ABSTRACT

Title of Document: VALUING FOREST ECOSYSTEM SERVICES IN MARYLAND AND SUGGESTING FAIR PAYMENT USING THE PRINCIPLES OF SYSTEMS ECOLOGY

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Forests provide a multitude of vital benefits to the ecosystems, economies 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 storm flows, abate air pollution, and provide food, fiber, fuel and shelter. While markets exist to set the price for an economic good like timber, many of the ecosystem services listed above are poorly valued, if at all. This research provides a connection between biophysical and economic methods for evaluating the environment. The hydrology, soil, carbon, air pollution, pollination and biodiversity of a forest are measured from a biophysical standpoint with emergy and converted to dollars using new emergy-to-dollar ratios; termed eco-prices. The functioning of the forest is compared to the most likely alternative land-use (suburbia) and biophysical value is assigned based on this difference. The novel method for assigning value to ecosystem services and the ability to link biophysical evaluation and economic valuation has the potential to be influential in how ecosystem services are incorporated into the economy and used to guide decision making in the future.

The research seeks to value ecosystem services provided by forests in Maryland and proposes that an Ecological Investment Corporation (EIC) could be an additional tool for society to direct payments from consumers to land stewards to encourage the production of ecosystem services. To ensure that

Maryland forests continue to produce ecosystem services at the current rate, land stewards should receive compensation between $178 and $744 million. On a per capita basis, a resident of Maryland enjoys $850 worth of ecosystem services from the forest as public value. On an area basis, the typical acre of forest in Maryland generates over $2000 of ecosystem services as public value. Based on our compensation estimates for ecosystem services, a land steward should receive a fair payment price of $71 to $298 per year per a typical acre of forest. This research is a step forward for emergy science, providing novel methods for quantifying ecosystem services, calculating ecological debt, and converting renewable emergy flows to dollars.

VALUING FOREST ECOSYSTEM SERVICES IN MARYLAND AND SUGGESTING FAIR PAYMENT USING THE PRINCIPLES OF SYSTEMS ECOLOGY

By

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Dedication

To the memory of my father in-law, Shiva Nepal

and to my father, Daniel Campbell, two men of knowledge.

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Chapter 1: Introduction

Forests of the world provide a multitude of life-support benefits to ecosystems, economies and societies throughout the world. Without these benefits humanity would not exist. Among their services, forests regulate climate, stabilize coastlines and riverbanks, and provide food, fiber, fuel and shelter for humans. As humanity 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 its primary production, nature has played a larger latent role in protecting humanity from the accumulation of wastes and toxins in the environment. Loss of forests and the discharge of pollutants to land, air and water lowers the life-support capabilities that the environment can provide for free to humanity.

Forests in Maryland provide a multitude of ecosystem services, economic goods and social amenities to society. The ecosystem services provided by forests include: providing wildlife habitat, generating and maintaining soils, improving water quality, dampening storm flows, abating air pollution, and reducing the urban heat island effect. The most dominant economic good is by far timber which supplies lumber, veneer, plywood, pulp & paper. Social amenities include: hunting, fishing, hiking & camping, birding, horseback riding, and automotive touring. While markets exist to set the price for an economic good like timber, many of the ecosystem services 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 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, 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 desires 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 programs have achieved 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 service (i.e., ecosystem services). This inefficiency comes mainly from the fact that federal payments to farmers were 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 these services to human welfare. Economic metrics have been used to value ecological services but these metrics are from the perspective of the receiver of the services (the economy) rather than 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 energy invested in all studied aspects of a system, called environmental accounting or emergy synthesis, 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: "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" (Odum and Odum, 2000).

This research introduces a novel method for linking the biophysical measurement of ecosystem function (donor value) with the economic value (receiver value) that people place upon that function. Efforts have been made to value ecosystem services from a purely biophysical standpoint (Hall, 2011) and from the purely economic perspective (Daily, 1997, Costanza et al 1997) but taken from these singular perspectives they fall short of capturing the full picture (Odum, 1996, Odum and Odum, 2000, Daly, 2004). Environmental accounting has attempted to value ecosystem services (Campbell, 2012, Pulselli, 2011) but these evaluations still tend towards the biophysical perspective and fail to capture what society is willing to pay for ecosystem services. This study uses the "eco-price", analogous to shadow pricing in ecological economics (Howarth, 2002, Richmond, 2007) to assess the value of ecosystem services. Thus, the biophysical reality of ecosystem performance is joined with economic measures of the value people place on ecosystem services and a novel method is born. This method should allow more informed decision-making for both the sustainability of ecosystems and humanity since both sides are considered.

1.1.1 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 and are thought of as being very inclusive, with any benefit derived from an ecosystem considered an ecosystem service. The Millennium Ecosystem Assessment categorizes ecosystem services as provisioning, regulating, supporting, and cultural. These categories involve providing goods to humanity, regulating systems that humanity depends on, supporting systems that provide goods, and enhancing people's intellectual or recreational experiences, respectively. This study restricts the definition to only services from ecosystems that provide a tangible benefit to society (i.e. not aesthetics) and are not already paid for in some way (i.e. recreation), thus included in the existing economic system. This is because I will be asking equitable payments for the services from consumers of the services so it is not fair to ask payment for services that cannot be measured reliably or that are already being paid for. This study introduces the concept of "public value". Public value is an estimate of the total benefit to society from ecosystem services. A dollar estimate for public value is obtained by using the average emergy to dollar ratio for the state economy (the ratio of total emergy use in the state to Gross State Product) to convert the emergy of an ecosystem service to dollars.

This study attributes the difference in performance between a typical Maryland forest and the most likely alternative land-use, suburban development (Maryland DOP, 2011) to the ecosystem service provided by the forest, measured in emergy. I propose a novel method for conversion of emergy to dollars, the eco-price. The value of the ES being suggested is less than the value if the total function of the forests was considered or if the traditional emergy to dollar methods were used. The reasoning behind this is that it would not be fair to ask the people of Maryland to pay for function they would receive regardless of the forest land-use. The eco-price was used to more accurately assess what people are willing to pay for ecosystem services. The method I propose can be viewed as “stacking” ecosystem services (payments for multiple ecosystem services from the same piece of land), a divisive issue in ecosystem service valuation (Carroll, 2008). Part of the reason I only value the ecosystem service in excess of the most likely alternative land-use attempts is to address concerns with the stacking of ecosystem services and avoid potentially overvaluing forest land. This was also done because ecosystem services are from the perspective of people. Our valuation reconciles the biophysical reality of what the ecosystem provides to people with the value that people place upon the ecosystem services being provided. It is vital to incorporate ecosystem services into the economy because if they are considered to be free subsidies increase in scarcity will not be felt until an ecosystem service becomes limiting to economic activity, at which point the cost to society would likely be much more than if an investment in natural capital was made prior to economic limitation.

1.1.2 Maryland and It’s Forests

The state of Maryland is 40% forested, covering 1.1 million ha of land (MDNR, 2012). Seventy six percent (76%) of forest land in Maryland is privately owned. Maryland’s population growth of a half a percent (0.5%) per year led 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, at the point where they would receive greater economic benefit from selling it for development than keeping it as silviculture or for preservation value. However, when the land is developed society as a whole loses the value of the ecological services provided by the land that are not considered in the economic decision making process. A model (*EcoInvest*, see Chapter 10) was developed in order to help reconcile the value invested in ecosystems vs. the value received by society, derived from these ecosystems. This will provide an additional incentive for forest landowners to keep their land in forest rather than an alternative land-use that would provide society with less of these ecosystem services and create an additional load on the ecosystem, such as urban or agricultural land-uses. If the results of this model are used to guide policy then the overall system of Maryland should maximize benefit for all. Once the value of ecosystem services being provided is established, the next step is to design an institutional structure that allows consumption to be directly linked to production. This institution will facilitate reinforcement of ecosystem services by charging those who consume services (the public) and paying the producers of the services (forest landowners) based on the amount of ecosystem services they either produce or consume.

The system being studied was analyzed at multiple scales. Analyzing a system at multiple scales allows each individual scale to be more fully understood. Insight into the context of the system studied is gained when one understands systems larger and smaller than the system of primary interest, in this case the forests of Maryland (Odum, 1996). To fully understand what is going on a state level the larger system, the country, must be understood as well to give context to the flows entering and exiting the state. The same is true in the natural world. If you are studying one wetland it is not functioning independent of the hydrology in the greater area, and to fully understand the flows of water and nutrients into the studied wetland the greater region should be evaluated as well. The emergy synthesis of the State of Maryland will be referenced in placing the forests of Maryland into the context of the larger system. Fully understanding how Maryland’s forests function and fit into the system as a whole is a objective of this research.

1.2 Research Approach

The goal of this research is twofold. The first aspect is to develop the energetic basis for the valuation of key ecosystem services provided by forests of Maryland. The second aspect is 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 for the human economy.
2. Determine the emergy-based value of key ecosystem services to include:
    a. Soil generation and maintenance
    b. Carbon sequestration
    c. Air pollutant removal
    d. Biodiversity protection
    e. Stormwater Runoff avoidance
    f. Groundwater recharge promotion
    g. Water quality improvement

The second goal has the following objectives:

3. Assess how much value Maryland forests are generating in ecosystem services to determine how much compensation should be generated from consumers.
   Assess the value of the ecosystem services being consumed within MD.
   Develop a state-wide model that would allow the consumers of ecosystem services to compensate stewards of forest lands that produce ecosystem services.

4. Based on the state-wide model, develop a tool that could be used to assess the value of the ecosystem services being generated by any particular forest stand within Maryland.

To complete the goals and objectives of the project, the following actions were followed:

a. The energy baseline of Maryland was evaluated using environmental accounting.

b. The trend of ecological debt in Maryland was calculated from 1700 until the present.

c. 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.

d. A series of eco-prices were found by assessing 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.

e. A range of monetary values for each ecosystem service will be found by multiplying a service's emergy flow by a range of specific emergy-to-money ratios (i.e., eco-prices).

f. The EcoInvest Model simulates the Ecosystem Investment Corporation, which integrates ecosystem service values into the existing socio-economic system of Maryland

g. The tool for assessing the value that particular forest stands are producing will be developed as a standard spreadsheet that assessors could employ to do site valuations. Energy systems language. A working document was developed that allows a forest landowner to assess their own forest land and ascertain the ecosystem services that it provides.

1.3 Dissertation Outline

This dissertation is laid out in a top-down way beginning with evaluation of the state as a whole then to individual ecosystem services and then returns to the state scale in simulating the EIC in Maryland and a synthesis discussion. This organization was done partly to present the methods, results and discussion of each ecosystem service together and concisely. Chapter 2 is a review of the literature relevant to the history of the understanding of value, ecosystem services, environmental accounting of forest systems, and Payment for Ecosystem Service (PES) programs in Maryland as well as other parts of the United States. The basic methodology for environmental accounting, including a list of terms, is laid out in Chapter 3. Chapter 4 introduces the eco-price, a novel method for converting emergy to dollars, and presents methods regarding how it is calculated for each ecosystem service and for commodity markets. The State of Maryland is evaluated in Chapter 5. The emergy flows of the state are relevant to ecosystem services in that it allows the emergy of ecosystem services to be placed in the context of the State as a whole and compared to both State environmental and anthropogenic flows. Chapter 6 enumerates the ecological debt of Maryland, captured by loss of natural capital, from 1700 to 2010. Chapter 7 presents each ecosystem service calculated for the forests of Maryland. Each subsection follows the subsequent format: a description of the system and the model used to simulate the ecosystem, the data that was used in the model and its origin, a description of how the parameter’s for the model were estimated, presentation of the results of the model, the value generated by the three eco-prices and the public value of the ecosystem service, and finally a discussion of the individual ecosystem service. Original models were developed for stormwater runoff mitigation, groundwater recharge promotion, soil fertility, and soil erosion. Quantification of the remaining ecosystem services relies upon existing models. Chapter 8 is reserved for the ecosystem service of biodiversity, explored more thoroughly than the other ecosystem services. Two models were designed, the first to better understand the relationship between emergy and biodiversity along with latitude. The other model was designed specifically to value the biodiversity ecosystem service of a natural forest compared to a suburban forest based on the difference in emergy throughput. Chapter 9 summarizes the ecosystem service values using the three proposed eco-prices and compares them to the public value. The potential role that an Ecological Investment Corporation could play in Maryland, as either a private or public entity, is modeled and discussed in Chapter 10. Chapter 11 is a synthesis discussion, highlighting the importance of the eco-price used in determining ecosystem service value, the comparison of the EIC and existing programs in Maryland, the connection between ecosystem services and ecological debt, the link between biophysical and economic value facilitated by the EIC, limitations to the study, conclusions, and next steps for the research.

Chapter 2. Literature Review

Completion of this research was reliant on a thorough understanding of forest ecology, ecosystem services, environmental accounting and ecological economics. A through exploration of scientific literature was conducted in order achieve this understanding. The following publications were reviewed because of their particular relevance to valuation of ecosystem services and as progenitors of this work.

2.1 History of Value and Ecosystem Services

The understanding of value has evolved over time. The French physiocrats were among the first to put forth a well formed theory of value; asserting that the ultimate source of wealth was land (Quesnay, 1758). Adam Smith published the seminal Wealth of Nations (1776), debuting the labor theory of value. This was the dominant paradigm for much of the world until the advent of neo-classical economics. Thomas Matlthus (1823) and George Perkins Marsh (1864) were among the first to recognize the value that nature gives to humanity. Malthus introduced the concept of natural capital and the fact that the environment can limit the population that can be supported. Marsh (1864) recognized that deforestation in the Mediterranean region had led to desertification of land, and that the forest had been providing a service to humanity, although not in those terms. Karl Marx introduced the concept of "means of production", e.g. land, technology and natural resources vs. "relations of production", e.g. labor and the social system. Marx was critical of capitalism, specifically he felt "surplus value" the value added by human labor, disproportionately benefits those that control the means of production rather than the laborer. Marx recognized the contribution of nature, acknowledging that nature is the ultimate source of all wealth, including labor (Marx, 1887).

The foundation of neo-classical was laid in the late 1800's by the works of several economists, termed the "Marginal Revolution". Jevons (1871), Menger (1871) and Walras (1874) were all seminal works and introduced the concepts of marginal utility and supply and demand, still influential in today's understanding of economics. These works and neoclassical economics in general deemphasized the role that the environment has in the economy, moving the emphasis away from means of production and towards market dynamics (Gómez-Baggethun, 2009). The neoclassical economist Solow (1956) completely removes land from the economic production function, ascertaining that the work of nature could be substituted for by manufactured capital. Georgescu-Roegen (1971) refutes the claim that nature can be substituted for and asserts that economics are governed and limited by thermodynamic limits. A similar claim was made by Odum (1971) where he elucidates the link between environmental work and economic wealth. At this time valuation of the contribution that the environment makes to the economy began to diverge into two camps: biophysical valuation (emergy, energy return on investment, life cycle analysis, etc) and ecological economics (contingent valuation, hedonic pricing, production function analysis, etc, see Daly and Farley, 2003).Works from the two paradigms are presented in the following sections.

2.2 Biophysical Value-Emergy

H.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 states that "Economic systems are sustainable only by reinforcing their environmental basis". This statement is especially relevant to the EIC project. The EIC provides a mechanism for economic systems to reinforce their economic basis in a novel way. This work was also important in demonstrating 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 evaluated how the human economy values tropical forests in comparison to the value given by the environment and to suggest an optimum use level that balanced economic gain and the environmental value of the forest. Realization of this tradeoff is not fully possible if dollar values alone are considered.

Izursa (2008) 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 extraction 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.

Doherty (1995) evaluated forests from several locations and under varying land-uses. The locations included Florida, Sweden, Puerto Rico, Thailand and Papua New Guinea. Doherty uses 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 is 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 of timber 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.

Brown et al. (2007) was influential on the biodiversity model used in this research. Brown et al. use an existing ecological network analysis of the everglades (Heymans, 2002) and modify the analysis to calculate transformities (emergy per joule) of the network components and the total emergy throughput of the system. From these results they calculate an analog of the Shannon Diversity Index, which they term the Ecosystem Shannon Diversity Index and measures of the emergy of an individual component relative to total throughput and the emergy of an individual component relative to the expected value (as determined by the maximum empower principle), termed Emergy Importance Value (EIV) and Expected and Observed Emergy Throughput (EOET), respectively. The authors conclude that the quality adjusted Ecosystem Shannon Diversity Index improves upon the traditional index by having the index applicable at the ecosystem scale and making the goal of maximum evenness in the equation more realistic. The EOET was found to be highest in higher trophic levels, indicating deviation from expected value in these trophic levels. This indicates disturbance in the system, likely anthropogenic in nature.

Pulselli et al (2011) studies the relationship between ecosystem services and emergy flow without directly linking them or calculating ecosystem service using emergy. They look at an input (emergy/eco-exergy)-output (ecosystem services) model that does not consider the state or structure of the system. In this way they establish a general ratio of global ecosystem services (Costanza et al, 1997) and global renewable emergy flow (Campbell, D.E. 2000). The resulting ratio is less than the lowest ratio of emergy to dollars observed in any countries economy and the authors claim this is a result of the ecosystem's higher ability to efficiently produce services. With the qualifier that their analysis is a simplification of reality, the authors conclude that emergy evaluation helps to increase understanding of the basis of the benefits to society provided by ecosystems.

2.3 Ecological Economic Value

Costanza and Daly (1992) suggest that a minimum level of natural capital is necessary for sustainability of society. They stress that maintaining stocks of natural capital is necessary given the large uncertainty surrounding what level of natural capital is necessary for long term sustainability. Capital is defined as "a stock that yields a flow of valuable goods or services into the future" and capital is divided into natural, non-renewable, human, and manmade categories. The authors state that human or manmade capital are not perfectly substitutable for natural capital given that the relationship is demonstrably not reversible, manmade capital originates from natural capital through a transformation process. The authors suggest that natural capital should be valued based on its contribution to society rather than the individual, based on the embodied energy and using special methods to capture willingness-to-pay. They warn of a potential “societal trap” when using discount rates where near future benefits are valued at detriment to long term sustainability and advise a low discount rate be used when valuing natural capital. The authors make the following operational recommendations: limit the human scale (population and standard of living) within the carrying capacity of a region, focus technological progess on increasing efficiency rather than output, renewable natural capital should be used sustainably, and non-renewable capital should be used at a rate equal to the rate of creation of renewable substitutes.

Farber et al (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) brings up the question of quality of fuels affecting the ability to assess a system purely with available energy. Emergy synthesis corrects for the inequality of energy forms by use of transformities.

The article discusses how values can be dependent on situation. For example, 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.

Costanza et al (1997) 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 to 54 trillion/year, with an 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) synthesized 30 refereed articles over that time period dealing with freshwater ecosystem services. The authors distinguish 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 include 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. This article illustrates 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, 1997) 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 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 conclude 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.

Daily et al (2009) proposes a conceptual framework for incorporating ecosystem services into large scale decision making for communities, corporations and governments. Daily introduces the InVEST (A Tool for Integrated Valuation of Ecosystem Services and Tradeoffs) model that takes stakeholders and possible scenarios into account while generating values for ecosystem services in biophysical, economic, and cultural terms. Daily et al stress that while valuing ecosystem services can be useful in some situations for its true potential as a tool for increasing long term sustainability they must be integrated into decision making in a systemic way. The proposed framework involves biophysical models being used to quantify services from an ecosystem, economic and cultural models used to place value on the service, this information being fed to institutions which then influence decisions through incentive provision that positively feedback to the ecosystem. Hawaii is used as an example of how the proposed framework could function. A key tract of land on O'ahu was assessed using the InVEST model and the information generated was given to the Hawaii House of Representatives who then passed a resolution requiring an analysis of incentives with the goal of promoting conservation on private lands. Daily et al concludes that it is a great challenge to achieve the laid out framework but the ultimate goal for doing so is potentially the improvement of global well-being.

