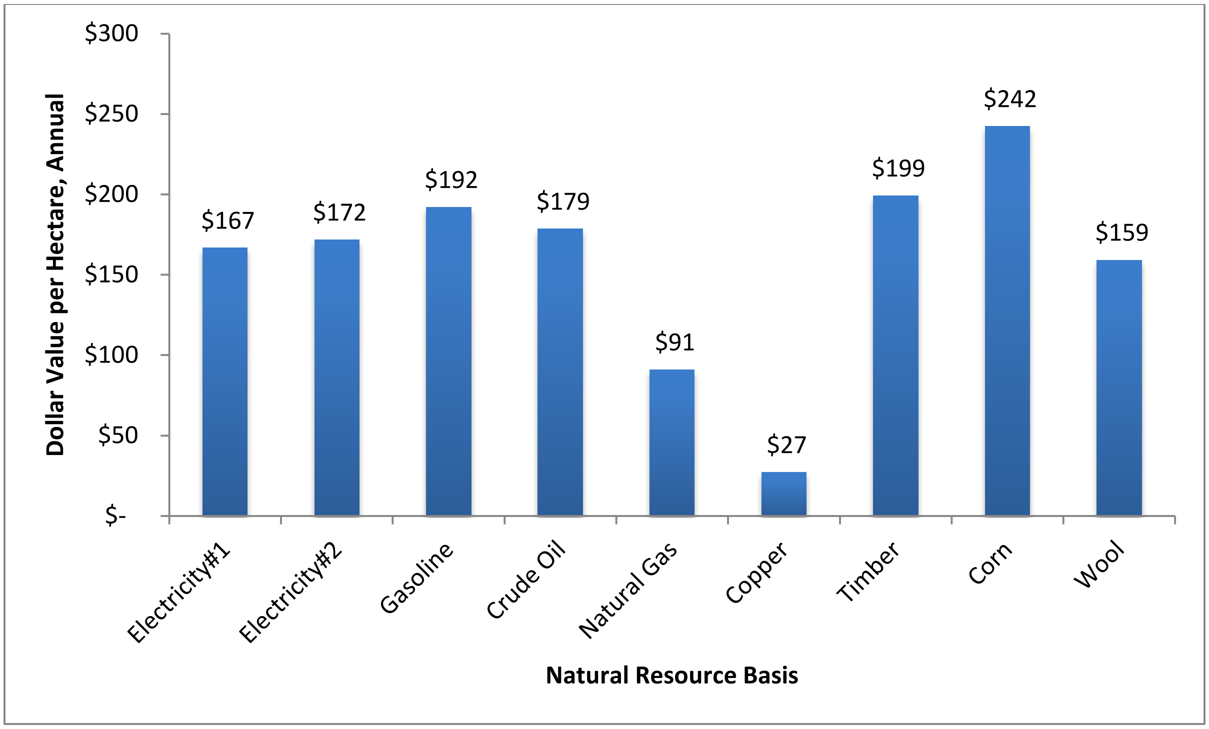


Figure 15.3. Annual dollar value of ecosystem services from Maryland forests if they were based on a single natural resource commodity.

The implication for the EIC is that selection of the commodity to represent the eco-price (sej/$) for forest ecosystem services strongly affects the valuation. Selection of a commodity with a low eco-price, such as timber, provides a higher estimate than if a commodity with a high eco-price, such as copper, is chosen. The mean Commodity eco-price was used to estimate the fair payment price of the ecosystem services evaluated in the study, which would likely be a safe choice for using the Commodity eco-pricing method. Using the mean of a basket of natural resources would likely maintain a more stable eco-price because no single resource would be in control.

15.2.1. Sensitivity of fair payment price to forest productivity

The net primary productivity of forests varies with geography, age, climate and forest type. The sensitivity of the fair payment price for forest productivity to its rate of production is given in Figure 15.4. It clearly shows that the fair payment price was directly affected by the rate. The annual value ranged from $50 to $350 per ha, when the eco-price of electricity was used. Electricity was used as the representative commodity for the sensitivity analysis because it has one of the more stable commodity prices.

The implication for the EIC would be that land steward compensation should be tied to forest productivity with more productive land receiving more compensation.

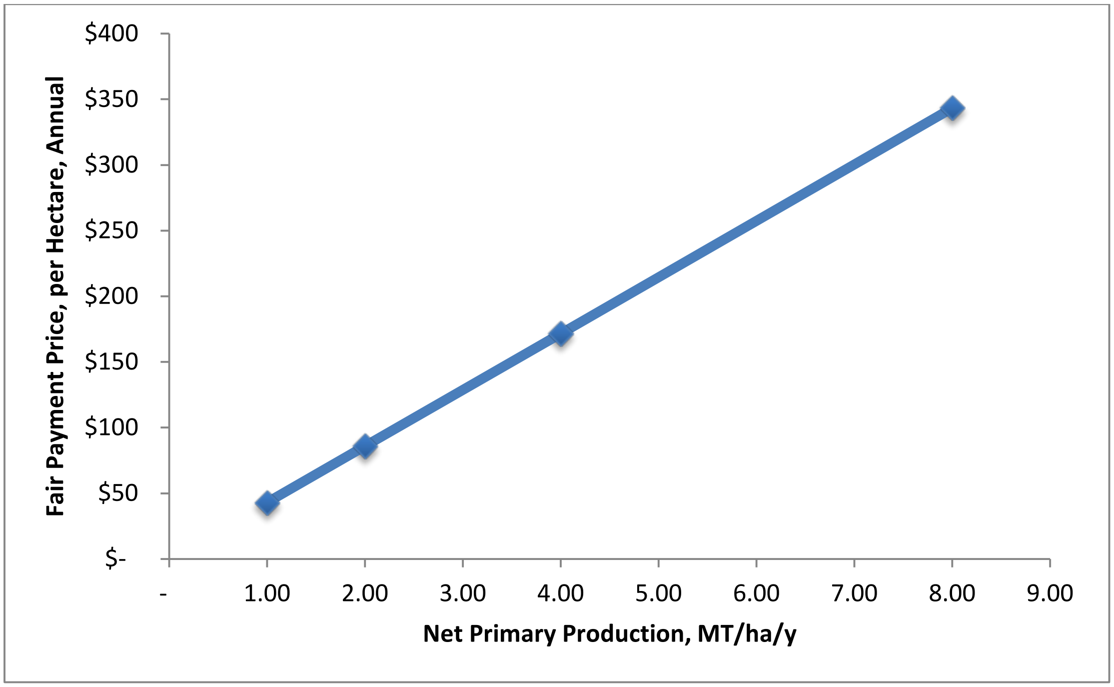


Figure 15.4. Sensitivity of the value of forest productivity to net primary production.

15.2.2. Sensitivity of fair payment price to solar transformity of the forest

The amount of emergy produced by a forest also varies with geography, age, climate and other factors. The sensitivity of the fair payment price of forest productivity to the natural variability in its emergy was explored by varying the solar transformity of forest productivity (Figure 15.5). The annual fair payment price ranged from $70 to $380 per ha, when the eco-price of electricity was used and solar transformity ranged from 10,000 to 55,000 sej/J (Tilley 1999). A solar transformity of 10,000 sej/J, which is expected for a fast growing forests that is younger than 50 years, would produce ecosystem services annually at about $70 per ha (Figure 15.5). In contrast an old-growth stand that was 250+ years old and had a solar transformity of 55,000 sej/J (Tilley 1999), would produce ecosystem services annually at over $350 per ha.

The implication for the EIC is that Land Stewards that preserve old-growth forests should be paid more than Stewards that have immature forests. It also implies that Land Stewards should be paid more each year because their forests are aging, accumulating new qualities and emergy. Thus, the escalating scale would work as an incentive for Stewards to participate on a long-term basis and stay in the program once they agree to membership.

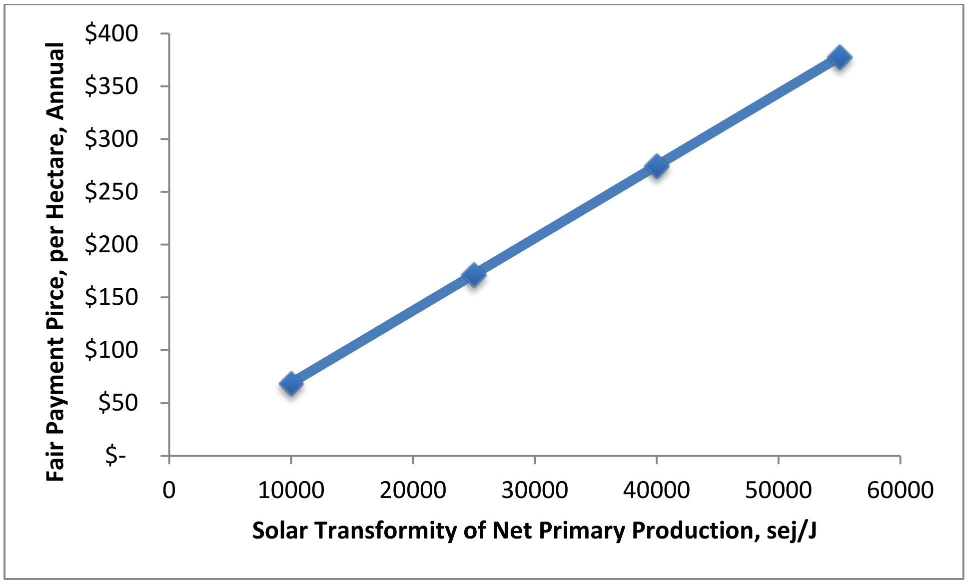


Figure 15.5. Sensitivity of the fair payment price of forest productivity to solar transformity of productivity.

15.2.3. Present value of fair payment price and affect of discount rate

The Present Value of future dollar flows for ecosystem services is affected by the discount rate chosen (Figure 15.6). A higher discount rate lowered the present value of future payments. Annual dollar flows of $172/ha had a present value of $5400/ha at a 2% discount rate applied over a 50 y time period, but only $2100/ha at an 8% rate (Figure 15.6). A land steward who had forest enrolled in the EIC for 50 years could be paid a one time fee of $5400 assuming the 2% discount rate was justified.

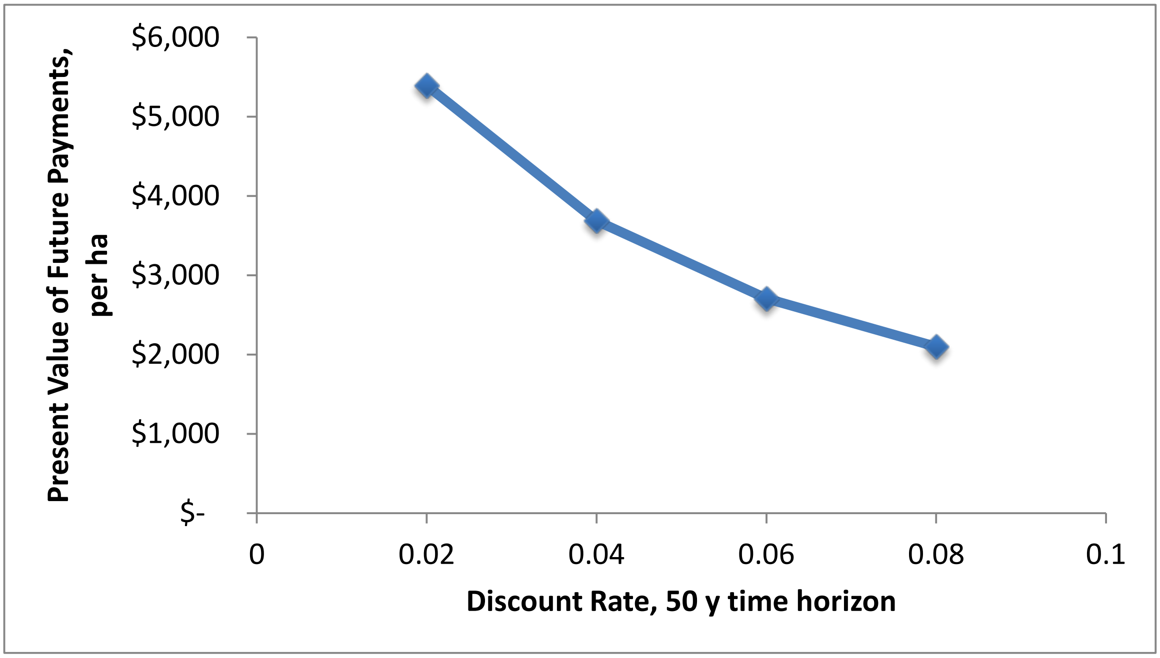


Figure 15.6. Effect of discount rate on present value of 50 years of future annual ecosystem service payments.

15.2.4. Sensitivity of Present value of fair payment price to time horizon

The time horizon over which the annual payments are made also affected the Present Value of the fair payment price. A longer time horizon gave a higher Present Value (Figure 15.7). For a 50-year time horizon, annual payments of $172/ha/y had a Present Value of $5400/ha, assuming a 2% discount rate. A 30-year or 10-year period reduced the Present Value to $3850 and $1500/ha, respectively.

The obvious implication for the EIC is that land stewards could receive larger up-front payments for longer-term agreements to keep their forest land in the EIC.

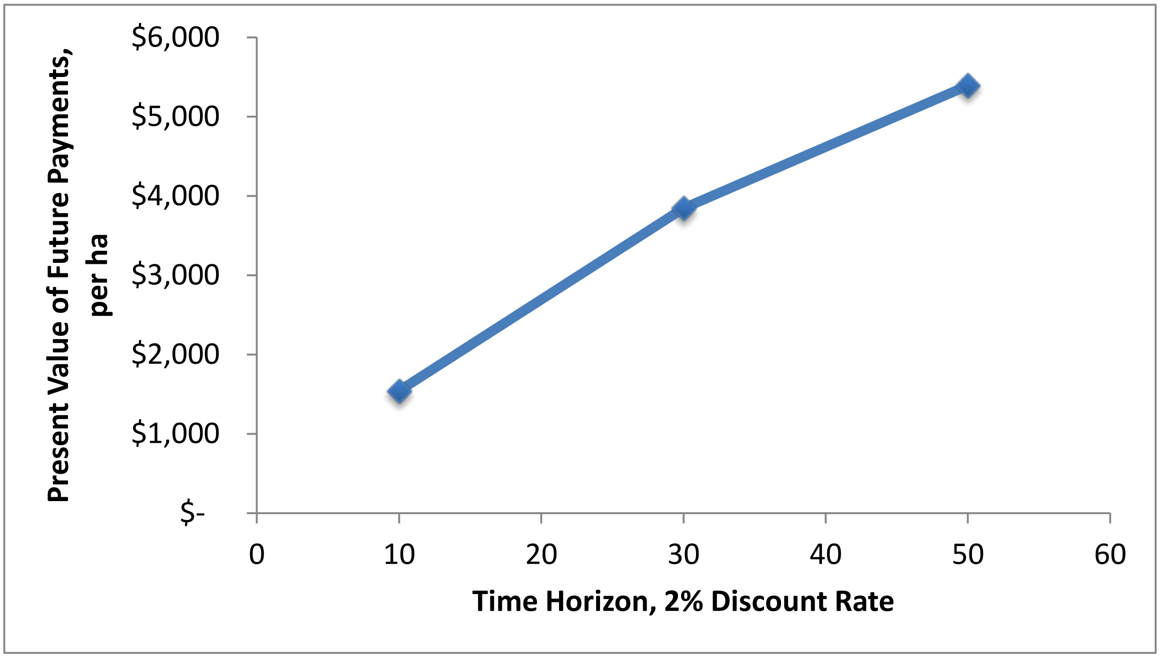


Figure 15.7. Effect of Time Horizon on Present Value of future annual ecosystem service payments assuming a Discount Rate of 2%.

16. Simulation of EcoInvestCorp Model

16.1. Simulating the EcoInvestCorp

16.1.1. Model of the EcoInvestCorp

EcoInvestCorp is a dynamic simulation model that shows how a Maryland Ecological Investment Corporation (EIC) will collect flows of money (**N**) generated from consumers of ecosystem services and distribute to Stewards (**M**) and Stockholders (**V**) (Figure 16.1). The EIC is eligible to receive consumer fees in proportion to how much ecosystem service value (**S**) they have secured from Stewards. The EIC must then pay its Stewards an amount, **M**. The EIC will also be allowed to pay a stock dividend, **V**, in proportion to the amount of ecosystem services paid to Stewards (**M)** and collect administrative costs (**F**) in proportion to the amout of ecosystem services paid to Stewards. The dividend rate, **v**, and administrative cost rate, **f**, could be controlled by a State Authority. The EIC accumulates financial assets, **E**, as a balance of these inflows (**K, N)** and outflows **(V, M, F**).

<u>Stewardship Income and Ecosystem Service Production</u>. Income for a forest Land Steward participating in an Ecological Investment Corporation would be the difference between the revenue they generated from the EIC (**M**) and the costs incurred in restoring, managing and certifying their forests (**R**). Thus, Steward income is M–R (Figure 16.1). The Steward's Revenue (**M**) will be the amount of ecosystem services (**S**) they provided times the fair payment price (i.e., $\mathbf{P_m}$, eco-price) for their basket of ecosystem services.

<u>How are Ecosystem Service Production (**S**) and Fair Payment Prices ($\mathbf{P_m}$) measured</u>? Emergy evaluation, as a systems ecology-based method, allows the multitude of ecosystem services to be quantified in an integrated fashion and on an equal basis as a unified unit the solar emjoule. The emergy-systems ecology-based approach reconciles the fact that each type of ecosystem service is unique and has different physical units of measure but by recognizing that all were ultimately made possible due to the Earth's incoming solar energy. Therefore, emergy accounting of ecosystem services traces how much solar energy was ultimately required both directly and indirectly to produce an

ecosystem service. Emergy allows for all ecosystem services to be quantified in the same units, namely solar emjoules (sej).

In *EcoInvestCorp*, the amount of ecosystem services (**S**) provided by Land Stewards was estimated as solar emergy in the previous sections of this report. In the Scenarios that follow, S was assumed to be supplied at a constant rate. The rate of ecosystem services production was divided by an estimate of the Fair Payment Price (eco-price, $\mathbf{P_m}$) (see Table 7.1 for a list of eco-prices). See Section 7 for a more detailed explanation of eco-prices and their derivation.

<u>What is the basis for collecting money from consumers of ecosystem services</u>? Consumers do not directly consume ecosystem services, but they do consume goods that have measurable quantities of solar emergy, just as ecosystem services do. Thus, an ideal and energetically consistent framework for collecting payments from consumers would be to base their payments on their total consumption of solar emergy. The payment for each type of good consumed would be proportional to its solar emergy. Candidate goods with large amounts of embodied solar energy include: transportation fuels, electricity, nitrogen fertilizer, solid waste, potable water and municipal wastewater. However, for the current scenarios explored with EcoInvestCorp, the amount of money collected by the EIC was expressed more simply. The amount collected was taken as a function of a monthly rate consumed per participant and the fraction of the state's population that participated.

Future research should explore cases where consumer payments are equal or at least proportional to their direct consumption of solar energy. This research should also explore the ramifications of variable eco-prices.

<u>How much **public value** is generated relative to payments made?</u> The amount of value produced via ecosystem services for the public (i.e., public value) (**B**) was found by dividing **S** the production rate by the mean emergy-price for all economic product in the state ($\mathbf{P_n}$), which was 2.82E12 sej/$ (i.e., $\mathbf{B = S/P_n}$).

As explained in earlier sections of this report, the public value is the value enjoyed by the public and the larger system of the economy and ecosytems, whereas the fair payment price is the value that should be paid to land stewards. Each Scenario below assumed that land steward payments were $241/ha/y, which was based on the mean ecosystem service eco-price method.

Once the public value produced (**B**) and the money collected from consumers (**N**) were known, the **EERPI (ecological economic return on private investment)** was estimated as **B/N**. When this ratio is greater than one, it indicates that the public received more value than it gave up in payments.

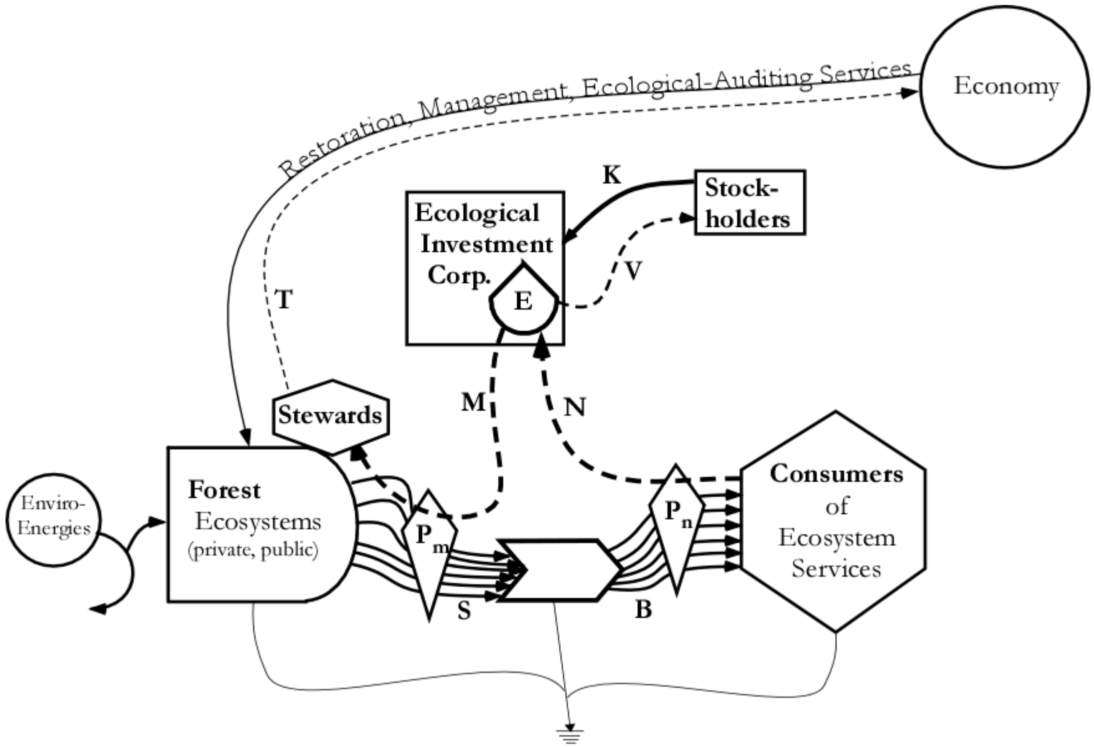


Fig. 16.1. Simulation model for operating a statewide Ecological Investment Corporation. (*EcoInvestCorp*).