2.4 Ecosystem Service Market Development and Legislative Status

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 over the next two years. 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 with the goal of improving salmon habitat, 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 and an estimate of some ES on their property. 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.

In 1991 Maryland passed the Forest Conservation Act (Natural Resources Article, Section 5, 1601-1612) with the goals of minimizing forest loss due to development, identifying optimal restoration lands, protecting important forest resources and to increase the overall forest cover in Maryland. This law requires that before a development project proceeds the affected lands need to be evaluated by a licensed forester or landscape architect. The amount of forest replacement is dependent on the extent of disturbance caused by the project and how the land is zoned. Mitigation must be ¼:1 below the suggested forest cover of the land-use and 2:1 above it. Development projects less than 40,000 sq ft are exempt from the MFCA (Annotated Code of Maryland (COMAR) Title 08 Subtitle 19), thus almost all single family homes are exempt. This law has failed in its stated goal of preventing forest loss in Maryland, as currently Maryland loses 3,000 ha of forest land per year (Maryland DNR). Several laws as well as state and federal programs exist to facilitate forest landowners managing their land. Tax incentives include the Forest Conservation and Management Act (FCMA), Woodland Assessment, MD Income Tax Modification, and Public Law 96-451. FCMA and Woodland Assessment work similarly in that landowners owning at least 5 acres of contiguous forest land enter into a minimum of 15 year agreement to management their land according to a forest stewardship management plan and periodically overseen by a MDNR forester in exchange for a reduction in taxes paid ($50 per acre is the average in MD, these programs reduce the tax below $2 per acre but have a cost to enroll). The FCMA has had limited success in Maryland; 84,000 acres are enrolled in 1,300 FCMA agreements (MD DNR, 2011). MD Income Tax Modification and Public Law 96-451 both provide tax incentives that partially compensating for the cost of reforestation. Cost share programs exist such as Environmental Quality Incentive Program (EQIP), the Conservation Reserve and Enhancement Program (CREP), and Woodland Incentive Program (WIP). EQIP and WIP are federal programs that will partially (50-65% for qualified lands) fund replanting, stand improvement and site preparation. The federal CREP program funds either fully or partially, depending on the priority of the land, planting of a forested buffer for wetlands or waterways (information regarding forest tax programs from www.timbertax.org, accessed 2012).

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 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.

Chapter 3. Methodology for Conducting an Emergy Synthesis

3.1.1 Determine Boundary

The first step in conducting an emergy synthesis 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. The boundary is often easy to define, such as when studying a state, country or a bounded ecosystem (e.g. a national park) but can be more nebulous, such as if one is evaluating the floating islands of the everglades or a specific industry in an economy. 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 is often drawn. This pictorially represents 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 standard time period is one year, but this can vary as the study dictates.

> *Ecosystem Service Method:* When calculating ecosystem services from forests in Maryland a new boundary was derived for each ecosystem service, dependent on the characteristics of the individual ecosystem service. For example, soil fertility has a boundary of the top 2 m of soil under the forests of Maryland, while the hydrologic services have a boundary that encompasses all the forests of Maryland.

3.1.2 Data Collection

Once the storages and flows to be evaluated are established the next step is to establish the appropriate quantity of each emergy flow in the system and identify the average emergy value of the storages in the system over the time period studied. Ideally, the most current and accurate data is used for the most recent time period. Common data sources are government databases, private industry data, data published in the scientific literature, university databases, and calculations made by the researcher.

Ecosystem Service Method: Data for the flow of ecosystem services was predominately derived from comparing the energy flow in a typical Maryland forest to the energy flow in a typical developed tract of land (40% impervious cover). The energy of the developed land was subtracted from the energy of the forest, thus the additional energy flow was attributed to the ecosystem service of the forest. This is consistent with the concept of ecological debt (see Ch. 5).

3.1.3 Determination of Transformities (UEV's)

UEV stands for unit emergy value or the amount of emergy per existent unit in the system. The term transformity specifically refers to emergy per joule in the system. Transformities for global flows such as rain, wind, and heat flow are well established and have little variability across systems so it is acceptable to use transformities from the established literature. Unless a commensurate UEV already exists it should be calculated for flows that are specific to the study area. The use of transformities that are not specific to the area studied can be a major source of uncertainty in emergy studies (Ingwerson, 2010).

Ecosystem Service Method: Some transformities for ecosystem services were calculated in the model (stormwater runoff, biodiversity) and others were derived from the literature (see Table 3.1 and Chapter 7 for individual ecosystem services).

Table 3.1 Transformities Used in This Study

Item	Unit	Transformity (UEV)	Citation
Sun	J	1	by definition
Rain, chemical potential	J	3.10E+04	Odum et al, 2000
Rain, geopotential	J	4.70E+04	Odum et al, 2000
Transpiration	J	5.94E+04	This study
Wind	J	2.45E+03	Odum et al, 2000
Waves	J	5.10E+04	Odum et al, 2000
Tidal	J	2.43E+04	Odum et al, 2000
Earth Cycle	J	1.13E+04	Odum et al, 2000
Treated waste	g	3.89E+07	(Lucmi & Ulgiati, 2000)
Soil Erosion	J	7.26E+04	(Odum 1996)-Campbell (2000)
Coal	J	3.92E+04	(Odum 1996)-Campbell (2000)

Sand	g	1.31E+09	(Odum 1996)-Campbell (2000)
Clay	g	1.96E+09	(Odum 1996)-Campbell (2000)
Granite	g	4.91E+08	(Odum 1996)-Campbell (2000)
Limestone	g	9.81E+08	(Odum 1996)-Campbell (2000)
Coal	J	6.70E+03	(Odum 1996)
Natural Gas	J	4.35E+04	(Odum 1996)
Cement	g	1.94E+09	(Brown & Buranakarn 2000)
Steel	g	4.12E+09	(Brown & Buranakarn 2000)
Corn	J	3.96E+05	Campbell, 2000
Wheat	J	1.22E+05	Campbell, 2001
Barley	J	1.22E+05	Campbell, 2002
Soybeans	J	2.18E+05	Campbell, 2003
Hay	J	2.91E+04	Campbell, 2004
Electricity	J	1.60E+05	Odum, 1996
Plastics	g	3.30E+06	(Buranakam, w/o service, 1998)
Butadiene	g	3.30E+06	(Buranakam, w/o service, 1998)
Textiles	J	4.40E+06	(Odum, 1996)
Heavy Machinary	g	6.70E+09	Odum, 1996
Tree Biomass	J	3.62E+04	Tilley, 1999
Stormwater Runoff	J	1.24-1.55E+05	This study
Groundwater	J	1.32-1.56E+06	This study
Nitrogen	g	4.10E+09	Campbell, D.E. 2009
Phosphorus	g	2.16E+10	Campbell, D.E. 2009
Sediment	g	1.68E+09	Odum, 1996
Soil Organic Matter	J	1.43E+05	Cohen, 2007
CO	g	1.20E+09	Ganeshan, 2005
O3	g	6.23E+10	This study
S02	g	5.26E+10	Campbell, D.E., 2009
PM10	g	2.04E+10	This study
Hg	g	4.20E+13	This study
Pollen	J	4.26E+05	This study

3.1.4 Estimate of Solar Emergy

Once the flow or storage in joules or grams has been enumerated and the appropriate transformity has been determined, either through a separate calculation or in the literature, the solar emergy is found by multiplying the energy or mass of the flow or storage by the appropriate UEV (see Table 3.1, 3.2). The general equation is as follows—

Emergy= (*joules or grams existent in the system) * (sej/j or sej/g, as appropriate)*

Ecosystem Service Method: Typically in this study the ecosystem services energy or mass value, as determined by the additional energy/mass flow provided by forests, was multiplied by the appropriate unit emergy value to determine the solar emergy. This emergy value represents the additional benefit, adjusted for energy quality, which forests provide above developed land.

Ecosystem service= (*Emergy flow in the natural ecosystem, sej) –* (*Emergy flow in the most likely alternative land-use, sej)*

If the ecosystem service is the avoidance of a cost to society the equation would be reversed.

3.1.5 Estimate of Dollar Value Equivalence

The accepted method of converting emergy values to dollars is to divide the emergy value by the average emergy “purchasing power” of a dollar (emdollar ratio) in the economy being evaluated. This is the average quantity of emergy returned when a dollar is spent. This is normally done by dividing the emergy circulating in an economy in a given year by the dollars circulating in that same system (e.g. gross domestic product). However, the ratio of emergy to money in an economic exchange is highly variable. For example, when raw goods are purchased the emergy is high and the dollars are low, while when finished goods are purchased the emergy tends to be low and the dollars high.

Ecosystem Service Method: To more accurately represent what people are willing to pay an alternative is to use ecological ecosystem service prices (eco-price). Eco-prices base the emergy to dollar ratio on similar situations or analogous conditions where the good/service in question is exchanged for dollars.

Dollar Value of the ES= (*Emergy of the ES, sej)/(derived eco-price, sej/$)*

Table 3.2 Template for inventorying and weighting resource inputs and outputs in emergy synthesis.

1 Note	2 Item	3 Data	4 Units	5 Transformity (sej/unit)	6 Solar Emergy (sej/y)	7 Dollars (Em$/y)

Column 1 is the line item number, which is also the number of the footnote found below the table where raw data sources are cited and calculations are shown.
Column 2 is the name of the item, which is shown on the systems diagram.
Column 3 is the raw data in joules, grams, dollars or other units. The units for each raw data item are shown in column 4.
Column 5 is the transformity used for calculations, expressed in solar emergy joules per Joule or other appropriate units (sej/hr; sej/g; sej/$). Transformities may be obtained from previous studies or calculated for the system under investigation. Transformities from other authors will show source reference.
Column 6 is the solar emergy of a given flow, calculated as input times transformity (Column 3 x Column 5).
Column 7 is the public value in dollars of an item, which indicates its total contribution to the economic production (e.g., gross domestic product). It is found by dividing the solar emergy of Column 6 by the state's mean solar emergy-to-dollar ratio (i.e., emergy-price).

3.2 Definitions of emergy terms and indices:

The following list defines key terms used in emergy analysis and describes typical indices developed from aggregating resource flows (Figure 3.1). 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 (exergy) of one kind that is used in the transformations directly and indirectly to make a product or service. Emergy is measured in emergy-joules (emjoules). Sunlight, fuel, electricity, and human service and all other resource flows can be put on a common basis by expressing them in the emjoules of solar energy required to produce them, which is expressed as solar emjoules (sej). While other units, such as coal emjoules, were used in the past. Recent emergy studies track resource flows in solar emjoules.

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. 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).

Emergy per unit money: the emergy supporting the generation of one unit of economic product (expressed as currency). The average emergy/money ratio (sej/$) can be calculated by dividing the total emergy use of an 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=R+N+F) per unit of emergy contributed from the economy (F) (sej/sej)

Environmental Loading Ratio (ELR=(N+F)/R): emergy contributed from non-renewable and economic sources per unit of emergy contributed from renewable resources (sej/j) It is an indicator of the pressure of developed 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 property emdollars to distinguish from market-based dollars. However, this convention was not adopted for this report because I feel it is unnecessarily confusing to non-emergy analysts to use emdollars, when dollars will suffice.

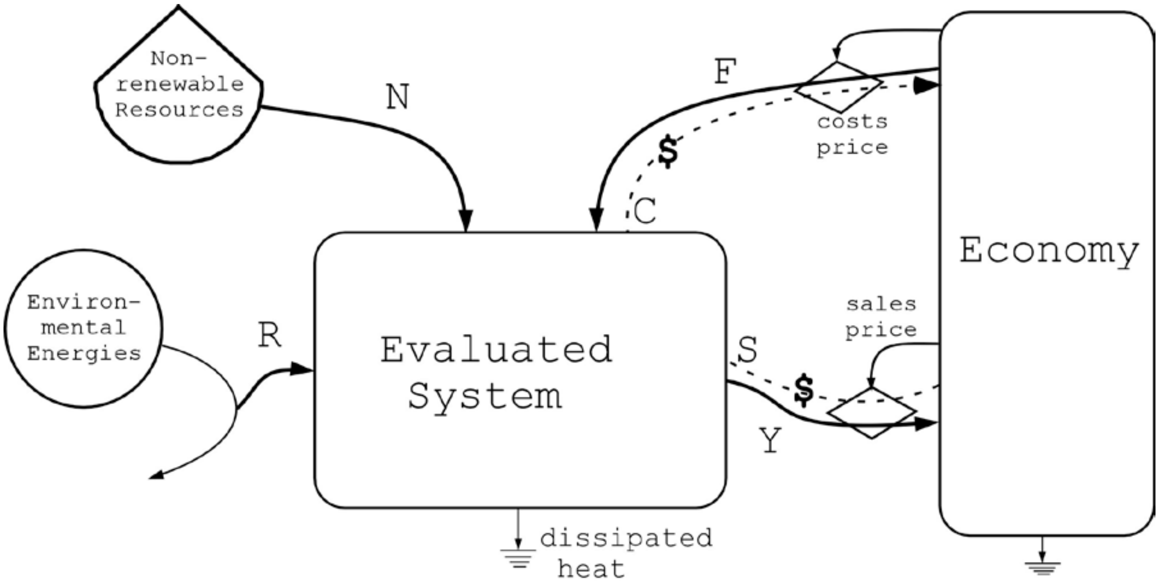


Figure 3.1. Energy systems diagram of the aggregated inputs (R, N, and F) to an evaluated system that produces a yield (Y) to the economy and generate sales revenue (S) which is pays for purchased costs (C).

3.3 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 synthesis to show the public value as a Column G in Table 3.2. However, since I was not only interested in public value, but also in the fair payment price (see section 5.2.2), I show the public value and three estimates of the fair payment prices in separate tables structured like those in Table 3.2 and 3.3.

Table 3.3 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 3.4 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; FPi and FP_j are the fair payment prices for ecosystem services i and j, respectively; FPT is total amount paid to land stewards as fair payment.

Table 3.5 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 ac per yr)**	**PREI (Public Return on Ecosystem Investment)**
Public Value	PV	PV/a	-
Commodity Price	FP_{cp}	FP_{cp} /a	PV/FP_{CP}
Mean Ecosystem Service Price	FP_{MESP}	FP_{MESP}/a	PV/FP_{MESP}
Specific Ecosystem Service Price	FP_{SESP}	FP_{SESP} /a	PV/FP_{SESP}

Notes: PV and PV/a are total and per area Public Value to Maryland, respectively; FP_{cp} and FP_{cp}/a are total and per 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 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 area value, respectively, of the Fair Payments to Maryland land stewards based on the Specific Ecosystem Service Price model. The Public Return on Ecosystem Investment is the ratio of public value to the suggested fair payment price, an estimate of the amount that total societal benefit exceeds suggested payment for the ecosystem service.

3.3.1 Estimating Fair Payment Price in Dollars

The fair payment price is the dollars that should be paid to a land steward for producing 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 4.2.2) 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) 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.

3.3.2 Public value versus Fair Payment Price

For each class of ecosystem service a table similar to Table 6.4 was developed to contrast the public value with the fair payment price. The tables will show the total and per area value to the state.

3.4 Ecological Debt

Development of the concepts of emergy and transformity established a medium (emergy) for accounting that made it possible to express economic and environmental work of all kinds on a common basis as solar emjoules. Environmental accounting using emdollars, can be used to produce a single income statement and balance sheet giving comprehensive accounts for the economy, society, and the environment. The ecological debt framework uses well-known methods from financial accounting and bookkeeping to guide the further development of emergy accounting methods. The important concept of environmental liability is defined and a conceptual basis for its operation and can be presented in the form of an energy systems model. Four categories of environmental debt are recognized and potential schemes for payment are based on the criterion that economic production be sustainable. These four categories are as follows: (1) The emergy of renewable resources extracted or diverted to be used in economic production (a liability if use exceeds replenishment) (2) Annual empower deficits suffered in impacted ecosystems as a result of resource removal and/or impaired production from the effects of wastes, land conversion, etc. (this amounts to “interest” on the debt) (3) The emergy of nonrenewable resources removed for use in economic production and (4) The emergy storages destroyed through the extraction of renewable and nonrenewable resources or the conversion of lands from natural to economic activities. Environmental debt is not necessarily bad; in fact our modern industrial civilization could not exist without incurring debt from the use of renewable and nonrenewable resources. Ecological Debt is a system of double entry emergy and monetary bookkeeping, which uses a combined emergy-monetary journal, separate emergy and money ledgers and an emergy-emdollar balance sheet to keep one set of books for the environment and the economy. Further development, testing, and adoption of environmental accounting tools like these will allow managers to finally determine the true solvency (the ability to pay both economic and environmental debts) of the firms and economic systems for which they are responsible. This research provides a first order measurement of the ecological debt of Maryland from 1700-2010.

Chapter 4: Assessing the Value of Nature: Eco-Price

Previously, emergy values (sej) have been converted to dollar values by dividing by the mean emergy –to-dollar ratio which is based on 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. 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. 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 public valuation estimating method is analogous to the economic multiplier effects that manufacturing jobs have on the economy. Historically, there were 3 to 5 jobs for every one manufacturing job.

Our goal for the EIC was to find a dollar value for forest ecosystem services that could be justifiably paid by consumers of ecosystem services. To develop this payable dollar value I divided the forest emergy flow by the expected eco-price (i.e., sej/$) of various ecosystem services and marketed natural resources. Using an eco-price to make the equivalency between the emergy of the service and dollars to be paid gives a value that members of society should be willing to pay for ecosystem services. One should note that this value is much less than the real wealth that the ecosystem service provides to the economy and society because of the discrepancy between willingness to pay for different types of work (human vs. environmental).

To estimate society's existing willingness-to-pay 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 good or service was divided by the dollars exchanged, generating an eco-price. An average of many eco-prices for each category of ecosystem services (carbon sequestration, hydrologic, soil etc) was used. It was necessary to use the average value because ecosystem services largely exist external to the economy. While there are many instances where markets, taxes and regulatory programs have paid for the continued provision of ecosystem services these are imperfect measures of WTP. They are examples of revealed "societal willingness-to-pay" rather than direct measures. A tax can be viewed as "revealed willingness-to-pay" because citizens of a State or country have given implicit consent/willingness to pay a tax given they are responsible for the electing the governmental officials and are participants in society. It is only through looking at the collection of revealed and direct estimates of WTP that a complete realization of how society values ecosystem services can be made. If not contained in the proceeding sections, Appendix 2 contains the equations used to calculate each eco-price.

4.1 Carbon Sequestration Eco-price Calculation

Eco-prices for carbon sequestration were estimated based on 1) the average price of carbon on the European Carbon Exchange over the last year, 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, 36,200 sej/J (Tilley, 1999), to obtain the emergy value of the wood. This value is then divided by the dollar value of the ton of wood to arrive at the eco-price (emergy per dollar). This general methodology was consistent through all eco-prices calculated.

4.2 Hydrologic Eco-price Calculation

Several eco-prices were calculated to estimate societal willingness to pay for hydrologic ecosystem services. New York City invested $1.5 billion in protecting the watersheds of NYC and a certain quantity of clean water has been supplied. The ratio of the emergy of the clean water supplied since the beginning of the program to the dollars spent was used to estimate an eco-price for freshwater. The ratio of emergy to dollars when municipal water in Maryland is purchased was assessed as was the emergy ratio of emergy benefit to dollars spent in the Chesapeake Bay Clean Water Act and the Water Quality Best

Management Practices Cost Share Program. The emergy of the nutrient inputs avoided through the implementation of these programs was divided by the dollar cost of the program. The average of the hydrologic eco-prices was 8.95E12 sej $\$^{-1}$, which was nearly four times the emdollar ratio in Maryland. See Appendix 2 for precise calculations.