$dE/dt = K + N – M – F – V$
where E is Assets of EIC ($ per year);
K is capital investment;
N is receipts from consumers of ecosystem services;
M is payments to land stewards;
F is costs for administration to include restoration, management, and auditing;
V is dividends paid to stockholders;
Revenue and costs were further defined as follows:
N = nU where n is mean per capita donation per month ($/month) and U is number of donors (#);
$M=P_mS$ where P_m is fair payment price ($/sej) and S is services produced (sej);
F=fM where f is administrative cost rate of EIC (%);
V=vM where v is dividend rate (%);
S=asA where a is participation rate of land stewards (%),
s is per area rate that ecosystem services are delivered from EIC forests, and
A is amount of forested land in Maryland (ha);
I is Stewardship Income ($)
I = M – R;
R is management and restoration cost ($)
R=arA
r is management and restoration cost rate ($/ha)
i = income per area ($/ha)
i = I/(aA)
B is public value of ecosystem services delivered ($/ha)
$B=S/P_n$
P_n = public emprice (sej/$) (mean emergy flow to economic product for MD)

16.1.2. Parameter Estimates

Table 16.1 contains the descriptions and values estimated or assumed for the parameters in *EcoInvestCorp*. Estimates of the parameters were based on the results given in the previous sections. Three parameters are shown as variable because they took on various values for the Scenarios run below. Assumed parameter values were based on best estimates.

We assumed an administrative cost rate of 2% of payments, believing that it was a low and reasonable rate. If the EIC were handling a cash flow of $20,000,000, then 2% would give an administrative budget of $400,000, which should be sufficient to employ 3 to 5 full-time employees and have operating funds of $50,000-$100,000.

The management costs for the land stewards were assumed to be $10/ha/y based on the expectation that they would be about 1 to 2% of the property taxes paid each year. If property taxes were 1% of assessed value and the mean assessed value was $50,000/ha ($20,000/ac), then property taxes would be $500/ha/y. Two-percent of $500 is $10. This parameter needs a better method for estimating that is based on actual costs and lifetime for restoration projects.

The dividend rate was assumed to be 0.5% of total payments made to land stewards. It was made proportional to payments to encourage stockholders to favor making payments. The rate of 0.5% was assumed to be fair and attractive to stockholders. It is slightly higher than the interest rate paid on savings accounts at banks during the last few years.

Table 16.1. Parameter descriptions, values, units and formulas for *EcoInvestCorp*. Parameters in bold were treated as variables in the Six Scenarios, while the one underlined (n) was solved to make the EIC profitable.

Parameter	*Description*	*Value*	*Units*	*Source*
a	**Participation rate of Land Stewards**	**variable**	**%**	
A	Forested area in MD	1,000,000	ha	Appendix 1
f	Administrative cost rate	2.0%	%	Assumed
n	Mean per capita donation	variable	per month	
P_m	Fair payment price (eco-price)	50.80E12	sej/$	Table 15.4
P_n	Public emergy/$ (emprice)	2.82E12	sej/$	Table 8.1
r	Management & restoration costs	$10	$/ha	Assumed
σ	Ecosystem Services delivered from forest	1.20E16	sej/ha	Table 15.4 ($230/ha/y) x (50.8E12 sej/$)
U	**Number of people donating**	**variable**	**participants**	
v	Dividend rate to stockholders	0.5%	%	Assumed
Formulas				
B	Public value of Ecosystem Services delivered to public	S/P_n	$	
M	Payments to land stewards	S/P_m	$	
m	Per area payments to land stewards	M/(aA)	$/ha	
S	ES produced from EIC lands	$a\sigma A$	sej	

16.1.3. Scenarios

Six scenarios were used to explore what the range of consumer payments should be using the parameter values given in Table 16.1. Under the assumptions and estimates used, land stewards were paid $241/ha/y. Each scenario assumed either a high, medium or low consumer participation rate (50,000; 250,000; or 500,000 participants). Since Maryland has a population of about 6 million, this is a participation rate of 0.8% to 8%. Each scenario assumed either a high or low land steward participation rate (50,000 or 200,000 ha). Since Maryland has about 1 million ha of forest land, this is a participation rate by land stewards of 5 or 20% of forest land.

Tables 16.2 to 16. 7 show the assumptions and results for each of the six scenarios. The monthly per capita donation was found after consumer and land steward participation rates were set by ensuring that after one year, the EIC had a profit. Return on capital was the dividends paid as a return on the $1,000,000 invested as capital. The EERPI indicates how much public value ($) was generated by the ecosystem services for each dollar donated by consumers.

Table 16.2. Scenario Low/Low: Low consumer participation rate (50,000) and low Land Steward participation (50,000 ha; 125,000 ac).

Item	Value
Monthly Per Capita Donation, n	**$30.00**
Dividend Rate, v	0.5%
Administrative Costs, f	2.0%
Participant Consumers (#)	50,000
Forest Area, (ha)	50,000
Land Steward Revenue	$18,571,429
Land Steward Costs	$6,500,000
Land Steward Income	$12,071,429
Income per hectare	$241
Capital Investment	$1,000,000
EIC Revenue	$19,500,000
EIC Payments	$18,571,429
Dividends	$92,857
Admin. Costs	$371,429
EIC Net Income	$464,286
Public Value	$230,496,454
Return on Capital	9.29%
Ecological-Economic Return on Private Investment (EERPI) ($/$)	11.8

Table 16.3. Scenario Medium/Low: Medium consumer participation rate (250,000) and low Land Steward participation (50,000 ha; 125,000 ac).

Item	**Value**
Monthly Per Capita Donation	**$6.00**
Dividend Rate	0.5%
Administrative Costs	2.0%
Participant Consumers	250,000
Forest Area, ha	50,000
Land Steward Revenue	$18,571,429
Land Steward Costs	$6,500,000
Land Steward Income	$12,071,429
Income per hectare	$241
Capital Investment	$1,000,000
EIC Revenue	$19,500,000
EIC Payments	$18,571,429
Dividends	$92,857
Admin. Costs	$371,429
EIC Net Income	$464,286
Public Value	$230,496,454
Return on Capital	9.29%
Ecological-Economic Return on Private Investment (EERPI) ($/$)	11.8

Table 16.4. Scenario High/Low: High consumer participation rate (500,000) and low Land Steward participation (50,000 ha; 125,000 ac).

Item	Value
Monthly Per Capita Donation	**$3.00**
Dividend Rate	0.5%
Administrative Costs	2.0%
Participant Consumers	500,000
Forest Area, ha	50,000
Land Steward Revenue	$18,571,429
Land Steward Costs	$6,500,000
Land Steward Income	$12,071,429
Income per hectare	$241
Capital Investment	$1,000,000
EIC Revenue	$19,500,000
EIC Payments	$18,571,429
Dividends	$92,857
Admin. Costs	$371,429
EIC Net Income	$464,286
Public Value	$230,496,454
Return on Capital	9.29%
Ecological-Economic Return on Private Investment (EERPI) ($/$)	11.8

Table 16.5. Scenario Low/High: Low consumer participation rate (50,000) and high Land Steward participation (200,000 ha; 500,000 ac).

Item	Value
Monthly Per Capita Donation	**$118.00**
Dividend Rate	0.5%
Administrative Costs	2.0%
Participant Consumers	50,000
Forest Area, ha	200,000
Land Steward Revenue	$74,285,714
Land Steward Costs	$26,000,000
Land Steward Income	$48,285,714
Income per hectare	$241
Capital Investment	$1,000,000
EIC Revenue	$76,700,000
EIC Payments	$74,285,714
Dividends	$371,429
Admin. Costs	$1,485,714
EIC Net Income	$557,143
Public Value	$921,985,816
Return on Capital	37.14%
Ecological-Economic Return on Private Investment (EERPI) ($/$)	12.0

Table 16.6. Scenario Medium/High: Medium consumer participation rate (250,000) and high Land Steward participation (200,000 ha; 500,000 ac).

Item	Value
Monthly Per Capita Donation	**$23.50**
Dividend Rate	0.5%
Administrative Costs	2.0%
Participant Consumers	250,000
Forest Area, ha	200,000
Land Steward Revenue	$74,285,714
Land Steward Costs	$26,000,000
Land Steward Income	$48,285,714
Income per hectare	$241
Capital Investment	$1,000,000
EIC Revenue	$76,375,000
EIC Payments	$74,285,714
Dividends	$371,429
Admin. Costs	$1,485,714
EIC Net Income	$232,143
Public Value	$921,985,816
Return on Capital	37.14%
Ecological-Economic Return on Private Investment (EERPI) ($/$)	12.1

Table 16.7. Scenario High/High: High consumer participation rate (500,000) and high Land Steward participation (200,000 ha; 500,000 ac).

Item	Value
Monthly Per Capita Donation	**$11.75**
Dividend Rate	0.5%
Administrative Costs	2.0%
Participant Consumers	500,000
Forest Area, ha	200,000
Land Steward Revenue	$74,285,714
Land Steward Costs	$26,000,000
Land Steward Income	$48,285,714
Income per hectare	$241
Capital Investment	$1,000,000
EIC Revenue	$76,375,000
EIC Payments	$74,285,714
Dividends	$371,429
Admin. Costs	$1,485,714
EIC Net Income	$232,143
Public Value	$921,985,816
Return on Capital	37.14%
Ecological-Economic Return on Private Investment (EERPI) ($/$)	12.1

The effect of participation rates of consumers and land stewards on consumer donation rate, dividends to stockholders, income to land stewards, and public value generated were further explored below.

How much do consumer payments need to be for the EIC to be profitable?

The amount of money paid by consumers to the EIC for it to be profitable depends on the number of consumers and land stewards that participate (Table 16.8). Six scenarios were used to explore what the range of consumer payments should be for land stewards to be paid $241/ha/y. Each scenario assumed either a high, medium or low consumer participation rate and either a high or low land steward participation rate. For the most optimistic scenario where there was 500,000 consumer participants and 200,000 ha (500,000 ac) of forest land in the EIC, the per capita monthly payment would be $11.75. On the other end of the range, under the least participation by consumers and land stewards (50,000 participants, 50,000 ha), the monthly payment would need to be $30.00. For $3.00 per month and 500,000 participants, the EIC could pay for 50,000 ha of forest ecosystem services (Table 16.8).

Table 16.8. Mean monthly payment by consumers for Land Stewards to receive $241/ha/y and for the EIC to by profitable.

Consumer Participation		**Land Steward Participation (ha)**	
		Low	High
		50,000	200,000
Low	50,000	**$30.00**	**$118.00**
Medium	250,000	**$6.00**	**$23.50**
High	500,000	**$3.00**	**$11.75**

How much will be paid in dividends to EIC stockholders?

The amount of money paid as dividends to EIC stockholders was 0.5% of the payments to land stewards (Table 16.1). Tying stockholder dividends to land steward payments provides the incentive for the EIC to maximize the production of ecosystem services. Six scenarios were used to explore what the range of dividend payments would be if land stewards were paid $241/ha/y and the EIC were profitable. Each scenario assumed either a high, medium or low consumer participation rate and either a high or low land steward participation rate. For the most optimistic scenario where there were 500,000 consumer participants and 200,000 ha (500,000 ac) of forest land in the EIC, the annual dividends were $371,429 (Table 16.9). On the other end of the range, under the least participation by consumers and land stewards (50,000 participants, 50,000 ha), the annual dividends were $92,857 (Table 16.9). Assuming that $1,000,000 was the capital value invested in the EIC by stockholders, the annual rate of return on capital would be 9.3% when land steward participation was low, or as high as 37% when steward participation was high.

Table 16.9. Mean annual dividend to stockholders Land Stewards to receive $241/ha/y and for the EIC to by profitable.