4.3 Air Pollutant Eco-price Calculation

The state of Maryland estimates that on average over the last ten years air pollution cost the state $400 million per year (Maryland.gov, 2011). This cost is derived from methodology found in Costanza et al (1997) and includes hospital costs and damage to crops, forests and water quality. The equation used calculates the cost in 1970 dollars and is as follows-- Cost of Air Pollution in 1970 = (National Costs for Different Aspects Scaled by State Characteristics) Plus (Costs of Air Pollution in Other Years Based on Ozone Levels and National Air Pollution Trends).

Ozone levels in Maryland were used to calculate the cost as it is the principal air pollutant of concern in Maryland (Improving Maryland's Air Quality, MDE, 2009). As such, the emergy of ozone (determined by multiplying the concentration of ozone by the volume of the urban airshed in Maryland, see Appendix 4 for details in Maryland on days where the NAAQS (National Atmospheric Air Quality Standards) were exceeded (only after standards are exceeded are costs incurred) was calculated and divided by the dollar cost to determine an eco-price of 3.88E12 sej/$ for ozone pollution in Maryland.

In addition, the Clear Skies Act of 2003 was used to assess the willingness of the public to invest in air pollution removal. It should be noted this legislation was never enacted, however the program was estimated to cost $4 billion over 15 years, and reduce SO_2, NOx, and Hg by 8.2, 3.4 and 0.000033 million tons, respectively. The total emergy of the pollutants was estimated by multiplying SO_2, NOx and Hg by transformities found in the literature. Then the total emergy was divided by the cost to find the eco-price of 1.14E13 sej/$.

4.4 Soil Eco-price Calculation

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 emergy content. Fill-dirt is mostly purchased in bulk for landscaping and land development. Fill-dirt is largely bought because of its low price and is largely inorganic; thus represents the inorganic fraction of soil. The eco-price for fill-dirt was found to be 1.53E14 sej/$.

The second estimate 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 emergy flows of the forest ecosystem, making the energy flows easily traceable to soil. The eco-price of mulch was found to be 7.54E12 sej/$.

While these may not be directly what society is willing to pay for soil or OM in a forest they are representative of the storage of natural capital that the forest fosters.

4.5 Pollination and Biodiversity Eco-price Calculation

Pollinators play an important role in promoting biodiversity. High pollinator diversity increases plant diversity (Tepedino 1979). Pollinators are important to sustain overall species diversity and agriculture (Ingram, 1996). This study focused on the impact that wild pollinators have on agriculture, since this is their most important economic function, estimated at $11 million dollars per year in Maryland (this study, see appendix 2).

The dollar contribution of native pollinators to US agriculture was estimated by Losey and Vaughn (2006). The estimate was adapted to Maryland, using the percentages of crops pollinated by native pollinators found in Losey and Vaughn and data on crops produced in Maryland from the USDA (www.nass.usda.gov, 2011). The emergy of the crops produced was derived by multiplying the mass of crops produced by a weighted average for vegetables produced in Maryland (transformities calculated in this study, see Appendix 1).

A representative eco-price for biodiversity was considered to be the price paid for land set aside in long-term conservation. Two organizations, Maryland Environmental Trust (MET) and The Conservation Fund Mid-Atlantic (CFMA) were the source of information used to determine the eco-price. This land was purchased in Maryland in the case of the MET and in the Mid-Atlantic region by the Conservation Fund. MET purchased nearly 3,000 acres in 2009 and the CFMA purchased 155,000 acres in Maryland since 1985. The organizations attempt to purchase land with the greatest potential for conservation of ecological and cultural value. In the case of both organizations the emergy of the purchased land (the renewable emergy flow for the year) in 2009 was divided by the cost to acquire the land. This perpetuates not only biodiversity but all the ecosystem services of the land. However, as biodiversity is key in supporting many other ecosystem services land conservation was determined to be a fair approximation of biodiversity willingness to pay. A payment that may be more representative of societal willingness to pay for biodiversity was also included: payments for hunting leases. A payment of $10 per acre per year was found to be typical in Maryland (UMD extension document, no author). The average renewable emergy flow of an acre of forest in Maryland per year was divided by the dollar amount to find the eco-price.

Table 4.1 Ecosystem Service Emprices

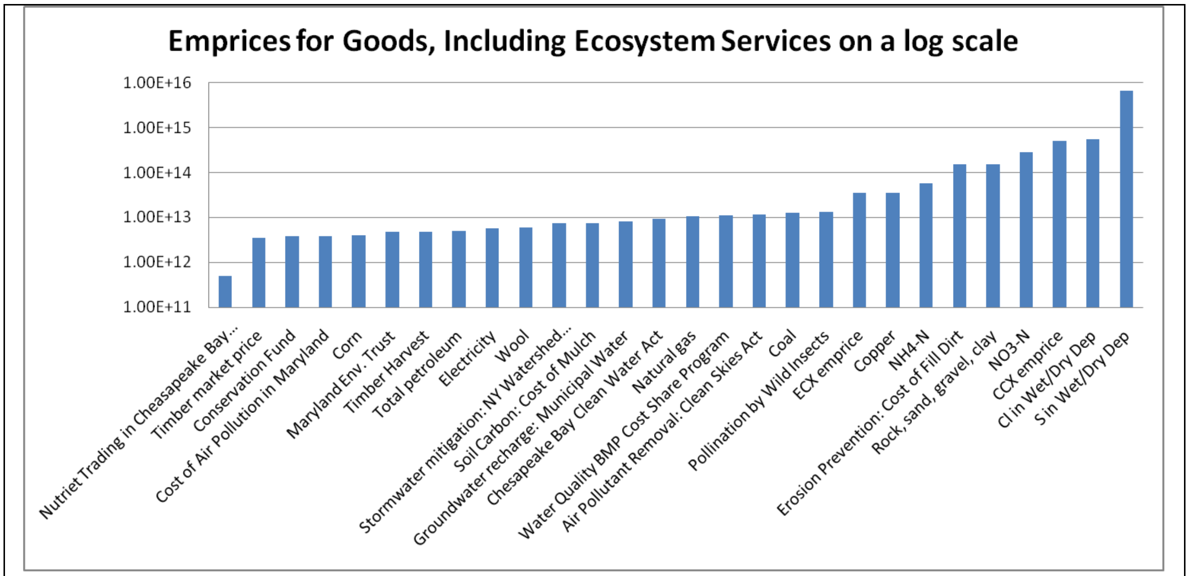
Note	Item	Emprice		$ per quadrillion solar emergy-joules
	Carbon Sequestration			
1	European Carbon Ex. emprice	3.54E+13	sej $\$^{-1}$	$19
2	Chicago Carbon Ex. emprice	5.06E+14	sej $\$^{-1}$	$3
3	Timber market price	3.50E+12	sej $\$^{-1}$	$286
	Avg for Carbon	1.82E+14	sej $-1	$102
4	Stormwater mitigation: NY Watershed Protection	7.34E+12	sej $\$^{-1}$	$136
5	Groundwater recharge: Municipal Water	8.23E+12	sej $\$^{-1}$	$122
	Nutrient Uptake			
6	Chesapeake Bay Clean Water Act	9.32E+12	sej $\$^{-1}$	$107
7	Nutriet Trading in Cheasapeake Bay Watershed	1.08E+12	sej $\$^{-1}$	$930
8	Water Quality BMP Cost Share Program	1.09E+13	sej $\$^{-1}$	$92
	Avg for Water	7.37E+12	sej $\$^{-1}$	$277
9	Erosion Prevention: Cost of Fill Dirt	1.53E+14	sej $\$^{-1}$	$9
10	Soil Carbon: Cost of Mulch	7.54E+12	sej $\$^{-1}$	$101
	Avg Soil	8.01E+13	sej $\$^{-1}$	$55
11	Air Pollutant Removal: Clean Skies Act	1.14E+13	sej $\$^{-1}$	$88
12	Cost of Air Pollution in Maryland	3.88E+12	sej $\$^{-1}$	$258
	Avg Air Pollution	7.64E+12	sej $\$^{-1}$	$173
	West Virginia Tax on Air Pollutants			
13	NO3-N	2.83E+14	sej $\$^{-1}$	$4
14	NH4-N	5.83E+13	sej $\$^{-1}$	$17
15	S in Wet/Dry Dep	6.58E+15	sej $\$^{-1}$	$0
16	Cl in Wet/Dry Dep	5.46E+14	sej $\$^{-1}$	$2
17	Pollination by Wild Insects	1.30E+13	sej $\$^{-1}$	$77
	Biodiversity			
18	Maryland Env. Trust	4.71E+12	sej $\$^{-1}$	$212
19	Conservation Fund	3.80E+12	sej $\$^{-1}$	$345
20	Hunting Lease	5.94E+13	sej $\$^{-1}$	$17
	Weighted Avg for Ecosystem Services	8.75E+13	sej $\$^{-1}$	$78
21	Coal	1.29E+13	sej $\$^{-1}$	$77
22	Rock, sand, gravel, clay	1.53E+14	sej $\$^{-1}$	$9
23	Timber Harvest	4.82E+12	sej $\$^{-1}$	$207

Table 4.1 Continued

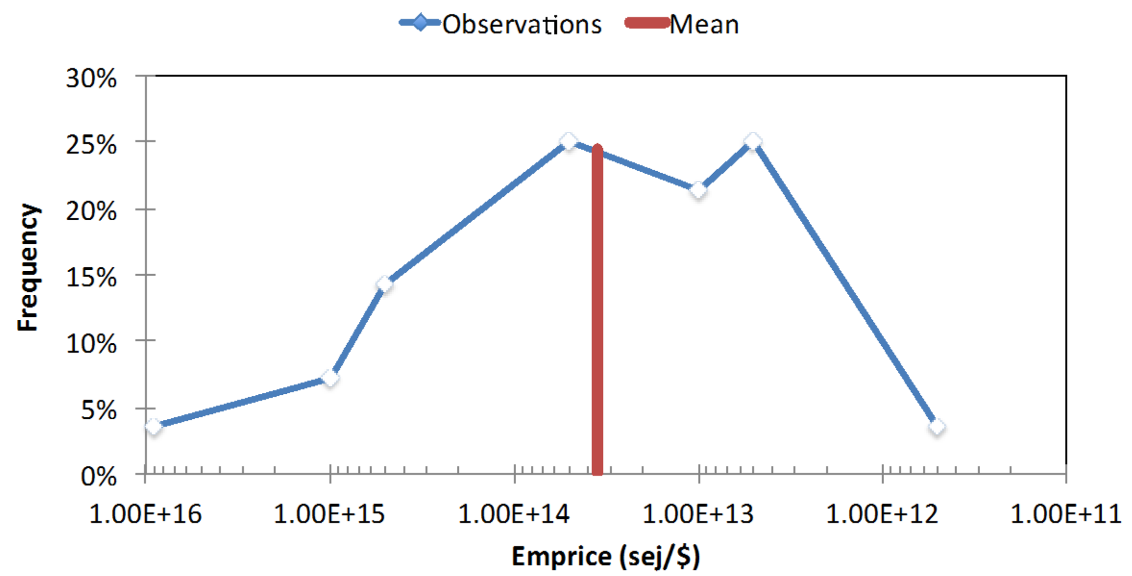
24	Natural gas	1.06E+13	sej $\$^{-1}$	$95
25	Total petroleum	5.00E+12	sej $\$^{-1}$	$200
26	Electricity	5.59E+12	sej $\$^{-1}$	$18
27	Copper	3.54E+13	sej $\$^{-1}$	$28
28	Corn	3.96E+12	sej $\$^{-1}$	$252
29	Wool	6.03E+12	sej $\$^{-1}$	$166
	Average of All Emprices	2.97E+14	sej $\$^{-1}$	$134

See Appendix 1 for footnotes detailing calculations

The eco-prices ranged from 4.9E11 for nutrient trading to 6.5E15 for sulfur deposition, which is a range of 10,000 or 4 orders of magnitude (Figure 4.1a). Considering all of the data, the frequency distribution of logarithm of eco-prices (Figure 4.1b) exhibited a bell-shaped curve with a mean of 3.5.e13 sej/$. This was the mean of the log transformed data, which was less than the arithmetic average of 3.06E14 sej/$. The high values skew the arithmetic mean.



(a)



(b)

Figure 4.1. Rank order (a) and frequency distribution (b) of Eco-prices for ecosystem services evaluated. The mean (3.5E13 sej/$) was based on the log transformed eco-price.

Chapter 5: Characterization and Emergy Analysis of the State of Maryland

5.1 Description of State of Maryland's Economy and Ecology

Maryland is the eighth smallest state in the United States, comprised of 9,772 square miles but has the 15th largest economy with a state domestic product of $273 billion dollars in 2008. During the recent economic recession 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 and commercial fishing in the Chesapeake Bay contributed $53.5 billion in 2006 (MD Archives, 2008).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. Maryland has five distinct terrestrial eco-regions and surrounds the majority of the Chesapeake Bay, the largest estuary in North America. The following paragraphs address Maryland's geology and climate.

Table 5.1. Physical, demographic and economic attributes for Maryland, 2000 **(US Census, 2000)**

Attribute	**Value**	**units**
Land area	2.53E+10	m^2
Continental shelf and bay area	1.14E+11	m^2
Forest land area	1.01E+10	m^2
Bay area	4.47E+09	m^2
Land + bay	2.98E+10	m^2
Shoreline, ocean	1.60E+05	m
Shoreline, waves	1.29E+07	m
Population, 2000	5.30E+06	ind
Per capita income, 1999	25,614	$/ind

5.1.1 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 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 (Edwards, 1981).

5.1.2 Climate

Maryland is diverse climatically considering that it is a small state. The western portion of the state averages lower temperatures and less precipitation (average of 9° C and 0.91 m at the extremes) than the eastern part of the state (with state high annual averages of 15° C and 1.24 m). 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.

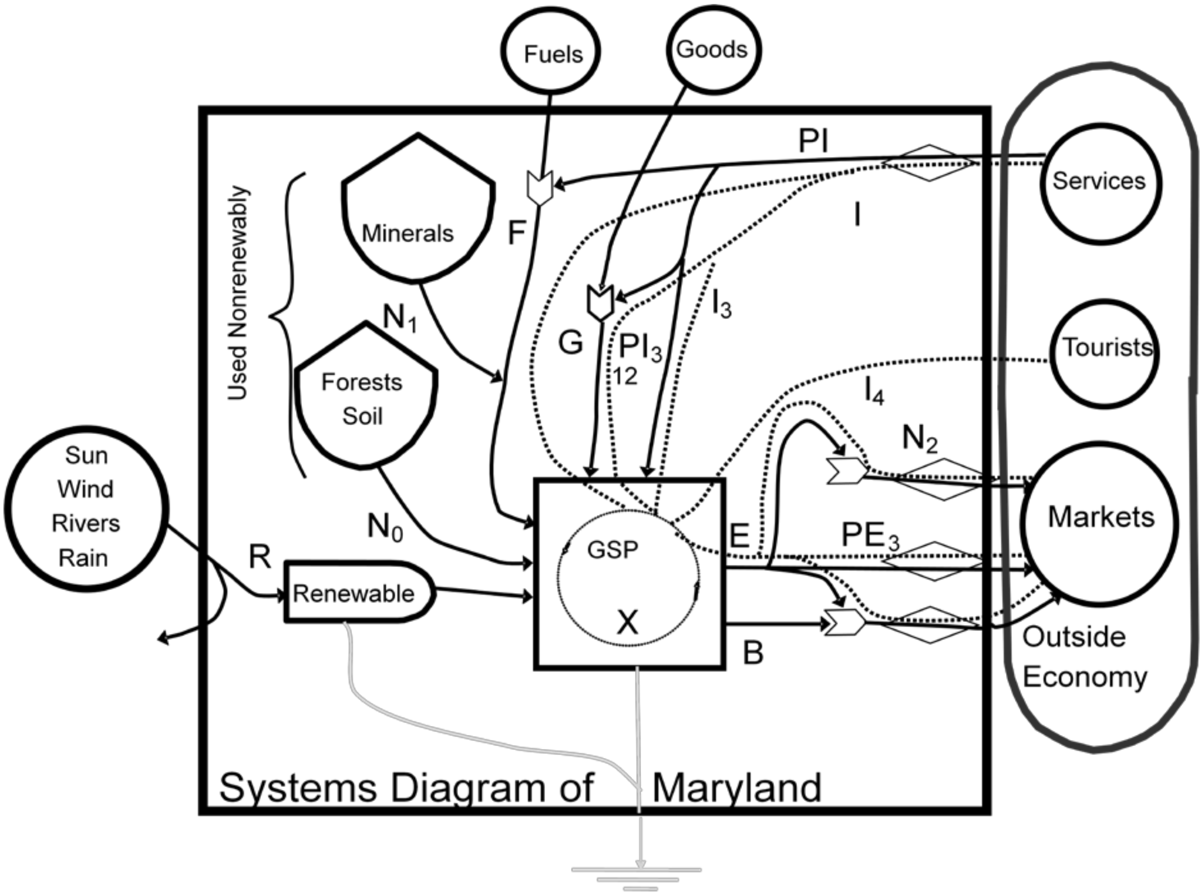


Figure 5.1. Energy Systems Language Diagram of Maryland- This diagram shows the environmental and economic flows into, out of, and within the system. Flow labels correspond to expressions in Table 5.4.

An emergy analysis of Maryland was started by Sherry Brandt-Williams and Daniel Campbell of the US Environmental Protection Agency and completed as part of this dissertation. 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 2004, 2009). A state emergy analysis serves to characterize the state, its economic flows, and its renewable base.

The flows for the year 2000 are summarized in Table 5.2 and Table 5.3. Table 5.2 details the flow of renewable emergy and economic production. Table 5.3 shows the emergy value of imports. Exports are a relatively minor portion of the emergy budget of the state and are not displayed here (see appendix 1 for exports). Indices calculated as part of the emergy analysis are summarized in Table 5.4. The calculations for the state of Maryland in 2000 are detailed in Appendix 1. Having the perspective of the state as a whole is important to place the integral system of the forests of Maryland into the context of the larger system. Among the more interesting aspects of the state of Maryland is that it is typical of many US states in that its emergy flows are dominated by non-renewable emergy, comprising approximately 97% of total emergy use in the state. The emergy from home sources index showed that total energy and resource consumption from in-state (i.e. Maryland) sources were only 12%, meaning that 88% of the emergy used in the state comes from external sources.

Table 5.2 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	0.01
2	Wind	1.67E+18	J	246	0.87
3	Tides	1.10E+17	J	266	0.94
4	Rain, Chemical Potential	4.11E+17	J	743	2.64
5	Transpiration (ET)	7.56E+16	J	212	0.75
6	Rivers used, Chemical potential	1.88E+17	J	343	1.22
7	Rain received, Geopotential	4.57E+16	J	47	0.17
8	Rain used, Geopotential	2.59E+16	J	71	0.25
9	Runoff	1.98E+16	J	54	0.19
10	Rivers, Geopotential	6.41E+16	J	174	0.62
11	Waves	4.28E+16	J	128	0.46
12	Earth Cycle	4.00E+16	J	135	0.48
	Renewables received (Rain chemical + tides + waves + River chemical)			1389	4.93
	Renewables, total used (ET + River chemical + River geo + waves + tides)			1124	3.99
	Economic and non-renewables, produced or extracted				
13	Waste treatment	7.44E+12	g	29	0.10
14	Soils	2.79E+15	J	20	0.07
15	Coal	1.21E+17	J	475	1.69
16	Rock, sand, gravel, clay	-	g	2059	7.30
18	Timber	7.99E+17	J	535	1.90
19	Natural gas	3.74E+13	J	0	0.00
22	Building materials	5.54E+12	g	<0.01	<0.001
23	Grains, fruits, vegetables	5.88E+16	J	1545	5.48
24	Paper products	0.00E+00		-	9.93
25	Electricity	1.75E+17	J	2799	0.01
26	Synthetic chemicals, plastics	3.23E+08	g	<0.01	<0.001
27	Textiles	1.03E+12		0.45	0.10
28	Aquaculture, fishing	6.45E+13	J	28	0.14
29	Meat, Dairy, Eggs	6.42E+14	J	41	0.61
30	Heavy Machinery	2.59E+11		173	0.10
				Sum Nonrenewable=	27.3

Table 5.3 Imports to the Maryland Economy

Description	**Data**	**units/yr**	**Emergy/Unit**	**Emergy E19 sej/yr**	**Billion em$**
Coal	1.92E+17	J	3.92E+04	753	2.67
Natural Gas	2.28E+17		4.35E+04	992	3.52
Aluminum	3.75E+11	g	1.25E+10	469	1.66
Electricity	1.75E+17	J	1.60E+05	2799	9.93
Refined fuels	3.75E+17	J	6.47E+04	2423	8.59
Services	9.09E+09	$	1.07E+12	973	3.45
Federal Government	4.51E+10	$	1.07E+12	4826	17.11
Domestic Goods/Imports					
Live animals and live fish	5.56E+10	g	4.39E+05	26	0.09
Cereal grains	2.04E+11	g	1.82E+05	62	0.22
Other agricultural products	5.37E+11	g	2.33E+05	154	0.55
Animal feed and products of animal origin, n.e.c.	3.79E+11	g	1.26E+06	978	3.47
Meat, fish, seafood, and their preparations	4.99E+11	g	3.27E+06	1737	6.16
Milled grain products and preparations, and bakery products	7.07E+11	g	2.00E+05	237	0.84
Other prepared foodstuffs and fats and oils	2.81E+12	g	1.21E+06	12571	44.58
Alcoholic beverages	3.53E+11	g	58900	11	0.04
Tobacco products	4.34E+09	g	650000	4	0.01
Gravel and crushed stone, natural sand	6.58E+12	g	9.81E+08	646	2.29
Nonmetallic minerals n.e.c.	6.67E+11	g	1.96E+09	131	0.46
Basic chemicals	5.52E+11	g	2.75E+09	152	0.54
Pharmaceutical products	1.52E+11	g	2.75E+09	42	0.15
				16750	59.40
Fertilizers					
Nitrogen	1.37E+10	g	2.41E+10	33	0.12
Phosphate	1.10E+10	g	2.20E+10	24	0.09
Potassium	4.44E+09	g	1.10E+09	0	0.00
Total	1.12E+11		2.99E+09	34	0.12
Chemical products and preparations, n.e.c.	7.89E+11	g	9.90E+09	781	2.77
Plastics and rubber	1.15E+12	g	2.71E+09	312	1.11
Logs and other wood in the rough	2.00E+11	g	6.87E+04	22	0.08
Wood products	1.99E+12	g	1.49E+09	297	1.05
Pulp, newsprint, paper, and paperboard	9.77E+11	g	4.95E+09	484	1.72
Paper or paperboard articles	5.54E+11	g	1.40E+05	124	0.44

Table 5.3 Continued

Printed products	7.82E+11	g	4.95E+09	387	1.37
Textiles, leather, and articles of textiles or leather	3.25E+11	g	7.18E+06	3199	11.34
Nonmetallic mineral products	1.95E+12	g	3.09E+09	603	2.14
Base metal in primary or semifinished forms and in finished basic shapes	1.35E+12	g	5.91E+09	796	2.82
Articles of base metal	9.54E+11	g	5.91E+09	564	2.00
Machinery	4.40E+12	g	7.76E+09	3412	12.10
Electronic and other electrical equipment and components and office equipment	4.20E+11	g	7.76E+09	326	1.16
Motorized and other vehicles (including parts)	9.56E+11	g	7.76E+09	742	2.63
Transportation equipment, n.e.c.	3.282E+10	g	7.76E+09	25	0.09
Precision instruments and apparatus	5.08E+10	g	7.76E+09	39	0.14
Furniture, mattresses and mattress supports, lamps, lighting fittings, and...	1.60E+11	g	2.89E+09	46	0.16
Miscellaneous manufactured products	6.29E+11	g	1.61E+09	101	0.36
Waste and scrap	2.06E+11	g	2.16E+09	44	0.16
Mixed freight	1.46E+12	g	6.32E+09	924	3.28
				13264	47.04
Emergy in imported goods				30015	106.43

Table 5.4 Emergy Analysis Summary Table for Maryland in 2000

Item	Name of Index	Expression	Maryland		Dollars, in 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	0.113		
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	0.0268		
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/m2	
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	

5.1.3 Forests in Maryland

Maryland forests account for seven percent of the renewable emergy flow per year in Maryland (quantified by the emergy of forest transpiration). If only the terrestrial portion of Maryland's renewable emergy is considered forest emergy comprises 38% of the total. Renewable emergy flow in forests is only 0.17% of the total emergy used in Maryland. The emergy of forest ecosystem services is not included in the total emergy used, as it is a relative (to urban conditions) measure of the contribution being made by ecosystem services. However, when compared to total emergy use it is 2.5% of the total. This indicates that the forests of Maryland have a much greater impact on society when measured from an ecosystem service perspective than is captured with a traditional emergy analysis.

Table 5.5 Characterization of Forests in Maryland	
Total renewable emergy in Maryland	7.0%
Forest renewable emergy, % of terrestrial renewable emergy	38.0%
Renewable emergy used in Maryland, % of total emergy use	2.9%
Forest renewable emergy, % of terrestrial renewable emergy	0.2%
Forest Ecosystem Service Emergy, % of total used	2.5%

Chapter 6: The Ecological Debt of Maryland—1700-2010

Ecological Debt, as defined by this study and valued using environmental accounting, is a measure of the value of the natural capital that has been lost due to anthropogenic activity in a given system. The idea was first put forth by Campbell (2007) and this research is the first example of applying the concept to an ecosystem. Analyzing the ecological debt of a system allows the impact that humanity has cumulatively had on the environment to be enumerated. It also has broader implications, like using double entry book keeping to track both financial and ecological debts; this research presents the gross debt for the state of Maryland. I look at how the natural environment of Maryland has changed from 1700 to 2010, using the acreage of forests and wetlands as a first order approximation of total natural capital. Data on forest and wetland coverage in the state was available for certain time periods. For forests estimates of forest cover were found for pre-colonization, in this case defined as prior to 1700. Historical evidence shows that forest extraction pre 1700 did exist but was likely limited and little is known regarding its extent. The peak of deforestation in Maryland occurred approximately in 1850. The first forest inventory was conducted in 1916 and semi-regular data exists on Maryland forest extent proceeding this date. Wetland extent in Maryland is less well documented prior to 1955.

The model used to calculate ecological debt multiplies the lost acreage of forest and wetlands by the assumed emergy storage (the emergy of stored natural capital in the form of tree/shrub biomass and soil organic matter) per acre. The emergy value is converted to dollars by dividing the emergy of ecological debt by the commodity eco-price. The commodity eco-price was used because it provides a median estimate of how people value the ecosystem. It may be appropriate to apply a discount rate to past loss, this should be explored in future research.

6.1 Data Collection and Parameter Estimate

The data for the acres of the forests of Maryland over the 230 year period of 1780-2010 was taken from USFS publications (Widdmann, 1999), University of Maryland extension documents (Kays, no publication date given) and an original State of Maryland report on the Forests of Maryland from 1916, one of the first of its kind in the United States (Besley, 1916). Data on wetland change in Maryland was taken from the Dahl (1999), MDE (2012), Tiner (1995) and Blankenship (1994). The emergy value of the natural capital of forests was calculated in this study drawing upon data from the USFS (Forest Inventory and Analysis, Carbon Online Estimator, both available online and last accessed in 2011).

The emergy value of the natural capital of wetlands was adapted from Brown and Bardi, 2001; I used an average natural capital storage value of the three wetland types presented there. The model estimated eco-price, 5 E13 sej/$, was used to convert sej of ecological debt to dollars.

Prior to 1850 a constant loss of forest acreage per year was assumed. The data for wetland loss was more sparse than for forests; necessitating using a constant loss per year for every year prior to 1955. Table 6.1 presents the rate of forest and wetland loss per time period.

The emergy of forest natural capital is the sum of tree biomass, shrub biomass, and soil organic matter emergy. The emergy of wetland natural capital is the average of the biomass, peat and water emergy for three Florida wetland types; herbaceous, scrub-shrub and forested (Brown and Bardi, 2001). Water storage on forest lands is not included to avoid double counting. It was assumed that each acre of forest was equal to 1E17 sej/acre of natural capital (the sum of biomass and soil OM storage, this study) and 4.5E17 sej/acre for wetlands (average of the natural capital, biomass+soil OM+water, of three wetland types, From Brown and Bardi, 2001). The Brown and Bardi (2001) study was the most recent example found where the emergy of natural capital had been calculated for wetland ecosystems. These ecosystems are representative of what is found in Maryland, although there is likely some divergence in values due to their occurrence in different eco-regions.

Table 6.1 Rate of Forest and Wetland Change

Forest		
Years	Δ Acres/yr	Reference
1700-1850	-35451	Kays
1850-1916	23697	Besley, 1916
1916-1950	22939	Widmann, 1999
1950-2010	-6256	USFS FIA, 2011
Wetland		
1700-1955	-4724	Dahl, 1999
1950-80	-800	Blankenship, 1994
1980-90	-625	Tiner, 1991
1990-2010	38	MDE, 2011

6.2 Results

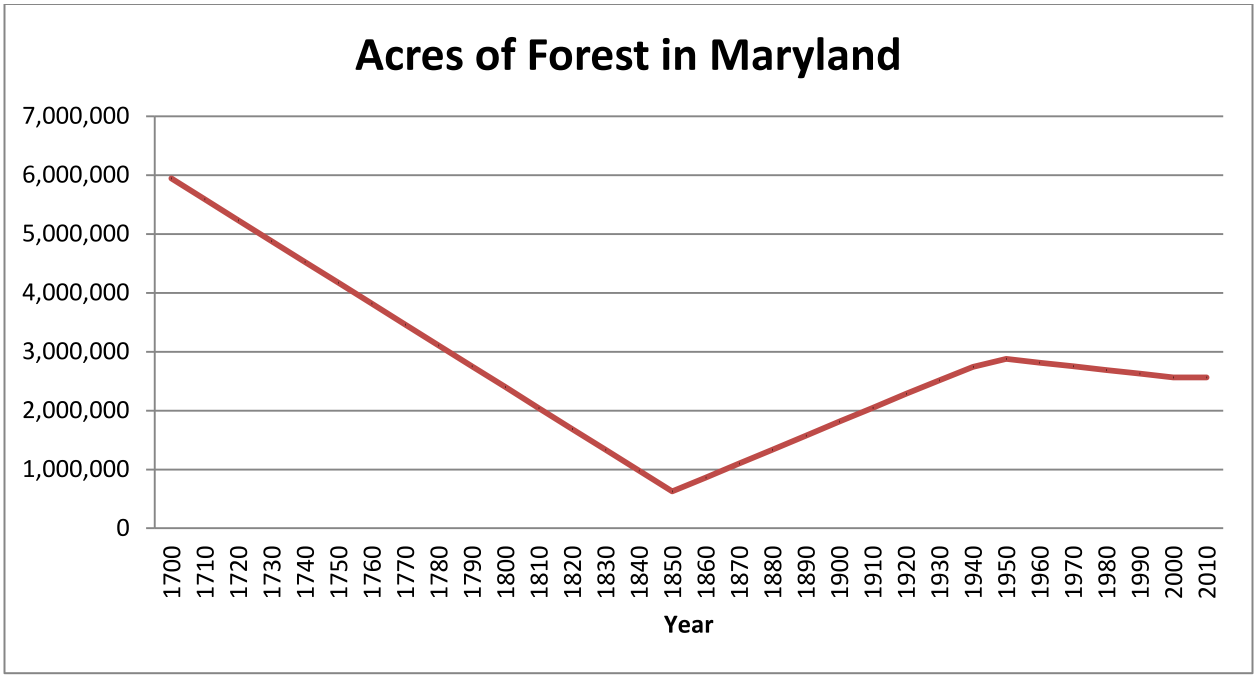
Table 6.2 The Change in the Natural Capital and Ecological Debt in Maryland, 1700-2010

	Acres of Forest	Acres of Wetlands	Forest Natural Capital, sej	Wetland Natural Capital, sej	Total Natural Capital, sej	Ecological Debt, sej	Ecological Debt,in $'s, 5E13 sej/$ conversion
1700	5,943,200	1,650,000	5.97E+23	7.54E+23	1.35E+24	0.00E+00	0
1710	5,588,693	1,602,760	5.61E+23	7.33E+23	1.29E+24	5.72E+22	$1,125,628,924
1720	5,234,187	1,555,520	5.26E+23	7.11E+23	1.24E+24	1.14E+23	$2,251,257,849
1730	4,879,680	1,508,280	4.90E+23	6.89E+23	1.18E+24	1.72E+23	$3,376,886,773
1740	4,525,173	1,461,040	4.54E+23	6.68E+23	1.12E+24	2.29E+23	$4,502,515,698
1750	4,170,667	1,413,800	4.19E+23	6.46E+23	1.06E+24	2.86E+23	$5,628,144,622
1760	3,816,160	1,366,560	3.83E+23	6.25E+23	1.01E+24	3.43E+23	$6,753,773,547
1770	3,461,653	1,319,320	3.48E+23	6.03E+23	9.51E+23	4.00E+23	$7,879,402,471
1780	3,107,147	1,272,080	3.12E+23	5.81E+23	8.93E+23	4.57E+23	$9,005,031,396
1790	2,752,640	1,224,840	2.76E+23	5.60E+23	8.36E+23	5.15E+23	$10,130,660,320
1800	2,398,133	1,177,600	2.41E+23	5.38E+23	7.79E+23	5.72E+23	$11,256,289,245
1810	2,043,627	1,130,360	2.05E+23	5.17E+23	7.22E+23	6.29E+23	$12,381,918,169
1820	1,689,120	1,083,120	1.70E+23	4.95E+23	6.65E+23	6.86E+23	$13,507,547,093
1830	1,334,613	1,035,880	1.34E+23	4.73E+23	6.07E+23	7.43E+23	$14,633,176,018
1840	980,107	988,640	9.84E+22	4.52E+23	5.50E+23	8.01E+23	$15,758,804,942
1850	625,600	941,400	6.28E+22	4.30E+23	4.93E+23	8.58E+23	$16,884,433,867
1860	862,570	894,160	8.66E+22	4.09E+23	4.95E+23	8.56E+23	$16,841,100,757
1870	1,099,539	846,920	1.10E+23	3.87E+23	4.97E+23	8.53E+23	$16,797,767,646
1880	1,336,509	799,680	1.34E+23	3.65E+23	5.00E+23	8.51E+23	$16,754,434,536
1890	1,573,479	752,440	1.58E+23	3.44E+23	5.02E+23	8.49E+23	$16,711,101,426

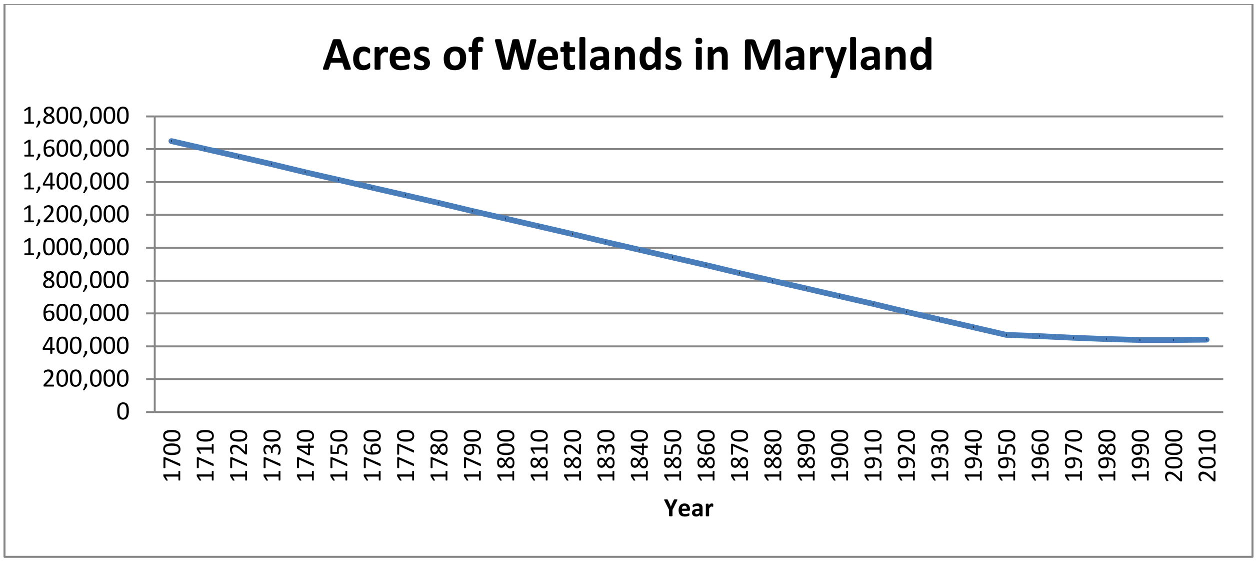
Table 6.2 Continued

1900	1,810,448	705,200	1.82E+23	3.22E+23	5.04E+23	8.47E+23	$16,667,768,316
1910	2,047,418	657,960	2.06E+23	3.01E+23	5.06E+23	8.45E+23	$16,624,435,206
1920	2,284,388	610,720	2.29E+23	2.79E+23	5.08E+23	8.42E+23	$16,581,102,096
1930	2,513,775	563,480	2.52E+23	2.58E+23	5.10E+23	8.41E+23	$16,552,755,678
1940	2,743,161	516,240	2.75E+23	2.36E+23	5.11E+23	8.39E+23	$16,524,409,261
1950	2,877,760	469,000	2.89E+23	2.14E+23	5.03E+23	8.48E+23	$16,683,396,503
1960	2,815,200	461,000	2.83E+23	2.11E+23	4.93E+23	8.57E+23	$16,879,009,798
1970	2,752,640	453,000	2.76E+23	2.07E+23	4.83E+23	8.67E+23	$17,074,623,094
1980	2,690,080	445,000	2.70E+23	2.03E+23	4.73E+23	8.77E+23	$17,270,236,389
1990	2,627,520	438,750	2.64E+23	2.01E+23	4.64E+23	8.86E+23	$17,450,105,573
2000	2,564,960	439,130	2.58E+23	2.01E+23	4.58E+23	8.93E+23	$17,570,327,067
2010	2,564,960	439,510	2.58E+23	2.01E+23	4.58E+23	8.92E+23	$17,566,908,346

Table 6.2 shows how the forest and wetland acreage, and associated emergy of the natural capital stored in the forest or wetland, has changed in Maryland from 1700-2010. Maryland forests comprised 95% and wetlands covered 26% of the land area of Maryland in 1700 (forested wetlands are included in both categories). Maryland Forest acreage and natural capital storage reach a nadir in 1850 at 10% of the state, increase to 46% in 1950 and then slowly decrease to the current percent cover of the state (41%). This percentage is calculated as the number of forested or wetland acres divided by the total land and water area of Maryland, excluding the Chesapeake Bay. The controlling factor prior to 1950 is land-use change due to changes in the state economy; post 1950 land use change is driven by population increase. Wetlands decrease rapidly until 1955 when the rate of loss slows until 1990, where the trend is reversed and wetlands increase slightly from 1990-2010. The composition of wetland loss also changes over the historical record, with many coastal wetlands being lost prior to the 1970 Maryland Tidal Wetland law.



a)



b)

Figure 6.1 Two graphs showing the change in the acreage of forests (a) and wetlands (b) in Maryland from 1700-2010.