Consumer Participation		**Land Steward Participation (ha)**	
		Low	High
		50,000	200,000
Low	50,000	**$92,857**	**$371,429**
Medium	250,000	**$92,857**	**$371,429**
High	500,000	**$92,857**	**$371,429**

How much income do land stewards collect?

The amount of money earned by land stewards is the difference between payments from the EIC and costs associated with management, auditing and restoration. Six scenarios were used to explore what the range of income would be if land stewards were paid $241/ha/y and their costs averaged $10/ha/y. That is, their net income per hectare of forest would be $231/ha/y. The total statewide income would then be $231/ha/y times the number of hectares in the EIC. Each scenario assumed either a high, medium or low consumer participation rate and either a high or low land steward participation rate. For the most optimistic scenario where there was 500,000 consumer participants and 200,000 ha (500,000 ac) of forest land in the EIC, the statewide income was $48,285,714 (Table 16.10). On the other end of the range, under the least participation by consumers and land stewards (50,000 participants, 50,000 ha), the statewide income was $12,071,429 (Table 16.10). Obviously, if costs were higher, income would be less.

Table 16.10. Mean annual income for all Land Stewards assuming payments were $241/ha/y and costs were $10/ha/y.

Consumer Participation		**Land Steward Participation (ha)**	
		Low	High
		50,000	200,000
Low	50,000	**$12,071,429**	**$48,285,714**
Medium	250,000	**$12,071,429**	**$48,285,714**
High	500,000	**$12,071,429**	**$48,285,714**

How much public value is generated by the ecosystem services in the EIC?

The amount of public value generated by the ecosystem services was their solar emergy divided by the mean “price” for solar emergy in the state (Table 16.1). Six scenarios were used to explore what the range of public value would be. Each scenario assumed either a high, medium or low consumer participation rate and either a high or low land steward participation rate. For the most optimistic scenario where there was 500,000 consumer participants and 200,000 ha (500,000 ac) of forest land in the EIC, the statewide public value was $921,985,000 (Table 16.11). On the other end of the range, under the least participation by consumers and land stewards (50,000 participants, 50,000 ha), the statewide public was $230,496,000 (Table 16.11). Under the most optimistic scenario, the public value generated per dollar paid into the EIC was $12.1, while it was $11.8 under the least optimistic scenario.

Table 16.11. Mean annual public value generated by ecosystem services in EIC.

Consumer Participation		**Land Steward Participation (ha)**	
		Low	High
		50,000	200,000
Low	50,000	**$230,496,000**	**$921,985,000**
Medium	250,000	**$230,496,000**	**$921,985,000**
High	500,000	**$230,496,000**	**$921,985,000**

16.2. Discussion of *EcoInvestCorp*

The current study did not inquire as to how many consumers of ecosystem services would be willing to donate to the EIC. However, we assumed that 4% of Marylanders could be persuaded to donate $6 per month per person. This would be comparable to a subscription to a movie service such as Netflix, or 1/20th of what households spend on electricity, or 1/6th of what households spend on potable water. One method to entice consumers to donate to the EIC would be to show them that each $1 donated generates $12 of public value.

Rather than target individual consumers, it likely would be worthwhile for the EIC to market their services to for-profit and non-profit corporations, towns and cities, and other large organizations that want to offset their consumption of ecosystem services. For example, a small, progressive town like College Park or Takoma Park, might be willing to invest and donate to an EIC to offset all of the ecosystem services their businesses and residents consume for transportation, air conditioning, heating, lighting and such.

EcoInvestCorp assumed that Stewards would register their ecosystem services with the EIC if they were paid $241/ha/y. This value was based on the emergy analyses of the individual services and their eco-prices (emergy per dollar), not on a survey of interest or willingness for them to participate. The majority of forestland in Md is owned as tracts of less then 10 ac (4 ha). At the payment rate of $241 ($100/ac/y), the average landowner would receive payments of $1000/y. This would seem to be an attractive amount of revenue for many, but certainly not all, small landowners. Certainly, if a landowner wanted to sell an acre of undeveloped land they could make more (~$5,000-$30,000), but they would most likely lose all rights to the land. As part of the EIC they retain many of the original land rights, but would be responsible for ensuring that ecosystem services were being produced.

Participation of 250,000 consumers and 50,000 ha (5% of forested land) would require donation of $6 per month per person. This would generate income for land stewards of more than $12,000,000 per year. It would also create ecological value for the public at a rate greater than $230,000,000 per year. For comparison, this is roughly equivalent to the state budget for the Department of Natural Resources.

Investors should be attracted to the EIC since dividends could be paid in the range of $92,000 per year. If $1 million were invested, then the Return on Capital would be 9%. The drawback to paying dividends as profit sharing, is that the EIC would not be a tax deductible non-profit organization, which might preclude consumers from participating without a tax deduction.

17. Next Steps

To operationalize the EIC we suggest a pilot test whereby a region of Md is targeted. The region should include one major urban/suburban area (Montgomery, Prince Georges or Baltimore Counties) and its surrounding rural counties. Montgomery, Frederick, Washington and Allegany Counties might be a good pilot-testing region since they are contiguous, share political boundaries, watersheds and physiographic provinces. With populations of 925,000, 222,000, 143,000, and 72,000, respectively, as of 2006 (http://www.bea.gov/), the region has over 1.3 million citizens. The rural counties also account for a large portion of the forest land in Md.

The EIC needs to be marketed to both consumers and land stewards. Consumers could be enticed to donate once they know how little they have to contribute to be participants and understand the great return the public will get for their donation. Digital and hard copy campaign literature would be needed to target consumers, especially in the municipalities of Montgomery Co. Donations could be tax deductible if the EIC did not pay out dividends as profit-sharing with stockholders. However, if there were no dividends, then it would be difficult to attract investors to capitalize the EIC. If the EIC were capitalized with private investors, then it would be able to borrow money to leverage the power of its donations.

A survey of land stewards needs to be conducted in the pilot-testing region to ascertain the payment levels that would entice them to commit their forest land to the EIC. A list of the responsibilities and covenants placed on land stewards would need to be created and explained so that it can be easily understood by stewards for their decision-making process.

17.1. Land Steward Tools for Estimating Value

There are two proposed tools that could be used by land stewards to evaluate the ecosystem services provided by their land:

1. **Forest stand survey and hydrologic budget (FSSHB):** A survey of the forest stand would be conducted following standard forestry practices (age, species, DBH, density, area, etc). In addition it would be necessary to assess the average leaf area index (LAI), soil OM, bulk density, topography, and rainfall of the previous year. These measurements would be used as inputs to models in a similar fashion as has been done over the course of this research.

The limitation of the FSSHB is that it would be time intensive and costly. This would likely deter smaller landowners from participating in the program, which would limit the scope of the EIC.

2. **Geographic Information System Survey (GISS):** This tool would use existing GIS resources and online data to estimate the flows of ecosystem services in a given area of land.

The primary advantage of this method is that it could be done quickly and at a low cost, enabling a wider range of participants in the EIC. The disadvantage is that the values would be more approximate and it would be more difficult to distinguish between land providing high value ecosystem services vs. low value. Integration with the Bay Bank Landserver online tool (www.landserver.org/) would likely be possible.

17.2. Funding the Ecosystem Investment Corporation

While this research project did not investigate specific mechanisms for funding the EIC, we believe it is appropriate to briefly offer some ideas on how funding could be achieved. The following is a non-exhaustive list of options for generating revenue for the EIC.

1. **A voluntary contribution system**. Consumers of ecosystem services could be provided information on how much ecosystem service they consume and then offered the opportunity to pay into the EIC to offset some of their consumption. The public value of consumption could be based on converting the solar emergy of their consumption to dollars in a manner similar to what was done in this report to value the production of ecosystem services.

Politically, this may be the easiest way to generate funding, but the amount of funding may be low. A sophisticated marketing plan would be needed to encourage individuals, organizations and corporations to contribute. The marketing would need to explain how their contributions would be used. Contributors are likely motivated by various reasons, so this should be a topic of research.

2. **Ecosystem Services Mitigation**: The state could pass legislation that requires equivalent mitigation of all forest ecosystem services lost due to land development. This could be modeled on wetland mitigation banking, whereby loss of wetland acreage is replaced by restoring wetland acreage somewhere else. This policy would mandate a **no net loss in statewide ecosystem services**. The equivalency of losses and gains could be measured using solar emergy rather than just simply acreage to ensure fuller equity between the losses and gains.

3. **Tax credits**. Forest landowners who enrolled in the EIC could be given tax credits rather than payments from the EIC. Since payments would be considered income, some landowners may find it beneficial to have the credit rather than the payment. The EIC would still need a funding stream to cover operational and administrative costs, which could come from Voluntary Contributions (#1 above).

4. **A tax on high impact goods**, such as gasoline, fertilizers, and inefficient vehicles could be used to generate revenue for the EIC. A weakness to this method is that the amount of revenue generated would not necessarily match the value of ES provided by forests. In addition, this tax could potentially have a disproportionate cost for lower income individuals and small businesses. Politically, taxation of this kind would likely be unpopular and therefore difficult to enact.

5. **Income tax**. Revenue from the state tax income tax could be directed to the EIC. The main weakness with this method is that raising income taxes is politically difficult. If taxes were not raised but state revenues directed to the EIC, then other state programs would need to forgo revenue. The feasibility of this funding mechanism is low.

17.3. Registering Land Stewards to Participate in the EIC

Once the EIC has a reliable funding mechanism the next step is to entice landowners to enroll in the EIC. With over 80% of forest landowners owning less than 10 acres, which accounts for about 20% of the forestland in Maryland, it is imperative to reduce the barriers to enrollment. Application fees should be kept to a minimum to cover administrative costs since it could be a significant deterrent for the small landowner. A low barrier of entry is essential to getting at least a portion of these landowners to enroll.

The EIC has the potential to reduce the amount of forestland that is lost to development since it will alter the financial situation of many forest landowners. In addition the EIC should increase the visibility of ecosystem services as a need of the public at large. The vast majority of people do not realize the tremendous value they are receiving from the world around them. Asking people to pay a fair price for these services may be the best, and perhaps the only, way to make this connection tangible and real. The final conformation of the EIC will likely be determined by political and economic feasibility but it has the potential to strengthen the long-term sustainability for the people and forests of Maryland.