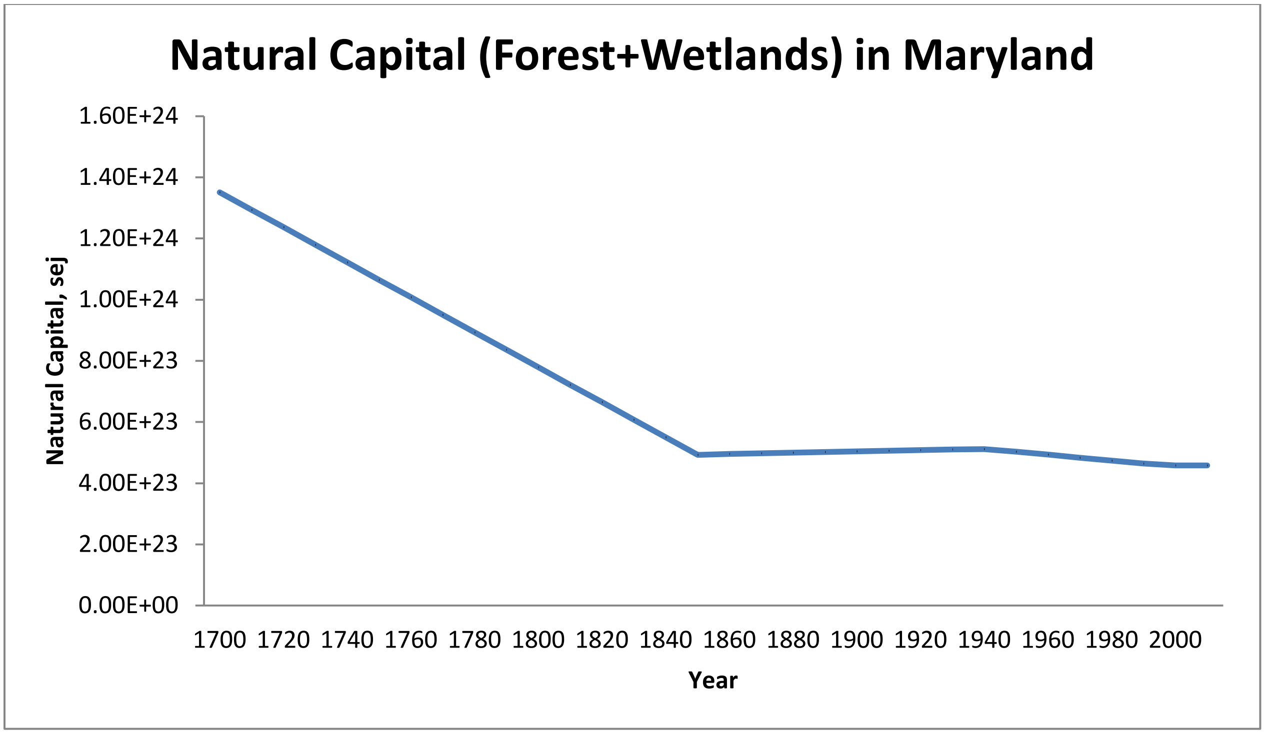


Figure 6.2 The storage of natural capital, quantified in emjoules, has decreased in Maryland since 1700.

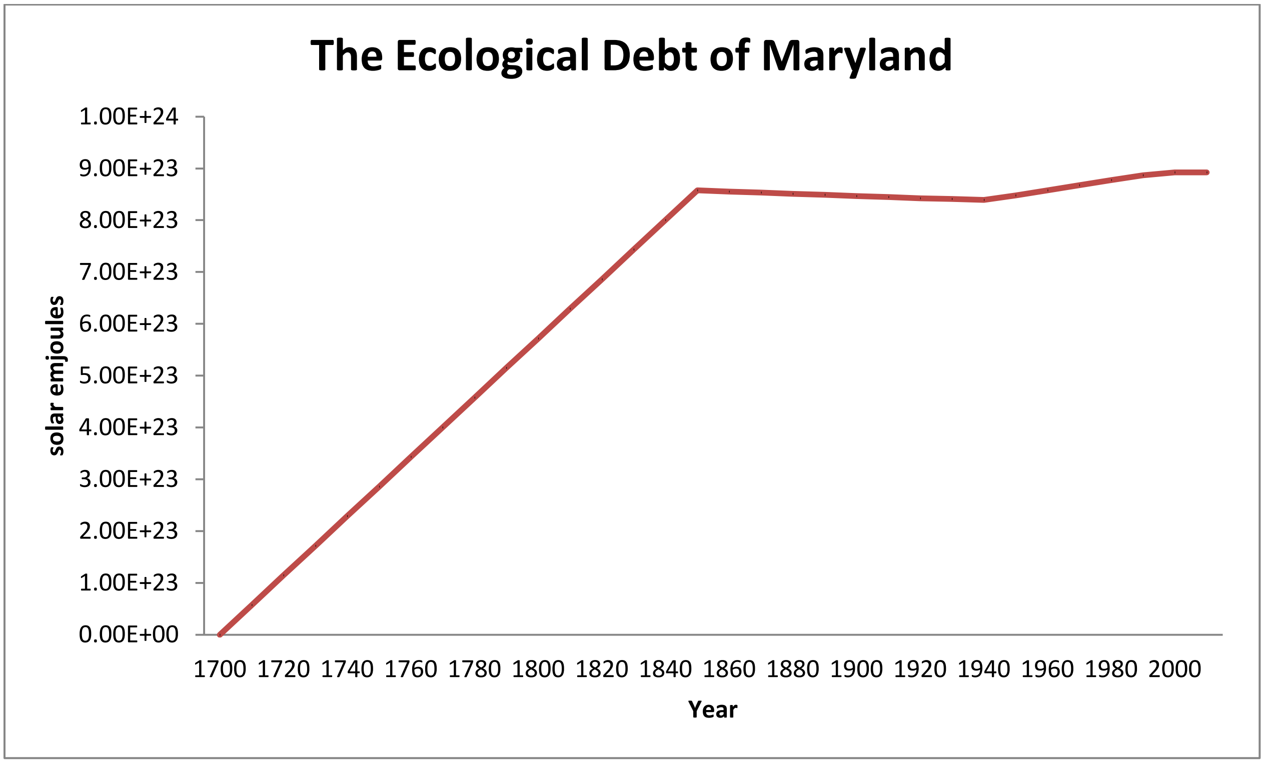


Figure 6.3 The ecological debt, here measured in emergy, has increased over time. It is currently increasing at the slowest rate since 1700.

6.3 Discussion

The Ecological Debt of Maryland measures the impact that land development has had on the environment. The pattern is quite clear and can be easily explained in accordance with Maryland history. Between 1700 and 1850 Maryland was an expanding agrarian society and 18 wood burning furnaces were built in the state for charcoal production (Davis, 1983). Land was cleared rapidly for agriculture and grazing lands and people tended to spread out across the state. Post 1850 the industrial revolution was under way and many people migrated to cities, creating abandoned land available for afforestation. After 1950 forests begin to decline again, in accordance with the expanding population of Maryland, necessitating land development.

A recovery period for wetlands is not seen along with forests, since wetlands that have been drained do not return without active reclamation. It is not until the 1970's and 1980's when wetland loss begins to slow, the point at which the Tidal Wetland Loss Act of 1971 began to make it harder for wetlands to be developed. In 1991 the Maryland Wetland No Net Loss Act was passed and along with the Federal No Net Wetland Act has led to a slight increase of wetlands in Maryland. However, these laws have drawn extensive criticism for making it too easy for developers to destroy natural wetlands and replace them with inferior (in terms of both structure and function) constructed wetlands (Whigham, 1999, Brooks, 2005). This leads us to the caveats that need to be stated along with this research; this is a first order approximation of ecological debt, I use general values for the natural capital of both forests and wetlands and the accounting of the natural capital storage is incomplete. Improvements on the forest natural capital calculation could be made if more was known regarding the nature of the forest at different points in history, specifically the forest stocking. A general trend, peak stocking rate initially, minimum in the late 1800's and an increasing trend 1950 until the present, is known but specific numbers are lacking. Data on the natural capital storage in Maryland wetlands would improve the wetland portion of the calculation; however this was beyond the scope of this research. Despite these limitations, the estimation that

Maryland has gone from $0 to on the order of $17 billion dollars of ecological debt in 230 years is likely reasonably accurate. Maryland’s ecological debt is no longer increasing rapidly in the 2000’s but we have a long way to go in making progress towards reversing the trend and paying off the principle. The implications of ecological debt on the economy and environment of Maryland are discussed in Chapter 12.

Chapter 7. Ecosystem Services from the Forests of Maryland

Figure 7.1 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 environment. The biologically diverse vegetation and wildlife of the forest work together to process dilute planetary energies to build rich soils teeming with moisture. 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 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.

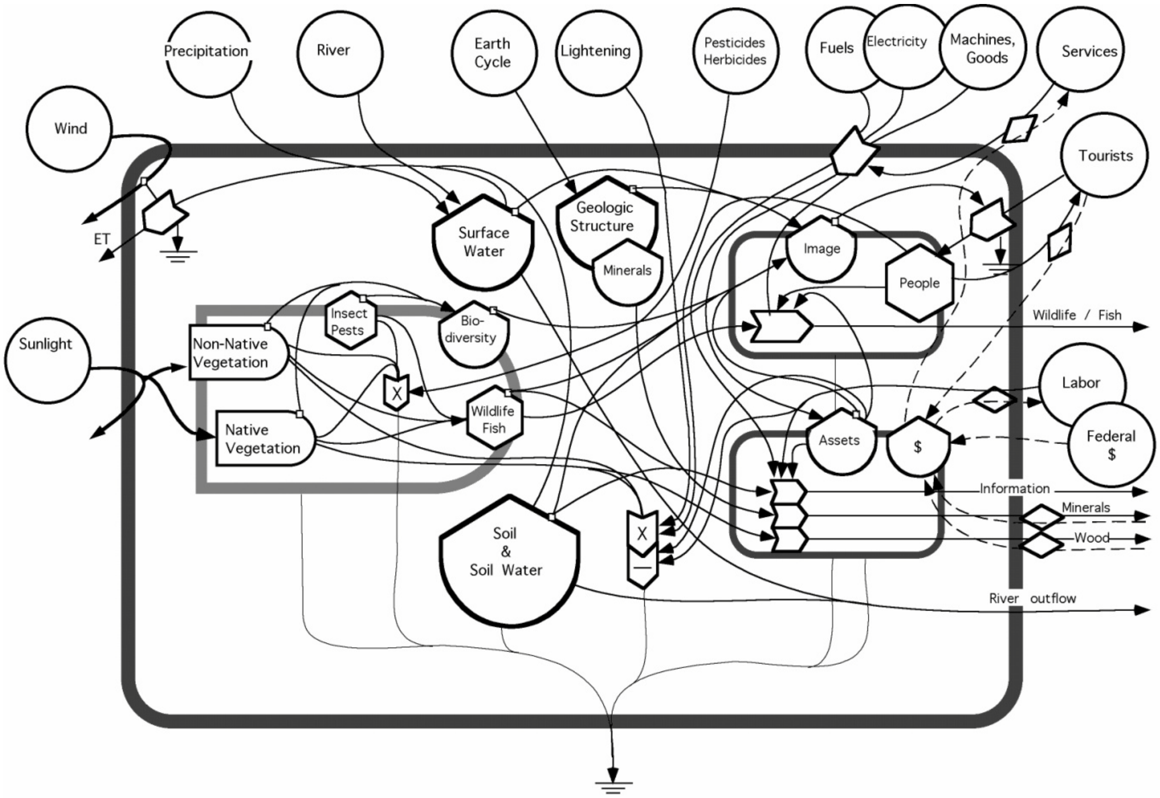


Figure 7.1. Overview systems diagram of the multiple ecosystem services provided by the forest of Maryland.

7.1 Carbon sequestration

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. Forests sequester carbon through the process of photosynthesis, taking in CO_2 and H_20 then emitting O_2 and synthesizing carbohydrates ($C_6H_{12}O_6$). The evaluation of carbon sequestration from the forests Maryland was done using existing data and models available from the USFS. Carbon sequestration varies by soil quality, and climate, which are not considered in the model. Making a fine scale calculation of this variability was beyond the scope of this study. A field study was conducted to determine how carbon stocks vary in Maryland with physiographic region and surrounding land-use and to ground truth the values generated by the USFS models.

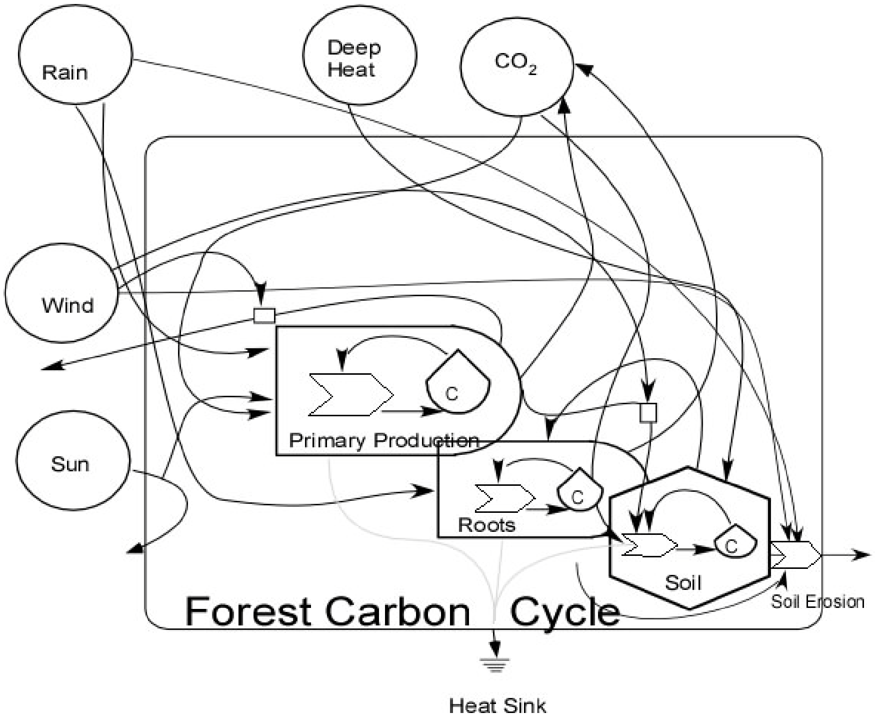


Figure 7.1.1 Energy Systems Diagram detailing Carbon storages and energy flow-through in a typical Maryland Forest.

7.1.1 Description of Energy Systems Language Diagram

The diagram in Figure 7.1.1 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 aboveground to the soil through the death of plants due to disease, pests, rot, soil erosion or excessive wind. Pruning of limbs through wind and leaf fall also moves carbon from aboveground to the soil. Within the soil, carbon is respired and put back into the atmosphere through the activity of the soil microbial community, taken back up by the plant community, and lost to the system through soil erosion. In this diagram I did not consider the role that consumers have on carbon storage— it is assumed that the vast majority of consumed carbon is kept within the system.

7.1.2 Data Collection

Data from the USFS Forest Inventory Analysis database (USFS, 2011) suggests that during an average year 1.5 metric tons of carbon is sequestered on a hectare of average forest land in Maryland. This number was found through a weighted average for carbon sequestration by forest by percentage that an individual forest type makes up of all Maryland forests.

Field work was conducted during the summer of 2009 for five forest sites around Maryland across three physiographic regions (i.e., Appalachian, Piedmont and Coastal Plain, see figure 7.2) and included the land-use categories of natural forest, urban forest, and restored forest. Standard forestry methodology was used at 15 1/10th acre plots at a randomly generated location in each study area. Data on the tree species and diameter at breast height (dbh) was taken for each tree or shrub with a dbh greater than 2 inches within the plot. The sample location was randomly generated using ArcMap™. Soil samples of the top 10 cm were taken at a random location within each plot using a soil auger. The organic content of the top 10 cm soil sample was estimated by uniformly mixing the sample and then using the loss on ignition method (Schumaker, 2002).

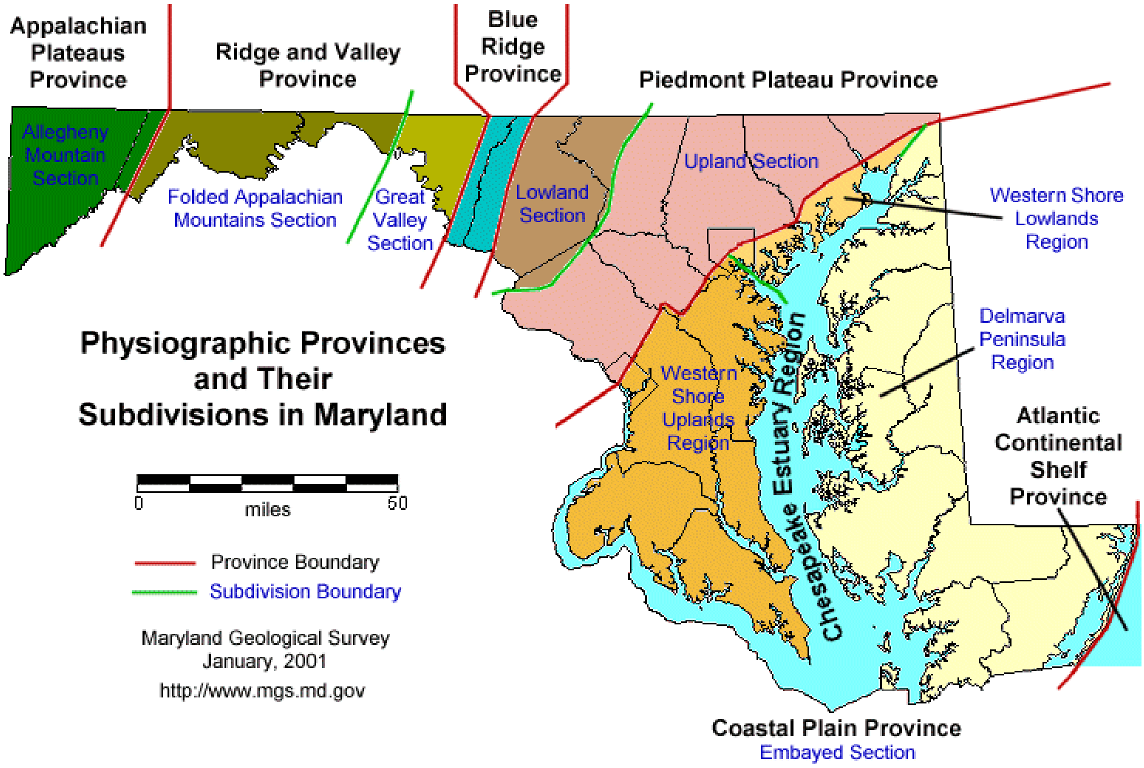


Figure 7.1.2 Map of Maryland's physiographic regions (Maryland Geographical Survey, 2001).