18. Appendix 1. Emergy evaluations of the State of Maryland

	State Land Area	2.53E+10	m^2	US Census
	Maryland Population (2000)	5.30E+06	people	US Census http://quickfacts.census.gov/qfd/states/24000.html
	Per Capita Income (1999)	2.56E+04	$/person/year	
1	**SOLAR ENERGY:**			
	Area =	1.39E+11	m^2	Average of five 1 minute squares used for Albedo and insolation (ETC) Go to NSA web site http://eosweb.larc.nasa.gov/cgi-bin/sse/grid.cgi?email=campbell.dan@epa.gov down lodad and average insolation and albedo for other squares in MD.
	Insolation =	3.84	KWh/m2/d	
	Energy(J) =	1.38E+08	J/m2/y	
	Albedo =	0.112		Number from one 1 minute square centered on 39.5 N Lat. -76.7 N Lon.
	Energy(J) =	(area incl shelf)*(avg insolation)*(1-albedo)		
	=	(____m^2)(____$Cal/cm^2/y$)(E+04cm^2/m^2)(1-____)(4186J/kcal)		
	Received Energy(J) =	1.93E+19	J/yr	
	Asorbed Energty (J)	1.71E+19	J/yr	
	Emergy per unit=	1		(Odum, 1996)
	Absorbed on land	3.50E+18	J/yr	
	Absorbed on land + bay	4.12E+18	J/yr	
	Absorbed on water (shelf +bay)	1.58E+19	J/yr	
	length of shoreline			
	Bay			
	Eastern Shore			
2	**WIND ENERGY:**			
	Area =	1.39E+11	m^2	
	Density of Air =	1.30E+00	kg/m^3	
	Avg. annual wind velocity =	3.99E+00	mps	Use NASA site and other squares for MD
	Geostrophic wind =	6.65E+00	mps	(Odum, 1996)
	Drag Coeff. Water =	1.00E-03	land 2.00E-03	
	Energy (J) =	(area)(air density)(drag coefficient)(wind velocity^3)		
	=	(_____m^2)(1.3 kg/m^3)(1.00 E-3)(______mps)^3(3.14 E7 s/yr)		
	Energy(J) =	1.67E+18	J/yr	
	Emergy per	1470		(Odum, 1996)

unit=			
Energyon land	6.10E+17		

3 **TIDAL ENERGY:**

Baltimore, Tolchester Beach, Annapolis, Cambridge, Solomons Island Stations-*NOAA Site-Stations Identification Number: Baltimore-8574680; Tolchester Beach-8573364; Annapolis-8575512; Cambridge-8571892; Solomons Island-857730*

Area =	1.14E+11	m^2	(Derived from nearest available data(NJ))
Avg Tide Range =	0.51	m	(NOAA Website)
Density =	1.03E+03	kg/m^3	
Tides/year =	7.30E+02		(Odum, 1996)
Energy(J) =	(shelf)(0.5)(tides/y)(mean tidal range)^2(density of seawater)(gravity)		
=	(____m^2)(0.5)(____/yr)(____m)^2(_____kg/m^3)(9.8m/s2)		
Energy(J) =	1.10E+17	J/yr	
Energy on bay	4.30E+15		
Emergy per unit=	24300		(Odum, 1996)

4 **RAIN, CHEMICAL POTENTIAL ENERGY:**

Land Area =	2.53E+10	m^2	
Shelf Area =	1.14E+11	m^2	
Rain (land) =	1.13	m/yr	(NOAA Website)
Rain (shelf) =	0.51	m/yr	(45% of land rainfall)
Energy (J)=	(land area)(rainfall)(Gibbs energy of rain) + (Shelf area)(rainfall)(Gibbs energy of rain)		
=	(____m^2)(____m)(1000kg/m^3)(4.74E+03J/kg)		
Energy(J) =	4.11E+17	J/yr	
Emergy per unit=	18100		(Odum, 1996)
energy rain land only	1.36E+17		
energy rain on the bay	2.40E+16		

5 **TRANSPIRATION, CHEMICAL POTENTIAL:**

Community type:	Forest		
Area:	1.04E+10	m^2	USDA, Forest Inventory and Analysis, 1999
Transpiration rate =	584	mm/yr	Penman-Moneith Equation
Specific gravity =	1.00E+06	g/m^3	
Energy (J) =	(land area m^2)(mm/yr)(0.001m/mm)(specific gravity g/m3)(4.94J/g)		
Energy (J) =	2.88E+16	J	
Emergy per unit=	2.81E+04	sej/J	
			1.9924E+00
Community type:	Wetland		
Area freswater:	3.4E+05	m^2	
Area saltwater:	2.52E+05	m^2	Maryland Department of Natural Resources, 1195 Wetland Survey
Transpiration rate freshwater	647	mm/yr	(Derived from pocosin swamp, Mitsch and Gosselink, 1993)

=

Transpiration rate saltwater = 1992 mm/yr (Derived from Great lakes costal marsh Mitsch and Gosselink, 1993)

Specific gravity = 1.00E+06 g/m^3

Energy (J) = 1.05E+12 J/yr

Energy (J) = 2.38E+12 J/yr

Total Energy Wetland= 3.43E+12 J/yr

Community type: Agricultural-Corn-

Area: 8.50E+09 m^2 Maryland archives http://www.mdarchives.state.md.us/msa/mdmanual/01glance/html/agri.html

Transpiration rate = 724 mm/yr Food and Agriculture Organization, Evapotranspiration rate Report

Specific gravity = 1.00E+06 g/m^3

Energy (J) = 2.92E+16

Transpiration rate derived from FAO crop coefficient for maize avaraged of four growning stage of corn

Community type: Urban

Area: 4.64E+09 m^2 Maryland Planning Department, Essential Facts about Growth in MD, 1997

Transpiration rate = 724 mm/yr assumed

Specific gravity = 1.00E+06 g/m^3

Energy (J) = 1.77E+16

Transpiration rate: assume 80% area with pasture use lawn ET; the other 20% imprevious surface with 100% evaporation rate.

Total energy, all communities = 7.56E+16

Emergy per unit= 2.81E+04 sej/J

6 **RIVERS, CHEMICAL POTENTIAL:**

Gibbs free energy = [(8.3143 J/mol/deg)(288 K)/(18 g/mol)] * ln [(1e6 - Solutes)ppm)/965000]

= 4.74 J/yr

Energy (J) = (volume flow)(density)(Gibbs free energy relative to seawater)

= 0.00E+00 J/yr

Emergy per unit= 50100 sej/J (Odum, 1996)

Gibbs free energy = [(8.3143 J/mol/deg)(288 K)/(18 g/mol)] * ln [(1e6 - Solutes)ppm)/965000]

Inputs:

Stream	**Volume m^3/yr**	**Solutes ppm**	**Gibbs Free Energy J/yr**	**Energy J/yr**	USGS Water Resources Data Maryland and Delaware, 2000
Susquehanna River	3.63E+10	133.38	4.72	1.71E+17	Station: 03075500 & 03076500
Chester River	1.15E+07	98.75	4.73	5.43E+13	Station: 01493000 & 01493000
Choptank	1.18E+08	96	4.73	5.58E+14	Station: 01491000

River					
Monocacy	5.18E+08	80.5	4.73	2.45E+15	Station: 01639000 & 01649000
Nanticoken River	8.17E+07	125.5	4.72	3.86E+14	Station: 01488500
Pocomoke River	6.50E+07	109.44	4.72	3.07E+14	Station: 01485000
Potomac River, border river	5.66E+09	181.3	4.72	1.33E+16	Station: 01595000 &01646500

Energy Inputs= 1.88E+17 J/yr

Outputs:

Stream	Volume m3/yr	Solutes ppm	Gibbs Free Energy J/yr	Energy J/yr	USGS Water Resources Data Maryland and Delaware, 2000
Youghioghen y River	4.24E+08	120	4.72	2.40E+11	Station: 03075500 & 03076500
Casselman River	3.53E+08	100	4.73	1.67E+11	Station: 03078000 & 03076500
Energy Outputs=	4.07E+11	J/yr			

Density (g/m^3) = 1.00E+06 g/m^3

Total Energy= 1.88E+17 J/yr

Emergy per unit= 18199 sej/J (Odum, 1996)

7 **RAIN RECEIVED, GEOPOTENTIAL ENERGY:**

Coastal Plains

Land Area = 1.29E+10 m^2

Rainfall = 1.12 m

Avg. Elev = 30.48 m

An Overview of Maryland Wetlands and Water Resources, Maryland Department of Environment, 2000

Elevations obrained from USGS

Energy(J) = (land area)(rainfall)(avg elevation)(gravity)

= (____m^2)(____m)(1000kg/m^3)(____m)(9.8m/s^2)

Note: Elevation is an avarage of known elevation rangewithin the area

Energy(J) = 4.33E+15 J/yr

Piedmont

Land Area = 6.47E+09 m^2

Rainfall = 1.10 m

Avg. Elev = 182.88 m

An Overview of Maryland Wetlands and Water Resources, Maryland Department of Environment, 2000

Elevations obtained from USGS

Energy(J) = 1.28E+16 J/yr

Blue Ridge

Land Area = 1.55E+09 m^2

Rainfall = 1.12 m

Avg. Elev = 457.20 m

Technique for estimating magnitud and frequency of peak flows in MD, USGS Report 95-4154, 1996

Elevations obtained from USGS

Energy(J) = 7.80E+15 J/yr

Ridge and Valley

Land Area = 2.07E+09 m^2

Rainfall = 0.95 m

Avg. Elev = 320.04 m

Technique for estimating magnitud and frequency of peak flows in MD, USGS Report 95-4154, 1996

Elevations obtained from USGS

Energy(J) 6.19E+15 J/yr

=

Appalachian

Land Area =	2.07E+09	m^2	Technique for estimating magnitud and frequency of peak flows in MD, USGS Report 95-4154, 1996
Rainfall =	1.10	m	
Avg. Elev =	655.32	m	Elevations obtained from USGS
Energy(J) =	1.46E+16	J/yr	
Total Energy=	4.57E+16		
Emergy per unit=	**10300**	sej/J	(Odum, 1996)

8 **RAIN USED GEOPOTENTIAL ENERGY:**

Coastal Plains

Land Area =	1.29E+10	m^2	An Overview of Maryland Wetlands and Water Resources, Maryland Department of Environment, 2000
Rainfall =	1.12	m	
Avg. Elev =	30.48	m	Elevations obtained from USGS
Runoff =	0.414782	m	
Energy(J) =	(land area)(rain-runoff)(Density)(avg elevation)(gravity)		
=	(____m^2)(____m)(1000kg/m^3)(____m)(9.8m/s^2)		
Energy(J) =	2.73E+15	J/yr	

Note: percentage runoff calculated from average precipitation and average runoff in the area.

Piedmont

Land Area =	6.47E+09	m^2	An Overview of Maryland Wetlands and Water Resources, Maryland Department of Environment, 2000
Rainfall =	1.10	m	
Avg. Elev =	182.88	m	Elevations obrained from USGS
Runoff rate =	0.3937	m	Runoff & Precipitation maps published by USGS circular 1123, 1995
Energy(J) =	8.20E+15	J/yr	

Blue Ridge

Land Area =	1.55E+09	m^2	Technique for estimating magnitud and frequency of peak flows in MD, USGS Report 95-4154, 1996
Rainfall =	1.12	m	
Avg. Elev =	457.20	m	Elevations obtained from USGS
Runoff rate =	0.3556	m	Runoff & Precipitation maps published by USGS circular 1123, 1995
Energy(J) =	5.32E+15	J/yr	

Ridge and Valley

Land Area =	2.07E+09	m^2	Technique for estimating magnitud and frequency of peak flows in MD, USGS Report 95-4154, 1996
Rainfall =	0.95	m	
Avg. Elev =	320.04	m	Elevations obtained from USGS NED
Runoff rate =	0.54175	m	Runoff & Precipitation maps published by USGS circular 1123, 1995
Energy(J) =	2.67E+15	J/yr	

Appalachian

Land Area =	2.07E+09	m^2	Technique for estimating magnitud and frequency of peak flows in MD, USGS Report 95-4154, 1996
Rainfall =	1.10	m	
Avg. Elev =	655.32	m	Elevations obtained from USGS
Runoff rate =	0.5715	m	Runoff & Precipitation maps published by USGS circular 1123, 1995

Energy(J) = 7.03E+15 J/yr

Total Energy= 2.59E+16

Emergy per unit= **27200** **sej/J** (Buenfil 2001)

9 **RUNOFF**

Coastal Plains

Runoff Area =	1.29E+10	m2	An Overview of Maryland Wetlands and Water Resources, Maryland Department of Environment, 2000
elevation =	30.48	m	
runoff rate =	0.414782	m	Runoff & Precipitation maps published by USGS circular 1123, 1995
Gravity =	9.81	m/s2	
Energy (J) =	(area)(mean elevation)(runoff)(density)(gravity)		
=	1.61E+15	J/yr	