7.1.3 Parameter Estimate

Allometric equations (Jenkins, 2003) were used to calculate the carbon stored in each tree measured in the field. A conservative estimate of 1.5 tonnes per ha 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 by forest cover type. COLE estimates carbon sequestration by forest type in all 50 states; data on the forest types that make up the forests of the state of Maryland was taken from the USFS FIA to generate a weighted average. To contrast the COLE estimate carbon sequestration values generated from the i-Tree Vue model (i-tree, 2012) are presented as well. The Vue model assumes 3 mt of carbon sequestration per year per ha of canopy cover (see section 7.4 for detailed methods for the i-tree Vue model). The forests in Maryland are approximately 82% canopy cover (NLCD, 2011) so the carbon sequestration per ha of forest generated by i-tree Vue is 2.5 mt per ha per year. 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 for the volume to mass and mass to energy conversions. Tree species richness for the four forest types is the average of the number of tree species found in the 15 sample locations in each forest. The Shannon-Wiener diversity index is also an average of the diversity of the 15 sample locations and was determined using the following formula— H= -sum(Pi*log(Pi)) where Pi is the proportion that individuals of the ith species makes up of the total number of individuals observed and H signifies the Shannon-Wiener Diversity Index.

Equation 7.1 Calculation for Emergy of Carbon Sequestration in Maryland in 1 year (Appendix 3)—

(1500000 g C /ha/yr)*(1.01E6 Forested Ha in MD)*(3.5 kcal/g C)*(4184 j/g)*(3.62E4 sej/J)

= 8E20 sej/yr

7.1.4 Results

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 7.1). The restored riparian forest had the least biomass, which was most likely because it had only been restored 12 years before sampling. Carbon values were found by assuming that 50% of the total biomass is made up by carbon (Lamlom, 2003). The values found in this survey are similar to previously found values for biomass in Maryland (USFS FIA, 2006). The highest average species richness and Shannon-Wiener Diversity Index was found at the Elvaton plots, a restored riparian forest. 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 ago and Elvaton between 2 to 5 years ago. The lower biomass found for Elvaton can be explained by the fact it was restored more recently. Lowered tree species richness in temperate forests that have high biomass supports the theory that richness and biomass are negatively related (Mitsch and Jorgensen 2004).

Table 7.1.1 Storages of Carbon and Biomass across the Physiographic Regions of Maryland

Forest Name	Physiographic Region	Condition	Biomass MT ha^{-1}	Carbon MT ha^{-1}	Tree Species Richness (#)	Shannon-Weiner Diversity Index
Cedarville State Forest	Coastal Plain	Natural	153	76	8.7	1.65
Savage River SF	Appalachian	Natural	233	117	7.7	1.44
Green Ridge SF	Piedmont	Natural	154	77	8.5	1.61
Spring Branch	Coastal Plain	Restored Riparian	126	63	6.3	1.38
Elvaton	Piedmont	Restored Riparian	86	43	10.5	2.10
Maryland USFS FIA Data						
North Central	Piedmont/Coastal Plain	mixed	167	83	-	-
Southern	Coastal Plain	mixed	180	90	-	-
Lower Eastern Shore	Coastal Plain	mixed	164	82	-	-
Western	Appalachian	mixed	124	62	-	-

7.1.5 Values of Carbon Sequestration

Forest sequestration of carbon provides $300-500 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 (output of equation 1) 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 state economic product.

Estimates of the fair price to be paid to land stewards ranged from \$4 ha-forest^{-1} yr^{-1} to \$15.8 ha-forest^{-1} yr^{-1} (\$1.6 acre forest^{-1} yr $^{-1}$ to \$6.4 acre forest^{-1} yr^{-1}), depending on which eco-price was used (Table 7.1.2). The Commodity Equivalency 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 7.1.2 Public value and fair payment price for forest sequestration of carbon.

Carbon Sequestration	**Maryland (million \$ per yr)** **COLE Model**	**Maryland** **(million \$ per year)** **i-Tree Vue model**	**Per Area (\$ per acre per yr)**
Public Value	\$300.0	\$500.0	\$121.41-\$202.35
Commodity Fair Payment Price	\$15.8	\$26.33	\$6.39-\$10.65
Mean Ecosystem Service Fair Payment Price	\$9.2	\$15.33	\$3.72- \$6.20
Specific Ecosystem Service Fair Payment Price	\$4.4	\$7.3	\$1.62- \$2.70

7.1.6 Discussion

The field study enumerated carbon storages in Maryland forests compared favorably with numbers generated by the COLE model (Table 7.1.1). These results support the decision to use the USFS FIA database and the COLE model for the state as whole. The results obtained through COLE are about 1 MT-C per ha less than when compared to another USFS model, the Urban Forest Effects model (UFORE) (1.5 MT-C per ha vs. 2.5 MT-C per ha). This highlights the variability in models used and the difficulty in obtaining precision when measuring ecosystem function on a broad scale. In proceeding calculations where values are summed (see chapter 9) the low estimate of carbon sequestration is used to avoid potential criticism for overestimation.

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. The public value is natural wealth that is created for the entire state and all of its citizens and visitors to enjoy.

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, eliminating the incentive to actually pay for the ecosystem service as there is a large discrepancy between price requested and willingness to pay. 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 water piping. The mining corporation is paid based on the price of copper in the Earth, not on its price as water piping. By analogy the ecosystem service should have its final consumption value, like copper water piping does (i.e., its public value), and its primary “mining value” like copper in a mineral deposit.

The three techniques developed here for estimating the primary “mining value” of ecosystem services gave the amount of money that should be paid to land stewards who produce ecosystem services, which serve as a “primary” source of emergy for the ecological-economic system. I call this the fair payment price. The public's return on ecological investment (PREI) is defined as the ratio of public value to the fair payment price. The PREI indicates how well the investment in the EIC creates public value. For carbon sequestration the PRIE ranged from 75 to 19, indicating that the EIC investors create a lot of public value for their investment.

7.2 Hydrologic Ecosystem Services

Forest lands provide a benefit to the overall system in the form of market services, societal services and ecosystem services. A large portion of this value comes from the positive impact that forests have on the water flowing through or falling on them. These benefits are the hydrologic ecosystem services. The hydrologic ecosystem services can be partitioned into nutrient/pollutant removal, stormwater runoff mitigation, and groundwater recharge promotion. This research focused on the hydrologic systems of the Piedmont and Coastal Plain regions in Maryland under two land-uses, forested and urban. The urban land-use was defined as 40% impervious cover; typical suburban/urban conditions in Maryland.

The emergy value of water on the landscape changes as the residence time of the water increases or decreases as the water moves through the landscape. This was demonstrated with a water balance model (Figure 7.2.1), which was simulated in Microsoft Excel™. The service of stormwater mitigation by forests is valued as the difference between the amount of stormwater runoff in a forested watershed and the amount in a suburban watershed.

7.2.1 The Model for Stormwater Mitigation and Groundwater Recharge

The emergy-hydrologic model SoilAqDyn was developed to simulate the emergy associated with hydrologic flows in a forested or urban system in either Piedmont or Coastal Plain physiographic regions (Figure 7.2.1).

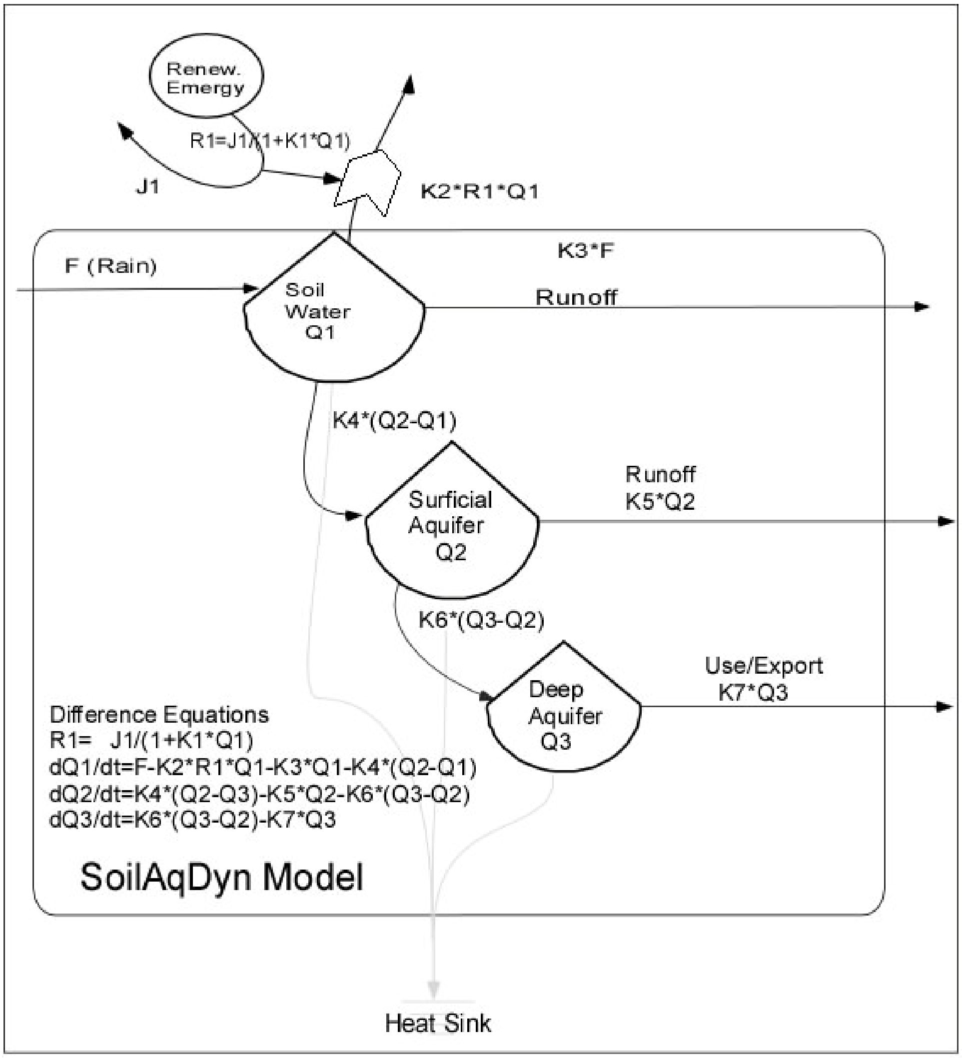


Figure 7.2.1. Energy Systems Language diagram of the SoilAqDyn model with the equations used to simulate it. Parameter values are given in Table 7.2.1.

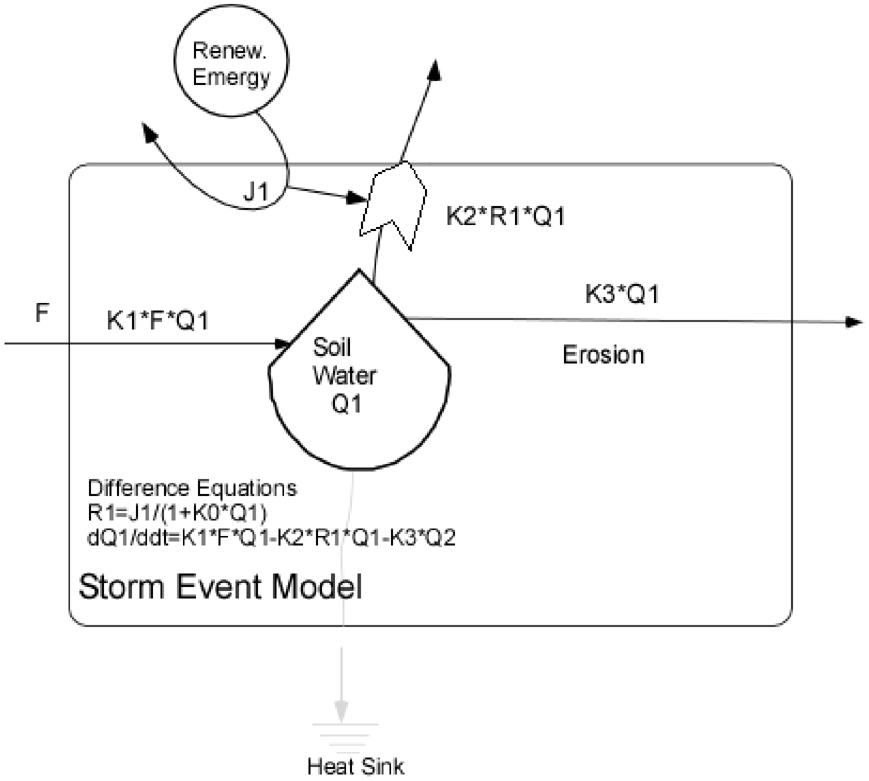


Figure 7.2.2 Energy systems language model of a 48 hour storm event with difference equations. Transpiration, K2*R1*Q1, is only calculated if it is not raining (F=0).

7.2.2 Storm Event Mini-Model

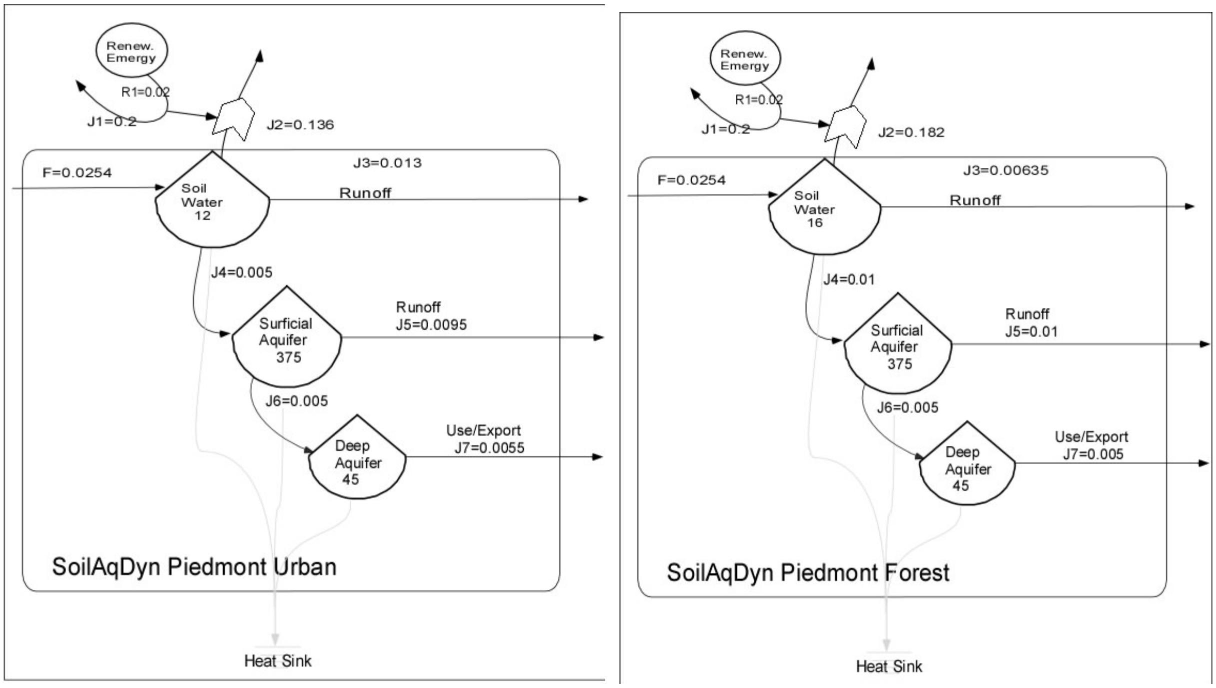
The Storm Event model simulated runoff and storage for 48 hours of a 2 cm rain event at an hourly time step for urban and forested land cover (see Fig. 7.2.2). Table 7.2.1 and figure 7.2.4 show the calibration values and initial conditions for the model.

7.2.3 Data collection and Parameter estimate

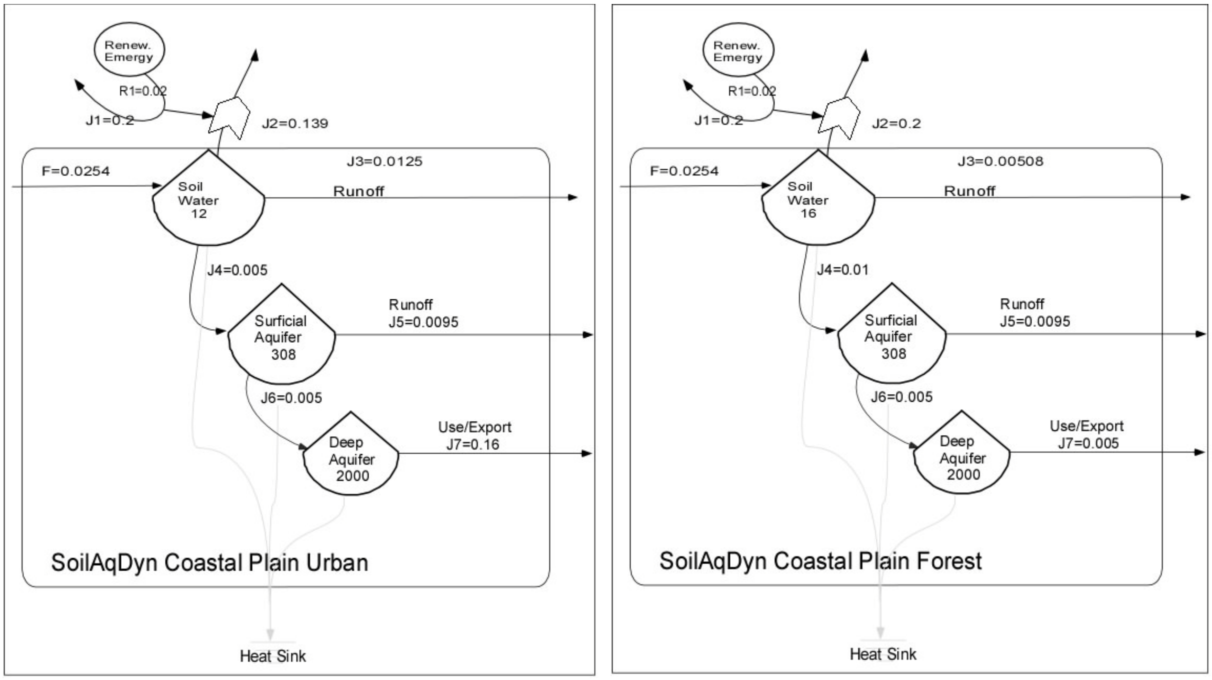
Data for the rainfall input to the SoilAqDyn was taken from two USGS weather stations, in the Piedmont and Coastal Plain Provinces of Maryland. When up-scaling the ecosystem services for the state as a whole rainfall data was obtained from NOAA.

Table 7.2.1 Initial Conditions and parameter estimates for SoilAqDyn in Figure 7.2.1 and 7.2.2. Units are in cm^3/cm^2 except for k values which are time (1 day)

	Piedmont		Coastal Plain		48 Storm Event	
	Forest	Urban	Forest	Urban	Forest	Urban
Q1=	16	12	16	12	0	0
Q2=	375	375	308	308	-	-
Q3=	45	45	2000	2000	-	-
F=	variable		variable	variable	0.30	0.30
J1=	0.2	0.2	0.2	0.2	0.2	0.2
K0=	0.625	0.625	0.625	0.625	0.625	0.625
K1=	0.0625	0.3	0.0625	0.1	0.0625	0.0625
K2=	0.625	0.483333	0.625	0.491667	0.03	0.03
K3=	0.25	0.5	0.2	0.491667	5.00E-03	2.00E-02
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	-	-



a) b)



c) d)

Figure 7.2.3 Calibration values and initial conditions for the SoilAqDyn model under four scenarios. Units are cm^3 of water per cm^2 of area over a 1 day time period.