Piedmont

Runoff Area =	6.47E+09	m2	An Overview of Maryland Wetlands and Water Resources, Maryland Department of Environment, 2000
elevation =	182.88	m	
runoff rate =	0.3937	m	Runoff & Precipitation maps published by USGS circular 1123, 1995
Gravity =	9.81	m/s2	
=	4.57E+15	J/yr	

Blue and Ridge

Runoff Area =	1.55E+09	m2	Technique for estimating magnitud and frequency of peak flows in MD, USGS Report 95-4154, 1996
elevation =	457.20	m	
runoff rate =	0.3556	m	Runoff & Precipitation maps published by USGS circular 1123, Wahl 1995
Gravity =	9.81	m/s2	
=	2.48E+15	J/yr	

Ridge and Valley

Runoff Area =	2.07E+09	m2	Technique for estimating magnitud and frequency of peak flows in MD, USGS Report 95-4154, 1996
elevation =	320.04	m	
runoff rate =	0.54175	m	Runoff & Precipitation maps published by USGS circular 1123, Wahl, 1995
Gravity =	9.81	m/s2	
=	3.52E+15	J/yr	

Appalachian

Runoff Area =	2.07E+09	m2	Technique for estimating magnitud and frequency of peak flows in MD, USGS Report 95-4154, 1996
elevation =	655.32	m	
runoff rate =	0.5715	m	Runoff & Precipitation maps published by USGS circular 1123, 1995
Gravity =	9.81	m/s2	
Energy =	7.61E+15		

Total energy = 1.98E+16

Emergy per unit= **27200** sej/J (Odum, 1996)

10 **RIVERS, GEOPOTENTIAL ENERGY:**

Energy (J) = S(volume flow)(density)(height in-height out)(gravity))

Density (g/m^3) = 1.00E+03 kg/m^3

Stream	Volume	Height In	Height out	Energy	USGS Water Resources Data Maryland and

	m^3/yr	m	m	J/yr	Delaware, 2000
Susquehanna River	3.63E+10	121.92	0	4.34E+16	Station: 03075500 & 03076500
Chester River	1.15E+07	1.08	0	1.22E+11	Station: 01493000 & 01493000
Choptank River	1.18E+08	1.04	0	1.20E+12	Station: 01491000
Monocacy	5.18E+08	103.88	0	5.28E+14	Station: 01639000 & 01649000
Nanticoken River	8.17E+07	7.99	0	6.40E+12	Station: 01488500
Pocomoke River	6.50E+07	4.25	0	2.71E+12	Station: 01485000
Potomac River	5.57E+09	693.73	11.56716	1.86E+16	Station: 01595000 &01646500
Energy=				6.26E+16	
Youghiogheny River	4.24E+08	717.38	472.845	1.02E+15	Station: 03075500 & 03076500
Casselman River	3.53E+08	636.72	504	4.59E+14	Station: 03078000 & 03076500
Energy=				1.48E+15	

Total Energy= 6.41E+16 J/yr

Emergy per unit= 27200 sej/J (Odum, 1996)

11 **WAVE ENERGY:**

Ocean City MD001 and MD002 Maryland Costal Management, MDNR 2000

Shore length = 1.60E+05 m

Wave height = 8.50E-01 m US Army Corps of Engineers Costal Data

Depth = 9.00E+00 m US Army Corps of Engineers Costal Data

Wave velocity = 9.39E+00 m/sec Calculated as a function of depth, Odum 1996

Energy(J) = (shore length)(1/8)(density)(gravity)(wave height^2)(velocity)(3.14E7s/yr)

= (_m)(1/8)(1.025 E3kg/m^3)(9.8 m/sec^2)(__m)^2(__m/sec)(3.14E7s/yr)

Energy(J) = 4.28E+16 J/yr

Emergy per unit= 30000 sej/J (Odum, 1996)

12 **EARTH CYCLE**

Area = 2.53E+10 m^2

Heat flow = 1.58E+06 J/m^2 IHFC, 2000

Energy (J) = (area)(heat flow)

Energy(J) = 4.00E+16 J/yr

Emergy per unit= 33700 sej/J (Odum, 1996)

Heat through Bay 7.06E+15

13 **WASTE TREATMENT**

Production = 7.44E+06 tons/yr Maryland Environmental Department, Waste Management Report

g/metric ton =	1.00E+06	g/ton	2000
Annual production =	7.44E+12	g/yr	
Emergy per unit=	3.89E+07	sej/g	(Brown, 2003)

Note: waste calculated from the difference from waste handle in the state minus waste imported and addition of MD waste exported to other states.

14 **NET SOIL LOSS OR BUILDUP**

Net loss of topsoil = (farmed area)(erosion rate)

Loss of organic matter = (net loss of topsoil)(organic fraction)

Energy loss= (loss of organic matter)(5.4 kcal/g)(4186 J/kcal)

Cultivated Crop =	5.0448E+09	m^2	National Agricultural Statistics Service, USDA, data 2007
Erosion rate =	986	g/m2/yr	2002 National Resources Inventory
Fraction organic in soil =	0.02		Dochester County Soil Survey, NRSC
Energy content in organic=	5.40	kcal/g	
Annual energy =	2.25E+15	J	
Non-Cultivate Land =	7.1348E+08	m^2	National Agricultural Statistics Service, USDA, data 2007
Erosion rate =	269	g/m2/yr	2002 National Resources Inventory
Fraction organic in soil =	0.02		Dochester County Soil Survey, NRSC
Energy content in organic=	5.40	kcal/g	
Annual energy =	8.68E+13	J	
Pastureland =	2.74E+08	m^2	National Agricultural Statistics Service, USDA, data 2007
Erosion rate =	157	g/m2/yr	2002 National Resources Inventory
Fraction organic in soil =	0.02		Dochester County Soil Survey, NRSC
Energy content in organic=	5.40	kcal/g	
Annual energy =	1.94E+13	J	
Forested Land =	1.04E+10	m^2	National Agricultural Statistics Service, USDA, data 2007
Erosion rate =	31	g/m2/yr	2002 National Resources Inventory
Fraction organic in soil =	0.06		Dochester County Soil Survey, NRSC

Energy content in organic=	5.40	kcal/g	
Annual energy =	4.39E+14	J	
TOTAL ANNUAL ENERGY=	**2.79E+15**	**J**	
Emergy per unit=	**7.26E+04**	**sej/J**	(Odum 1996)-Campbell (2000)

15 **COAL, production**

Mined amount =	4.55E+06	Sh tons/yr	EIA Energy Information Agency, (2000) Coal Industry Annual 2000, U.S. Department of Energy, DOE/EIA-0584, Washington, DC, Table 3 .
g/short ton =	9.07E+05		
Energy content =	2.94E+04	J/g	
Energy (J) =	(short tons)(g/short ton)(J/g)		
=	**1.21E+17**	**J**	
Emergy per unit=	**3.92E+04**	**sej/J**	(Odum 1996)-Campbell (2000)

16 **SAND&GRAVEL, NON-METALLIC MINERALS**

Sand& & Gravel

Mined amount =	1.31E+07	tons/yr	USGS Minerals Yearbook 2000
g ton =	1.00E+06	g/ton	http://minerals.usgs.gov/minerals/pubs/state/md.html
Annual production =	1.31E+13	g/yr	accessed Oct16, 2007
Emergy =	1.72E+22	sej/y	Page Last Modified: Wednesday, 11-Jul-2007 09:25:42 EDT

Clay

Mined amount =	2.71E+05	tons/yr	USGS Minerals Yearbook 2000
g/metric ton =	1.00E+06	g/ton	
Annual production =	2.71E+11	g/yr	http://minerals.usgs.gov/minerals/pubs/state/md.html
Emergy =	5.32E+20	sej/y	

Stones (granite crushed + Misc.) (Odum 1996)-Campbell (2000)

Mined amount =	5.91E+06	tons/yr	
g/metric ton =	1.00E+06	g/ton	USGS Minerals Yearbook 2000, Maryland
Annual production =	5.91E+12	g/yr	
Emergy =	2.90E+21	sej/y	http://minerals.usgs.gov/minerals/pubs/state/md.html
Transformities of Stone			
Sand Emergy per unit=	1.31E+09	sej/g	
Clay Emergy per unit=	1.96E+09	sej/g	(Odum 1996)-Campbell (2000)
Granite emergy per unit	4.91E+08	sej/g	
Limestone	9.81E+08		

	Sand Stone	1.31E+05	tons/yr	http://minerals.usgs.gov/minerals/pubs/state/md.html
		1.00E+06	g/ton	
	Annual production =	1.31E+11	g/yr	
	Emergy =	1.72E+20	sej/y	
	Limestone	1.84E+07	tons/yr	http://minerals.usgs.gov/minerals/pubs/state/md.html
		1.00E+06	g/ton	
	Annual production =	1.84E+13	g/yr	
	Emergy =	1.81E+22	sej/y	
	Total Mass of minerals	3.78E+13		
	Emergy of minerals	3.88E+22	sej/y	
17	**TIMBER**			
	Forest Harvest			Forestry inventory and Analysis, USDA Forestry Services, 1999
	=	2.94E+09	ft3/yr	
	=	8.33E+13	cm3/yr	
	dry wt =	0.5	g/cm3	
	Energy content =	19200	J/g	
	Energy (J) =	(vol forest harvested)(dry wt)(J/g)		
	=	**7.99E+17**	**J/yr**	
	Emergy per unit=	**6.70E+03**	**sej/J**	(Odum 1996)
18	**NATURAL GAS**			
	Amount =	3.40E+04	Thous ft3	Energy Information administration web page www.eia.doe.gov, 2000
	Energy content =	1.1E+09	J/thous ft3	
	Energy (J) =	(Thous ft3)(J/Thous ft3)		
	=	**3.74E+13**	**J/yr**	
	Emergy per unit=	**4.35E+00**	**sej/J**	(Odum 1996)
19	**BUILDING MATERIALS**			
	Cement			
	Production =	1.84E+06	tons/yr	USGS Mineral Industry Report 2000 data
	g/metric ton =	1.00E+06	g/ton	http://minerals.usgs.gov/minerals/pubs/state/md.html
	Annual production =	1.84E+12	g/yr	
	Emergy per unit=	1.94E+09	sej/g	(Brown & Buranakarn 2003)
	emergy	3.57E+21	sej/y	
	Steel			
	Production =	3.70E+06	tons/yr	Bethlehem Corporation Annual Report 2000
	g/metric ton =	1.00E+06	g/ton	
	Annual production =	3.70E+12	g/yr	
	Emergy per unit=	4.12E+09	sej/g	(Brown & Buranakarn 2003)
	emergy	1.52E+22	sej/y	

Total annual production = 5.54E+12
Total annual emergy = 1.88E+22

20 **GRAINS, FRUITS, VEGETABLES**

Data on from Maryland Agricultural Statistic for 2000

Commodity	*g/yr*	*Energy (joules)*	*Transformity(sej/J)*	*Emjoules*
Corn	*1.57E+12*	*3.10E+16*	*3.9602E+05*	*1.2271E+22*
Wheat	3.14E+11	*4.47E+15*	121678.8674	*5.4369E+20*
Barley	1.02E+11	1.51E+15	121678.8674	*1.8374E+20*
Soybeans	*5.52E+11*	*9.61E+15*	*2.1773E+05*	*2.0924E+21*
Hay	*6.45E+11*	*1.22E+16*	*2.9123E+04*	*3.5505E+20*
Total Energy=		**5.8765E+16**		**1.5446E+22**

21 **ELECTRICITY**

KWh:	4.86E+10		4.86E+07	Mwh w/o renew	Energy Information administration web page www.eia.doe.gov, 1999 data
Energy (J) =	KWh*3.6E6 J/KWh		6.06E-01	coal	
=	**1.75E+17**	**J**	2.85E-01	nuclar	
Emergy per unit input =	**1.60E+05**	**sej/J**	6.0E-02	gas	Odum, 1996
Electricity consumed	**6.05E+10**	**Kwh**			
energy	**2.18E+17**	**J**			http://www.eere.energy.gov/states/state_specific_statistics.cfm/state=MD#consumption

22 **SYNTHETIC CHEMICALS, PLASTICS**

Chemical category--Plastics	$1,312,481,000		
Production =	3.25E+02	tons/yr	$ value from Manufacturing survey 2000 and tons calculated from 1997 commodity flow survey.
Grams per ton =	9.08E+05	g/ton	
Annual production =	2.95E+08	g/yr	
Emergy per unit =	3.30E+06	sej/g	(Buranakam, without service, 1998)
Total sej/yr=	**9.74E+14**	**sej/g**	
Chemical category--Butadiene	$125,650,000		
Production =	3.10E+01	tons/yr	$ value from Manufacturing survey 2000 and tons calculated from 1997 commodity flow survey (Bureau of Transportation).
Grams per ton =	9.08E+05	g/ton	
Annual production =	2.81E+07	g/yr	
Emergy per unit =	3.30E+06	sej/g	(Buranakam, without service, 1998)
Total g/yr=	**3.23E+08**		

Total sej/yr= 1.07E+15

Tons calculated based on the MD 1997 commodity flow.