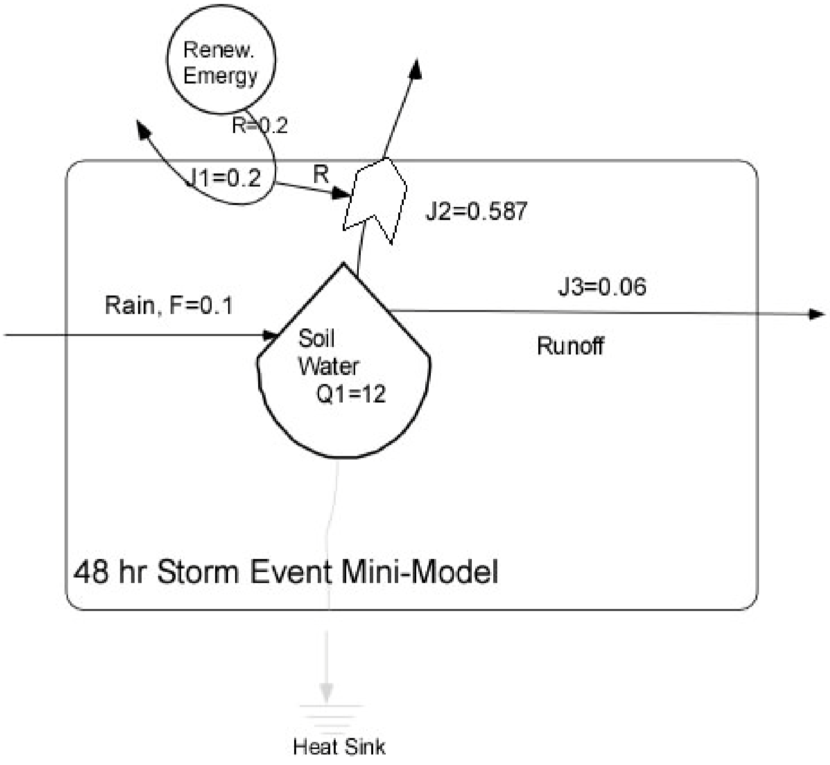


Figure 7.2.4 Calibration values and initial conditions for the 48 hour Storm Event mini-model. Units are cm^3 of water per cm^2 of area over a 1 hour time period.

7.2.4 Parameter Estimate

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 Chang's (2006) forest hydrology text. Rainfall rate (F) was taken from USGS weather station data for the calendar year of 2009. Model parameters were determined for reference conditions by solving for k values when the storage and flow values were known. It should be noted that the urban scenarios were calibrated to 40% impervious surface, a value found to be typical of Maryland urban/suburban settings (Maryland Department of Planning, 2011).Table 7.2.1 contains the initial value for storages and k's and table 7.2.2 and figure 7.2.3 show the initial flow values for each model scenario. Values are based on expected or observed characteristics of the reference state. The outputs of SoilAqDyn were then used to value the hydrologic ecosystem services that forests provide in the following way: the difference between the emergy of runoff in the urban and forest system was attributed to the service provided by the forest. The groundwater recharge service was the additional emergy of groundwater recharge in the forest system vs. the urban system.

Equation 7.2: Runoff Mitigation Calculation (Appendix 3)—

((1517005 j/m^2/yr of runoff avoided in the MD Hills + Mountain regions)*(5.25E9 m2 of Hill+Mountain Forest area)*(1.24E5 sej/j)) + ((1522858 j/m2/yr of runoff avoided in the Coastal Plain)*(4.84E9 m2 of Coastal Plain forest area)*(1.55E5 sej/j)= 2.13E21sej/yr

Equation 7.3: Groundwater Recharge Calculation (Appendix 3)—

((88468 J/m2/yr of groundwater promotion in the MD Hills + Mountain regions)*(5.25E9 m2 of Hill+Mountain Forest area)*(1.5E6 sej/j)) + ((89919 j/m2/yr groundwater promotion in the Coastal Plain)*(4.84E9 m2 of Coastal Plain forest area)*(1.32E6 sej/j)= 1.27E21sej/yr

7.2.5 Nutrient Removal

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. I 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. I assumed that urban lands had a net zero nutrient balance, but realize that due to fertilizer application they would be sources of nutrients. The nutrient removal service was the difference in emergy of nutrient outputs from forest and urban systems. 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.

Equation 7.4: Emergy of Forest Nutrient Removal Calculation (Appendix 3)—

((11 kg N uptake/ha/yr)* (1.01E6 ha of forest in MD)*(4.1E13 sej/kg)+ (9.6 kg P uptake/ha/yr)*(1.01E6 ha of forest in MD)*(2.16E14 sej/kg))= 2.54E20 sej/yr

7.2.6 Results

Four scenarios of SoilAqDyn were considered and the results from each of those scenarios in terms of storage of water are presented in figure 7.2.5 Forest lands were found to store 50% more water than urban lands and allow for 34% more ground water recharge. Groundwater levels from two USGS stations, located close to the weather stations where the rainfall data inputs to the model were taken, are displayed in figures 7.2.6. These graphs display depth to groundwater, not total storage calculated by the model (figure 7.2.6, a and b vs. figure 7.2.5) but it can be observed that the trends are similar.

Figure 7.2.7 compares runoff over a 48 hour storm event in forested and urban conditions. More water accumulated in the forested soils than in the urban ones (1.59 cm vs. 0.87 cm). Also, less runoff was generated from the forested soils (0.28 vs. 0.87 cm). For this 2 cm event the runoff mitigation ecosystem service was estimated to provide $14/ha of public value (see Table 7.2.4).

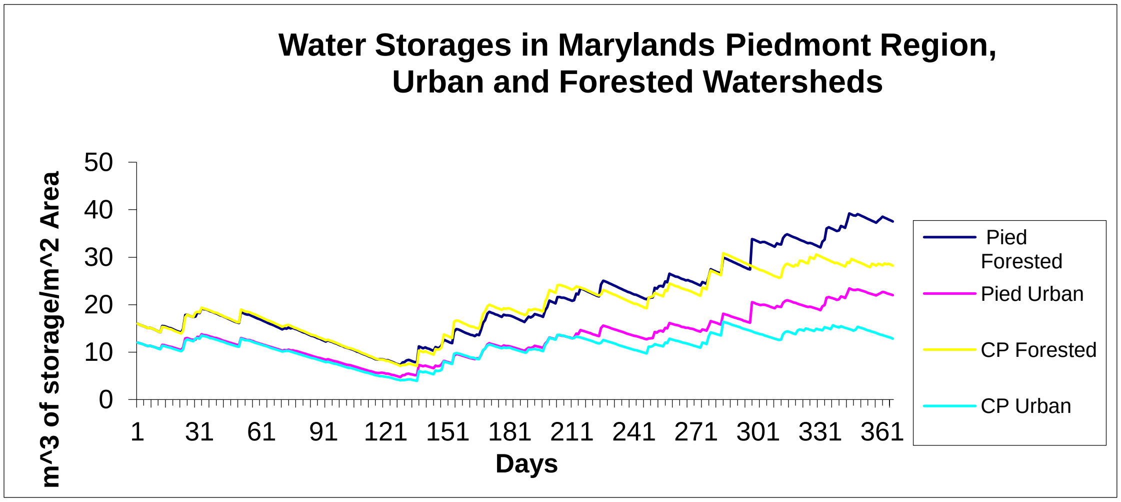
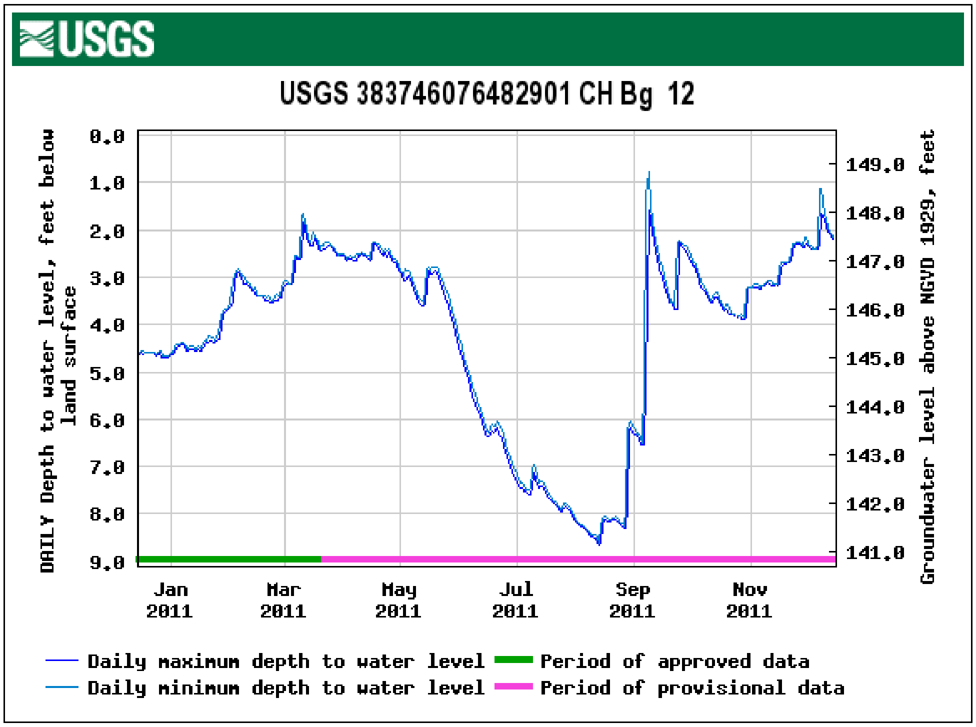
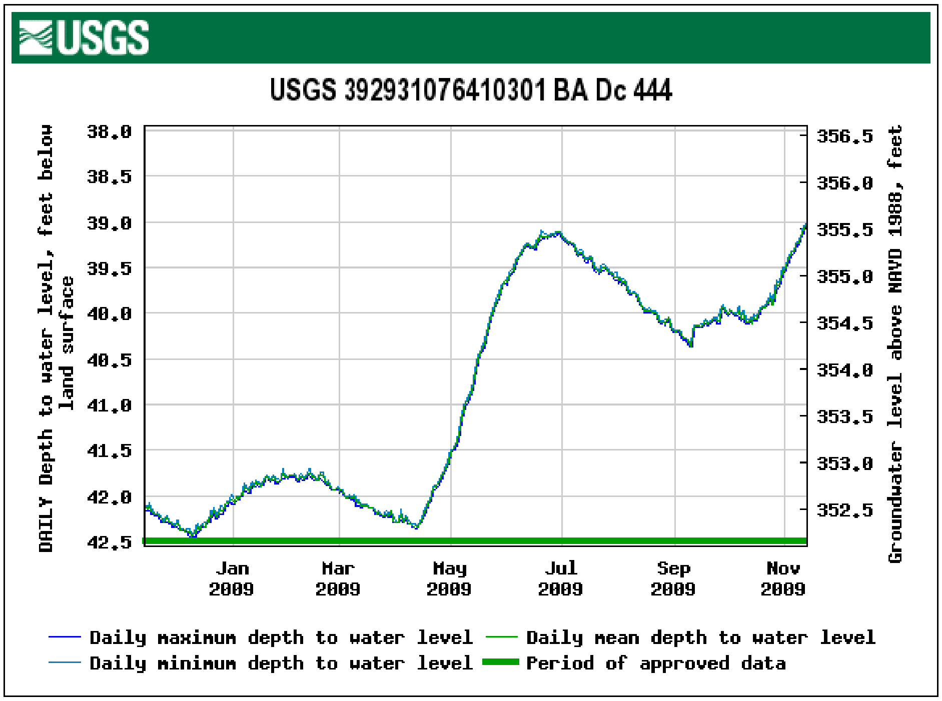


Figure 7.2.5 Water Storages in Maryland’s Piedmont Region, Comparison of Urban and Forested Watersheds over 1 year



a)



b)

Figure 7.2.6 Both Graphs display data on depth to water table from Nov. 13th, 2008 to Nov. 13th, 2009. Graph (a) shows data from a site in Charles County in the coastal plain physiographic province, and graph (b) displays data from a monitoring station in Baltimore County, located in the piedmont.

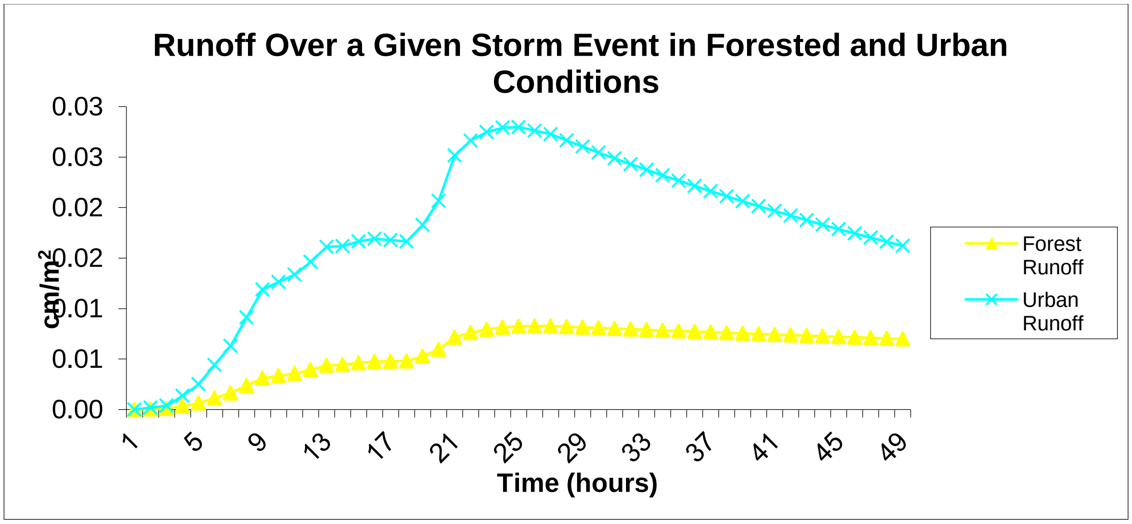


Figure 7.2.7 Results of the Storm Event model, urban conditions have a higher rate and volume of runoff.

7.2.7 Valuing the Service

Table 7.2.3 lists the yearly values for the stormwater mitigation and groundwater recharge ecosystem services for the state of Maryland and per individual acre of forest, using four different methods of assessing dollar value from emergy. Table 7.2.4 displays the value provided by a forest during a single storm event. The public value is the total benefit that society gains from the ecosystem service while the three other eco-prices estimate societal willingness to pay.

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 lands than in urban areas.

Table 7.2.2 Public value and fair payment price for forest hydrologic services

Stormwater Mitigation	**Maryland (million $ per yr)**	**Forest ($ per acre per yr)**	**PREI**
Public Value	$717.40	$290.30	1
Commodity Fair Payment Price	$37.40	$15.10	19
Mean Ecosystem Service Fair Payment Price	$21.80	$8.80	33
Specific Ecosystem Service Fair Payment Price	$238.00	$96.30	3
Groundwater Recharge			
Public Value	$478.60	$193.70	1
Commodity Fair Payment Price	$25.00	$10.10	19
Mean Ecosystem Service Fair Payment Price	$14.60	$5.90	33
Specific Ecosystem Service Fair Payment Price	$142.00	$57.50	3

Table 7.2.3 Stormwater Mitigation over a 48 hour, 2 cm Storm Event

	Dollars Per Acre Forest Land ($ per acre per 48 hr storm event)	**PREI**
Public Value	$14.00	1
Commodity Fair Payment Price	$0.78	18
Mean Ecosystem Service Fair Payment Price	$0.45	31
Specific Ecosystem Service Fair Payment Price	$4.41	3

7.2.8 Discussion

SoilAqDyn successfully simulated water dynamics over an annual cycle (simulated trend of groundwater storage followed the trend of groundwater levels observed at USGS monitoring wells). Runoff was larger in urban conditions than in forested conditions. Groundwater recharge was higher in forested conditions than in urban conditions. These trends were similar for both the Piedmont and Coastal Plain regions. The Piedmont forested and Piedmont urban had consistently higher water storage values than Coastal Plain forested and urban, likely due to the fact that the rain gauge data used for the Coastal Plain totaled 0.2 m less than the data used for the Piedmont region. The ecosystem service of mitigating runoff, had a public value of $270 ac^{-1} yr^{-1} for the Piedmont and $338 ac^{-1} yr^{-1}in the Coastal Plain and averages $290 ac^{-1} yr^{-1} for the state. These values are based on the amount of water that forests save from that would have runoff from the forest if the land-use was urban. The Storm Event mini-model demonstrated how the rate and volume of runoff from 1 m^2 of forest land differed from 1 m^2 in typical Maryland suburban conditions (40% impervious cover). The forest had a lower overall volume of runoff and a lower peak flow rate. This is an important aspect of the ecosystem service provided by forests as stormwater management is designed for peak flow rates. A watershed with more forest cover will likely have lower peak flow rates of runoff, necessitating less storm management infrastructure.

7.3 Soil Ecosystem Services

Soil ecosystems play an important role in provision of ecosystem services. They are the foundation for growth of primary producers, provide habitat for fauna, recycle nutrients, and sequester carbon, building the productivity of the soil. The properties of nutrient cycling and habitat provision are accounted for in other ecosystem service categories; this section will focus on how forests promote the building of soil organic matter and prevent soil erosion.

7.3.1 Soil Carbon Model: ForSoilCarbon

The model *ForSoilCarbon* was designed to simulate the carbon dynamics in forest and suburban soils (Figure 7.3.1). Vegetation is built up in the flora storage, and carbon is recycled from flora back to the soil storage. Soil carbon is lost to the system through erosion; the flora storage is decreased and lost to the system through consumer export.