23 **TEXTILES Natural Fibers -wool-**

$ value from Manufacturing survey 2000 and tons calculated from 1997 commodity flow survey.

Production =	108790	pounds/yr	
Annual production =	4.94E+07	g/yr	
	1.03E+12	J/yr	
Emergy per unit =	4.40E+06	sej/J	(Odum, 1996)

Data estimated from ratio wool cash recipts 2000 for Maryland $38,000 and total production USA 710,000lbs worth $248,000. MD doesn't produce any cotton.

NOAA's Marine Fisheries Services Report Data for 2000

24 **AQUACULTURE**

Product	***g/yr***	***j/yr***	***J/g***
Saltwater			
Catfish	6.20E+08	2.46E+12	3.9E+03
Bass Striped	1.23E+09	4.98E+12	4.1E+03
Eeel America	1.81E+08	1.40E+12	7.7E+03
Shark	2.33E+08	1.27E+12	5.4E+03
Croaker	6.81E+08	2.96E+12	4.3E+03
Weakfish	1.49E+08	1.23E+12	8.2E+03
Total	3.09E+09	1.43E+13	4.6E+03
Shellfish			
Oyster	4.98E+08	1.42E+12	2.8E+03
Clam	3.23E+09	1.00E+13	3.1E+03
Crab	1.06E+10	3.88E+13	3.6E+03
Total	1.43E+10	5.02E+13	3.5E+03

Total Energy (j)= 6.45E+13

Emergy per unit = 4.40E+06 sej/J

25 **MEAT, DAIRY, EGGS**

Data on from Maryland Agricultural Statistic for 2000

Porduct	***g/yr***	***j/yr***	***Emergy/Unit***	***sej/yr***
Poulty	5.77E+09	5.7210E+13		
Milk	6.08E+08	1.6294E+12	1.29E+06	2.1020E+18
Eggs	5.74E+08	1.2398E+12	4.4E+06	5.4553E+18
Cow beef	3.81E+10	4.6418E+14	8.6E+05	3.9919E+20
Honey	1.25E+08	1.5900E+12		
Hogs & Pigs	7.40E+09	1.1640E+14		
Total Energy (j)=		**6.4225E+14**		**4.0675E+20**

26 **HEAVY MACHINERY**

	$2,663,568,000		$ value from Manufacturing survey 2000 and tons calculated from 1997 commodity flow survey (Bureau of Transportation).
Production =	2.6E+05	metric tons/yr	
g/metric ton =	1.00E+06	g/ton	
Annual production =	2.59E+11	g	
Emergy per unit=	6.70E+09	sej/g	

19. Appendix 2. Ecoprices

Footnotes for Table 9.1- Eco-prices for Ecosystem Services

	Carbon Sequestration Eco-price			
	Price per ton C			
	Eurpopean Carbon Exchange (ECX)	15	$ ton-1	
	Chicago Carbon Exchange (CCX)	2	$ ton-1	ICE, 2010
		1.5	mt ha-1	ICE, 2010
	Emergy=	(mt ha-1)*(g mt-1)*(3.5 Kcal g C-1)*(4186 J Kcal-1)*(3.62E4sej J-1)		(Ra for MD forests)
	=	7.95E+14	sej ha-1	
1	ECX eco-priceeco-price= sej/ha/ $/ha	3.54E+13	sej $-1	
2	CCX eco-priceeco-price	5.06E+14	sej $-1	
	Eco-price of timber			
3	Market price	106	$ per m^3	
	avg density	700	kg/m^3	http://www.for.gov.bc.ca/ftp/hva/external/!publish/web/logreports/coast/2011/3m_Jan11.pdf
	Joules	1.03E+10	J	http://www.engineeringtoolbox.com/wood-density-d_40.html
	Transformity	3.62E+04	sej J-1	NYC.gov, calculated
	emergy	3.71E+14	sej	
	eco-price	3.50E+12	sej/$	
				(modeled)
4	**Stormwater Mitigation Eco-price**			
	NY State Watershed Protection			
	Supply	1381675300	m-3 yr-1	
	Energy=	(volume)*(1000kg/m^3)*(4940J/kg)		
	=	6.82548E+15	J yr-1	
	Transformity	124000	sej J-1	
		8.46359E+20	sej yr-1	Washington Suburban Sanitation Commision
	Average yearly investment	1.15E+08	$ yr-1	
	eco-price	7.34E+12	sej $-1	
5	**Groundwater Recharge Eco-price**			modeled
	Municipal Price of Water			
		3	$ 1000 gal-1	

	1000 gal=	3.78541178	m3	
	energy of 1000 gal=	(volume)*(1000kg/m^3)*(4940J/kg)		
	=	18699934.19	J	
	Transformity	1320000		
	emergy=	2.46E+13	sej	
	eco-price	8.22E+12	sej $-1	
	Nutrient Uptake Eco-price			
6	**The Chesapeake Clean Water and Ecosystem Restoration Act of 2009**			
	total program cost	2.13E+09	$ over 15 years	
	avg. yearly cost	1.42E+08	$ yr-1	
	reduction of N per year	1.30E+10	g N	
	reduction of P per year	1.79E+09	g P	
	reduction of Sediment per year	7.31E+11	g Sed	
	specific emergy N	4.10E+09	sej g-1	
	specific emergy P	2.16E+10	sej g-1	
	specific emergy Sed	1.68E+09	sej g-1	
	emergy N=	5.33E+19	sej yr-1	
	Emergy P=	3.87E+19	sej yr-1	
	Emergy Sed=	1.23E+21	sej yr-1	
	sum=	1.32E+21	sej yr-1	
	eco-price (emergy yr-1/$ yr-1)	9.32E+12	sej $-1	
7	**Nutrient Trading in Chesapeake Bay**	3.81	$ per lb N	
	grams N	453.59	g lb-1	http://www.dep.state.pa.us/river/Nutrient%20Trading_files/Workshops/NutrientTradingProgram-CreditGeneration-Lancaster.pdf
	Specific emergy	4.10E+09	sej g-1	Avg. for N forms from from D.E. Campbell, 2009
	emergy=	1.86E+12	sej	
	eco-price=	4.88E+11	sej $-1	
8	**BMP Cost share program**	$230,094.59		
	plus private funds	$28,761.82	approx 12.5 % of funds from landowner	http://www.mda.state.md.us/article.php?i=22550
	will prevent approximently	268	tons N	
		69	tons P	

		312	tons sediment
	specific emergy N	4.10E+09	sej g-1
	specific emergy P	2.16E+10	sej g-1
	specific emergy Sed	1.68E+09	sej g-1
	emergy N	9.97E+17	sej
	emergy P	1.35E+18	sej
	emergy sed	4.76E+17	sej
	sum	2.82E+18	
	eco-price	1.09E+13	
9	**Cost of Erosion: Price of Fill Dirt**	$18	$ yd^-3
		$13.76	m^-3
		1	yd^3
	1 yd3=	0.76	m^3
	assume 1.25 g/cm3		
		1250000	grams
		1.68E+09	sej g-1
		2.10E+15	sej
	sej/$	1.53E+14	sej/$
10	**Soil Carbon: Mulch**	20	$ yd^3
		26.15901239	$ m^3
		450	lbs yd^3
		588.5777787	lbs m^3
		266974.3896	g m^3
		3.5	kcal/g
		3911441781	J m^3
	transformity	50400	sej/j
		1.97137E+14	sej
	eco-price	7.53609E+12	sej/$
	Air Pollutant Removal Eco-price		
11	Clear Skies Act	4.00E+10	$ total investment over 15 years
	Dollars spent	2.67E+09	average per year
	Expected Reduction in Nox	3.4	mill tons
	Expected Reduction in SO2	8.2	mill tons
	Expected Reduction in Hg	33	tons

	Nox specific emergy	6.84E+09	sej g^{-1}	
	SO2 specific emergy	5.26E+10	sej g^{-1}	Campbell, D.E., 2009 Minnesota report
	Hg specific emergy	4.20E+13	sej g^{-1}	Campbell, D.E., 2009 Minnesota report
	emergy calculation=	(tons)*(1e6 g ton-1)* (sej g-1) /15 years		
	Emergy of Nox	1.55E+21	avg sej yr^{-1}	
	Emergy of SO2	2.88E+22	avg sej yr^{-1}	
	Emergy of Hg	9.24E+19	avg sej yr^{-1}	
	sum=	3.04E+22	avg sej yr^{-1}	
	eco-price=	avg emergy of pollutants avoided yr-1/average $ spent yr-1		
	=	1.14E+13	sej $\$^{-1}$	
12	**Cost of Air Pollution in MD**			
	Avg cost per year (2000-2010)	4.14E+08	$/yr	
	Urban Area of MD	2.80E+09	m^2	
	Air Shed Height	1000	m of ozone formation	Jacko, 1996
	Avg Days Exceeding Air Qual. Stds (2000-2010)	23	days/yr	
	Ozone on Exceeding days	9.01E+08	g O3	
	specific emergy	6.23E+10	sej/g O3	
	emergy on exceeding day	5.62E+19	sej/day	
	emergy on exceeding days	1.27E+21	sej/yr	
	PM10			
	Avg concentration	1.60E-05	g m^3	
	PM in MD	1.64E+10	g yr	
	specific emergy	2.04E+10	sej g-1	
		3.33E+20	sej yr	
	eco-price	3.88E+12	sej/$	
	West Virginia Air Quality Fees			
	All Filterable Air Pollutants	24	$/ton	
	Transformities			
13	NO3-N	6.80E+09	sej/g	
14	NH4-N	1.40E+09	sej/g	
15	S in Wet/Dry Dep	1.58E+11	sej/g	
16	Cl in Wet/Dry Dep	1.31E+10	sej/g	

17	Pollination Eco-price			
	$ value of crops pollinated by natives	1.12E+07	$ yr-1	
	emergy value of crops pollinat. by natives	1.45E+20	sej yr-1	Calculated from Losey and Vaughn, 2006
	eco-price	1.30E+13	sej $-1	
	Eco-price of Biodiversity Conservation			
18	Maryland Env. Trust			
	2009 Budget	1000000	$ yr-1	
	Ha Conserved	2325.23	ha in 2009	MD Env Trust, 2010
	Avg MD emergy per Ha	2.02E+15	sej ha-1	MD Env Trust, 2010
	emergy of land conserved	4.71E+18	sej yr-1	
	eco-price	4.71E+12	sej $-1	
19	Conservation Fund Mid-Atlantic			
	Cost Paid for land conserved	592011099	$	
	Ha of land conserved	846767.87	ha	Conservation Fund, 2010
	emergy of land conserved	1.72E+21	sej ha-1	Conservation Fund, 2010
	eco-price	2.90E+12	sej $-1	
	Hunting Lease	10	$/acre/year	Kay, 2010
	renewable emergy per acre	5.938E+14	sej/acre	this study
		5.938E+13	sej/$	
	Average of Biodiversity Eco-price	2.23E+13	sej/$	

Footnotes for Table 7.2 Maryland Commodities

20. Eco-price Coal

coal	1	ton	
price	$ 80	$/ton	July 29th, 2011 http://www.eia.gov/coal/news_markets/
energy content	12500	btu/lb	
	25000000	btu/ton	
	2.63E+10	J/ton	
transformity	**3.92E+04**	**sej/J**	Odum, 1996
	1.03E+15	sej/ton	
	1.29E+13	sej/$	

21. Eco-price of Fill Dirt	$18	$ yd^-3
	$13.76	m^-3
	1	yd^3
1 yd3=	0.76	m^3
assume 1.25 g/cm3		
	1250000	grams
	1.68E+09	sej g-1
	2.10E+15	sej
sej/$	1.53E+14	sej/$

25. Eco-price Electricity

electricity	1	kWh	
price	0.1	$/kWh	
	3.60E+06	J/kWh	
	160000	sej/J	
	5.76E+11	sej/kWh	
Eco-price Electricity (est#1)	5.76E+12	sej/$	
Eco-price Electricity (est#1)	5.59E+12	sej/$	Tilley (unpub) 2006 data

24. Eco-price Crude Oil

amount	1	bbl	
price	$ 100.00		Bloomberg.com June 2, 2011 http://www.bloomberg.com/markets/commodities/futures/
energy density	4.30E+04	J/g	
density	8.73E+02	kg/m3	West Texas, http://www.simetric.co.uk/si_liquids.htm
solar transformity	90000	sej/J	

	5.38E+14	sej/bbl	
Eco-price Crude Oil	5.38E+12	sej/$	

23. Eco-price Nat Gas

amount	1	MMBtu	
price	$ 4.80		Bloomberg.com June 2, 2011 http://www.bloomberg.com/markets/commodities/futures/
energy density	1.06E+09	J/MMBtu	
density	1.00E+00	kg/m3	
solar transformity	48000	sej/J	
	5.06E+13	sej/MMBtu	
Eco-price Natural Gas	1.06E+13	sej/$	

24. Eco-price Gasoline

amount	1	gallon	
price, commodity	$ 2.97		Bloomberg.com June 2, 2011 http://www.bloomberg.com/markets/commodities/futures/
energy density	1.35E+08	J/gal	
solar transformity	110000	sej/J	
	1.49E+13	sej/gal	
Eco-price Gasoline	5.00E+12	sej/$	

22. Eco-price Timber

Commodity Market Trade	235	$/1000 bd ft	Bloomberg.com June 2, 2011 http://www.bloomberg.com/markets/commodities/futures/
energy of 1000 bd ft	2.27E+07	J/bdft	
	0.235	$/bdft	
solar transformity	50000	sej/J	This study
Eco-price Timber	4.82E+12	sej/$	

26. Eco-price Copper

amount	1	lb	
price, commodity	$ 4.09		Bloomberg.com June 2, 2011 http://www.bloomberg.com/markets/commodities/futures/
energy density	2.20E+03	g/lb	
solar transformity	6.58E+10	sej/g	Huang and Odum, 1991.
	1.45E+14	sej/lb	
Eco-price Copper	3.54E+13	sej/$	

27. Eco-price Corn

amount	1	bushel	
price, commodity	$ 7.66		Bloomberg.com June 2, 2011 http://www.bloomberg.com/markets/commodities/futures/
energy density	1.90E+04	J/g	
density	7.60E+02	kg/m3	
	3.50E+01	l/bushel	
solar transformity	60000	sej/J	This study.
	3.03E+13	sej/bushel	
Eco-price Corn	3.96E+12	sej/$	

28. Eco-price Wool

amount	1	kg	
price, commodity	$ 14.32		Bloomberg.com June 2, 2011 http://www.bloomberg.com/markets/commodities/futures/
energy density	2.00E+04	J/g	
solar transformity	4.32E+06	sej/J	
	8.63E+13	sej/kg	
Eco-price Wool	6.03E+12	sej/$	

20. Appendix 3. Maryland Ecosystem Services

Footnotes for Table 15.2- Ecosystem Services in Maryland, 2009

1	**Carbon Sequestration**			
	MD Forest Area	1008724	ha	MDNR, 2010
	Average C sequestered	1500000	g ha-1 yr -1	MDNR, 2010
	Carbon Sequestered=	(g C ha-1 yr-1)*(Forested Ha in MD)		
	=	1.51E+12	g C yr-1	
		2.22E+16	J C yr-1	
	Transformity	3.62E+04	sej J-1	
2	**Stormwater Mitigation Service**			
	Mountain Phys. Regions	1517005	J m-2 yr-1	(SoilAqDyn Model)
	area	5.25E+09	m2	
	Energy of Stormwater=	7.96E+15	J yr-1	
	Transformity	124000	sej J-1	(SoilAqDyn)
3	Coastal Plain Phys. Reg.	1522858	J m-2 yr-1	(SoilAqDyn)
	area	4.84E+09	m -2	
		7.37E+15	J yr-1	
	Transformity	155000	sej J-1	(SoilAqDyn)
	Ground Water Recharge			
4	Mountain Phys Regions	88468.68	J m-2	
	Over Pied, App, Blue Ridg and Ridg/Valley Phys Prov	4.64E+14	J yr-1	
	Transformity	1500000	sej J-1	SoilAqDyn output, weighted Transformity of surficial and deep aquifer
5	**Coastal Plain**	89919.26	J m-2	
	Over Coastal Plain	4.35E+14	J yr-1	
	Transformity	1320000	sej J-1	SoilAqDyn output weighted Transformity of surficial and deep aquifer
	Nutrient Removal			
6	Forest N uptake	10.935	kg ha-1 yr-1	Data from Goodale et al, 2002
	total uptake=	(area)*(kg ha-1 yr-1)		
	=	1.1E+10	g yr-1	
	Transformity	4.1E+09	sej g-1	Campbell, D.E. 2009
7	Forest P Uptake	9.6	kg ha-1 yr-1	Yanai, 1992
	total uptake=	(area)*(kg ha-1 yr-1)		
	=	9.68E+09	g yr-1	

	Transformity	2.16E+10	sej g-1	Campbell, D.E. 2009	
8	**Soil Building Processes**				
	Avg. Carbon Sequestered by soil	274491.1	g ha -1 yr-1	ForSoilModel: Carbon	
	Soil Carbon Sequestered in MD=	area*g ha-1 yr-1			
	=	2.77E+11	g yr-1		
	energy of C=	(g yr-1)*(3.5 kcal g-1)*(4186 kcal g-1)			
	=	4.06E+15	J yr-1		
	Transformity	143115	sej/J		
9	**Erosion Prevention**				
	Mass Erosion Avoided	3302608	g ha-1 yr-1	ForSoilModel:Erosion	
	Erosion avoided=	(area)*(g ha-1 yr-1)			
	=	3.33E+12	g yr-1		
	specific emergy	1.68E+09	sej g-1		
	Air Pollutant Removal				
10	CO	1269.90	mt yr-1	i-tree Vue, 2010	
		1.27E+09	g yr-1		
	specific emergy	1.2E+09	sej g-1	Ganeshan, 2005	
11	NO2	6221.777	mt yr-1	i-tree Vue, 2010	
		6.22E+09	g yr-1		
	specific emergy	6.84E+09	sej g-1	Campbell, D.E., 2009 Minnesota report	
12	O3	14573.31	mt yr-1	i-tree Vue, 2010	
		1.46E+10	g yr-1		
	specific emergy	6.23E+10	sej g-1	calculated	
13	SO2	3475.07	mt yr-1	i-tree Vue, 2010	
		3.48E+09	g yr-1		
	specific emergy	5.26E+10	sej g-1	Campbell, D.E., 2009 Minnesota report	
14	PM 10	6842.515	mt yr-1	i-tree Vue, 2010	
		6.84E+09	g yr-1		
	specific emergy	2.04E+10	sej g-1	Weighted Averaged UEV of air pollutants	
15	Pollination by Wild Insects				
	area of MD farms relient on Wild Insect Pollination	20662.44	ha	USDA.gov, 2011 and Losey and Vaugh, 2006	
	number of hives necessary to support 1 ha	5	hives	www.extension.org	
		40000	bees per hive		
		90	mg per bee		4.13E+09
		3600	g per hive		
	Bees necessary to support 1 ha	18000	g ha-1		

energy content=	(g ha-1)*(24 KJ g-1)*(1000 J Kj-1)		
	4.32E+08	J ha-1	
Emergy of Soybean Pollen	1.03E+13	sej ha-1	calculated
Emergy of Alfalfa Pollen	3.57E+14	sej ha-1	calculated
avg.	1.84E+14	sej ha-1	
Transformity	425577.5	sej J-1	

21. Appendix 4. Ozone

Ozone Specific Emergy			
Emergy from Sunlight	3.93E+24	sej yr	
Avg. Width of Ozone Layer	3.15E-01	mm	Science of The Total Environment Volume 400, Issues 1-3, 1 August 2008, Pages 257-269
Area of the earth	5.10E+18	cm^2	
Volume of Ozone	1.61E+16	cm^3	
Density of Ozone	2.15E+00	g/l	
Turnover time of Ozone in the Atmosphere	2.00E+02	days	Liu, et al, 1987
=	1.61E16 cm^3*.001 cm^3/l*2.15 g/l		
=	3.45E+13	g of O3	
Specific Emergy of ozone=	(global emergy of sunlight*turnover time)/grams of Ozone		
=	6.23E+10	sej/g	
Eco-price of Ozone and PM10 in Maryland			
Cost of Air Pollution in MD			
Avg cost per year (2000-2010)	4.14E+08	$/yr	MDE, 2009
Urban Area of MD	2.80E+09	m^2	
Air Shed Height	1000	m of ozone formation	Fatogoma, 1996
Avg Days Exceeding Air Qual. Stds (2000-2010)	22.7	days/yr	MDE, 2009
Avg Ozone Concentration	0.32	mg/m^3	MDE,2009
Ozone on Exceeding days=	Urban Area*Ht of Air Shed*O3 Concentration*.001 g/mg		
=	9.01E+08	g O3	
specific emergy	6.23E+10	sej/g O3	This document
emergy on exceeding day	5.62E+19	sej/day	
emergy per year	1.27E+21	sej/yr	
Eco-price of PM10			
Avg concentration per day	1.60E-05	g m^3	MDE, 2009
PM in MD=	Urban Area*Ht of Air Shed*PM10 Concentration/day*365 days/yr		
=	1.64E+10	g yr	
specific emergy	2.04E+10	sej g-1	This research
emergy per year	3.33E+20	sej yr	
eco-price for O3 and PM10 in MD	3.88E+12	sej/$	

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