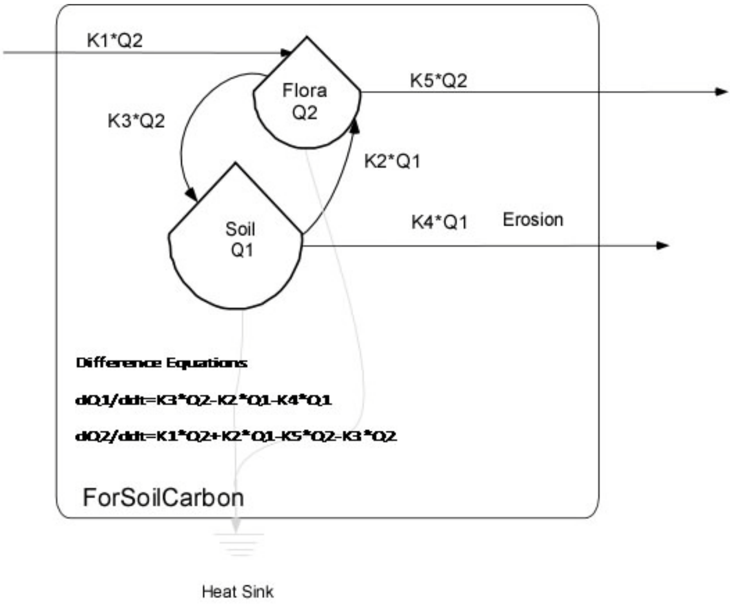


Figure 7.3.1 Model of soil carbon processes, calibrated for forest and urban conditions

7.3.2 Data Collection and Parameter Estimate

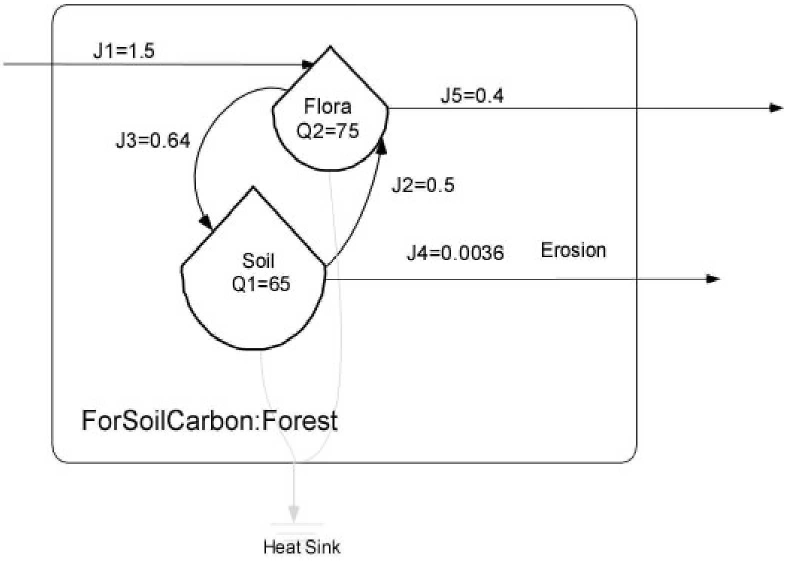
Valuation of the soil building ecosystem service relies on literature values for rates of organic matter accumulation on the forest floor in different forest types and how impervious surface cover affects the rate of organic matter accumulation (Pouyat 2002, 2006). COLE (Carbon Online Estimator, USFS 2010) was used to estimate storages and rates of carbon accumulation in different forest types.

The initial conditions in the Soil Carbon model were derived from the COLE model for different forest types in Maryland for the forest model. Initial conditions for both models are that the model considers 1 ha of land and a 1 m depth of soil with a bulk density of 1.25 g cm^{-3}. K values are calculated using the reference calibration values displayed in table 7.3.1 and figure 7.3.2. The urban version of both models assumed an impervious cover of 40% with 16% tree canopy, numbers consistent with other models (i-tree Vue, 2011).

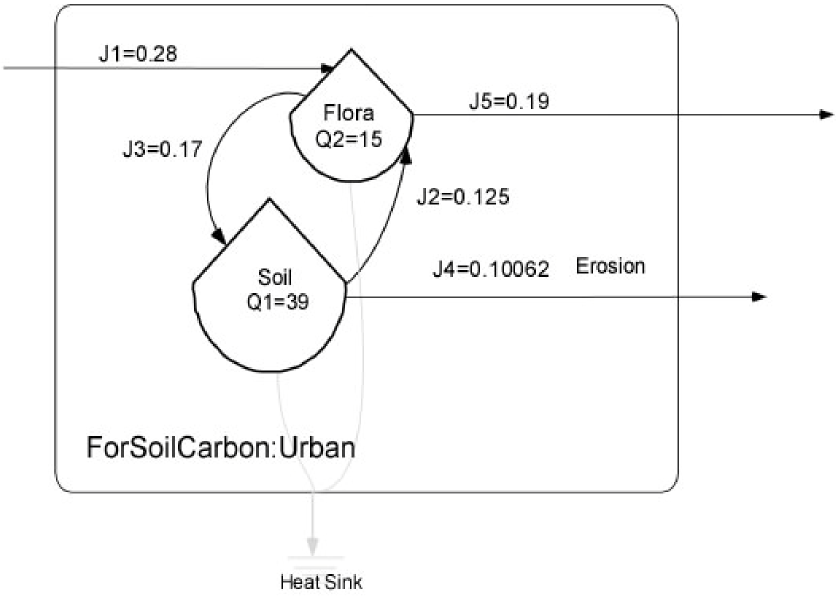
The model was developed to evaluate the net balance of carbon in forest soil. The evaluation of soil maintenance compares soil carbon dynamics in the urban environment to that of the forest environment. The additional carbon built up in the forest model vs. the urban model was attributed to the soil building ecosystem service of the forest.

Equation 7.5: Emergy of Soil Building Calculation (Appendix 3) —

(274491 g C/ha/yr)*(1.01E6 ha of forest in MD)*(3.5 kcal/g C)*(4184 j/kcal)*(1.43E5 sej/j)= 5.81E20 sej/yr



a)



b)

Figure 7.3.2 Calibration values and initial conditions for ForSoilCarbon under forested (a) and urban (b) conditions. Units are metric tons of carbon per ha per year.

Table 7.3.1 Initial Conditions and Parameters for ForSoilCarbon

	Soil Carbon		
	Forest	Urban	
Q1	65	39	mt C/ha
Q2	75	15	mt C/ha
K1	0.0200	0.0188	1 year
K2	0.0067	0.0083	1 year
K3	0.0085	0.0110	1 year
K4	0.0001	0.0026	1 year
K5	0.0053	0.0125	1 year
Reference Calibration Values			
K1*Q2 (J1)	1.50	0.28	mt C/ha/yr
K2*Q2 (J2)	0.50	0.13	mt C/ha/yr
K3*Q2 (J3)	0.64	0.17	mt C/ha/yr
K4*Q1 (J4)	0.004	0.10	mt C/ha/yr
K5*Q2 (J5)	0.40	0.19	mt C/ha/yr

7.3.3 Soil Erosion Model: ForSoilMineral

ForSoilMineral (Fig. 7.3.3) assumed that the accretion of soil emergy comes from two 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 but the physical quantity of soil in Q1 is determined only by the input from parent material and the erosion output. Emergy is tracked along with the physical grams of soil to enable the dynamic calculation of soil transformity over time.

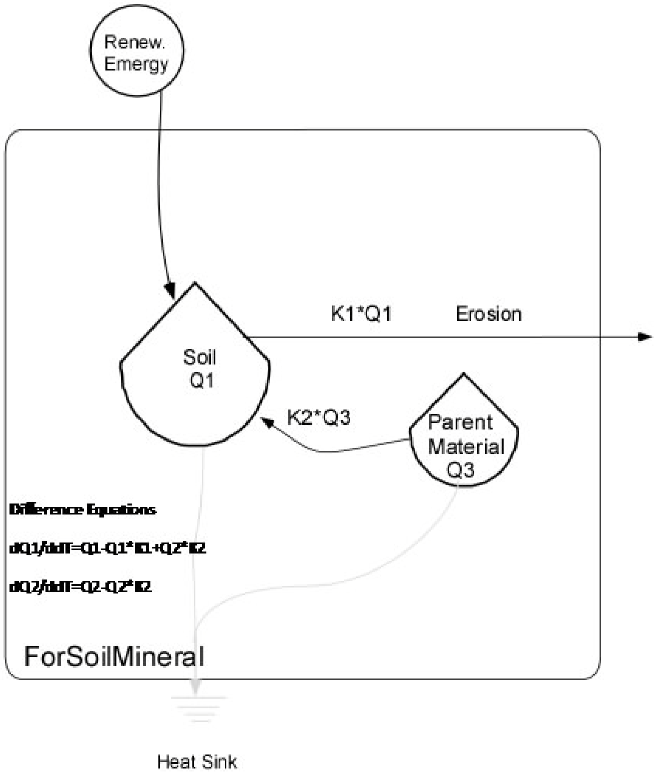


Figure 7.3.3 Model of soil erosion, simulated under both forest and urban conditions.

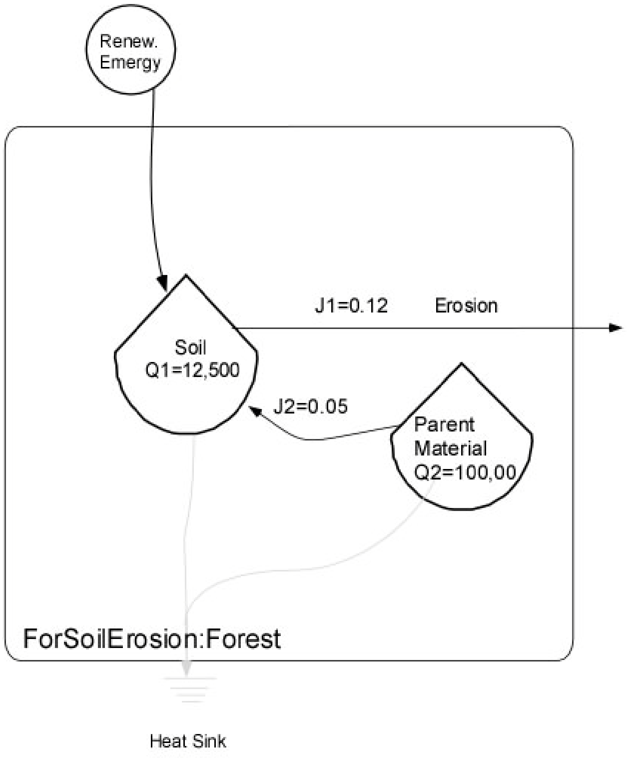
7.3.4 Data Collection and Parameter Estimate

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

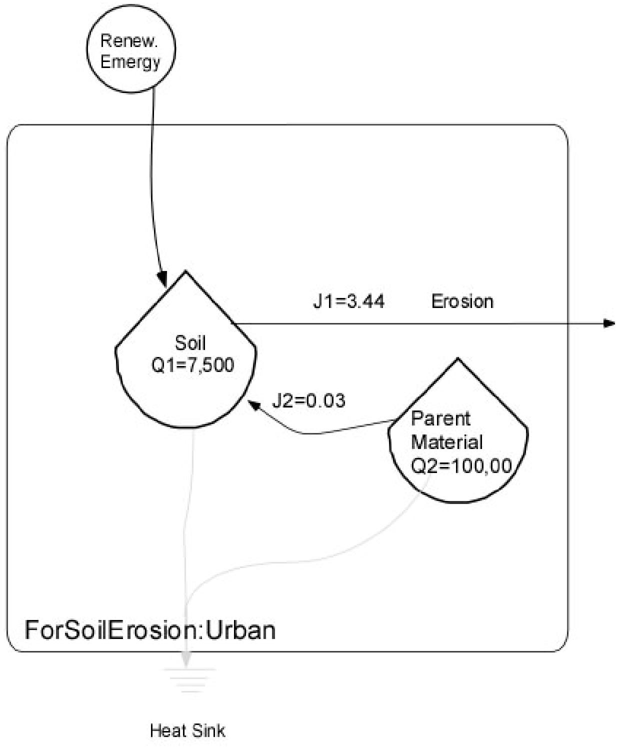
The initial conditions and calibration values are displayed in Table 7.3.2 and Figure 7.3.4. The amount of erosion reduced in the forest model vs. the urban model was attributed to the erosion ecosystem service. The value of the service is determined using emergy methodology (i.e. the amount of soil that was avoided being eroded was multiplied by the dynamically calculated transformity for an emergy value to be obtained).

Equation 7.6 Emergy of Erosion Prevention Calculation—

(330268 g of mineral soil/ha/yr)*(1.01 ha of MD forest)*(1.68E9 sej/g mineral soil)= 5.6E21 sej/yr


Renew. Emergy
Soil
Q1=12,500
J1=0.12
Erosion
J2=0.05
Parent Material
Q2=100,00
ForSoilErosion:Forest
Heat Sink

a)


Renew. Emergy
Soil
Q1=7,500
J1=3.44
Erosion
J2=0.03
Parent Material
Q2=100,00
ForSoilErosion:Urban
Heat Sink

b)

Figure 7.3.4 Calibration values and initial conditions for ForSoilErosion under forested (a) and urban (b) conditions. Units are in metric tons of mineral soil per ha per year.

Table 7.3.2 Initial Conditions and Parameters for ForSoilMineral

	Forest	Urban	
Q1	12500	7500	mt soil/ha
Q2	100000	100000	mt soil/ha
K1	0.0000096	0.0004587	1 year
K2	0.0000005	0.0000003	1 year
Reference Calibration Values			
K1*Q1 (J1)	0.12	3.44	mt soil/ha/yr
K2*Q2 (J2)	0.05	0.03	mt soil/ha/yr

7.3.5 Results

7.3.6 ForSoilCarbon

When soil carbon was simulated in a forested ecosystem it was shown to increase over time, while in an urban system soil carbon decreased over time. Over the simulated 100 year period soil carbon increased from 65 mt to 92 mt while urban soil carbon decreased from 39 to 34 mt. The rate of forest soil carbon accumulation increased overtime; the rate of urban soil carbon loss decreased. Figure 7.3.5 illustrates these trends.

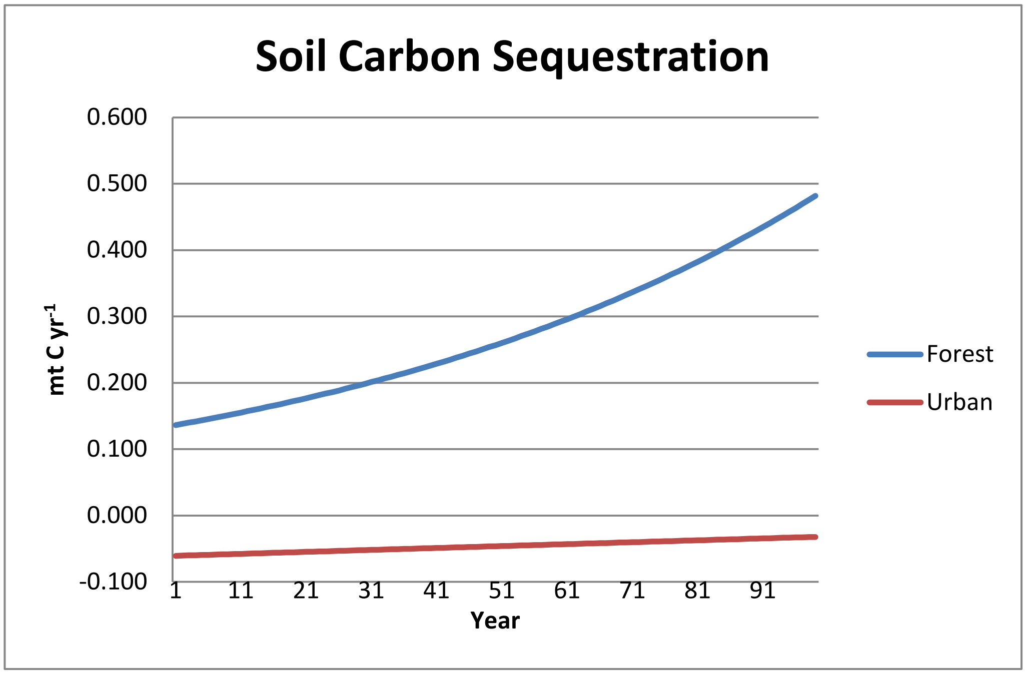


Figure 7.3.5 Simulation Results from ForSoilCarbon. The addition of Soil Carbon per year increases over time in forest systems. Soil carbon is lost in urban systems, but the loss decreases over time.

7.3.7 ForSoilMineral

The amount of soil erosion per year varied slightly over time; in the urban model soil loss decreased from 3.4 to 3.26 mt of soil per year over the 100 year simulation period and was unchanged in the forested model. The storage of soil in the forest system went from 12500 to 12493 mt per ha in the 100 year simulation period while the urban soil storage decreased from 7500 to 7170 mt per ha, a difference of 323 mt of soil (see Figure 7.3.6).

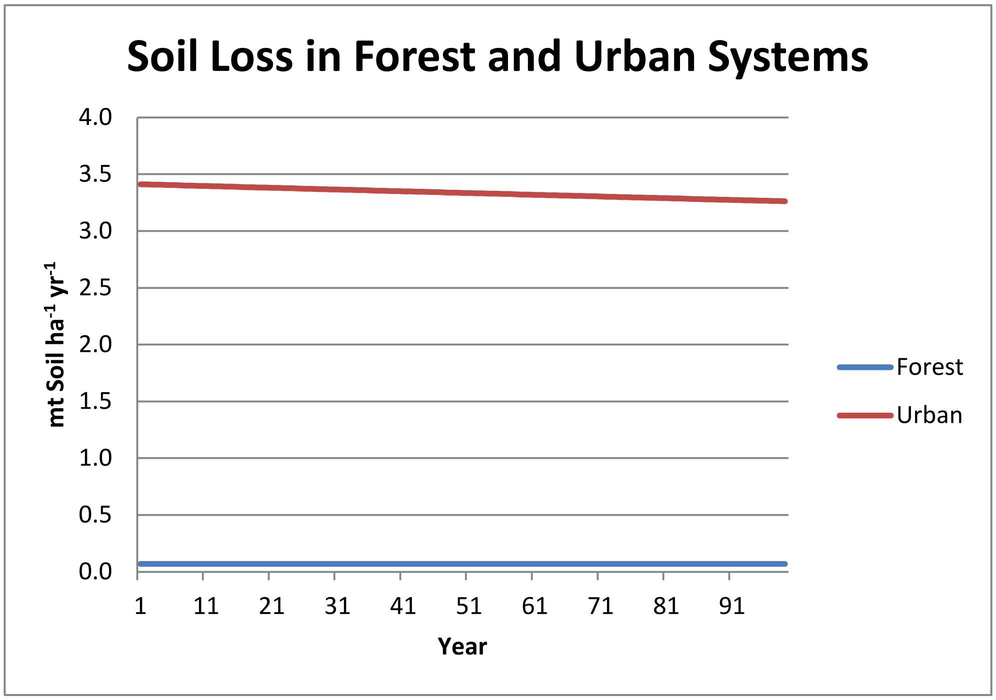


Figure 7.3.6. Simulation results from ForSoilMineral showing the change in the rate change in forest and urban systems. Soil loss through erosion decreases over time in urban systems and stays relatively constant in forest systems.

7.3.8 Valuing the Service

The soil ecosystem services were converted from mass values to emergy values using specific emergy values from the literature (Odum, 1996, Cohen, 2007). The emergy values are then converted to dollars using an eco-price (see eco-price chapter). The values for soil carbon building and erosion prevention ecosystem services, \$7 million and \$70 million, respectively, are displayed in Table 7.3.3 and the calculation can be found in Appendix 3.

Table 7.3.3 Public value and fair payment price for forest soil services.

	Maryland ($ millions per yr)	**Forest ($ per acre per yr)**	**PREI**
Soil Building			
Public Value	$219	$89	1
Fair Payment Estimates			
Commodity Equivalency Eco-price	$11	$5	19
Mean Ecosystem Service Eco-price	$7	$3	31
Specific Ecosystem Service Eco-price	$7	$3	31
Erosion Prevention			
Public Value	$2,112	$855	1
Fair Payment Estimates			
Commodity Equivalency Eco-price	$110	$45	19
Mean Ecosystem Service Eco-price	$64	$26	33
Specific Ecosystem Service Eco-price	$70	$29	30

7.3.9 Discussion

The ecosystem service of soil carbon building in Maryland forests was found to be $7 million dollars a year while the soil erosion prevention ecosystem services was ten times the soil building service, at $70 million dollars per year for Maryland, using the service specific eco-price. On average, forest soils built 0.27 metric tons more carbon per ha per year than urban soils. Urban soils lost 3.23 metric tons of mineral soil per hectare per year while forest soils remained relatively constant over time. The models simulated the dynamics of soil carbon and erosion and produced values largely consistent with existing literature values (Scheyer, 2005, Dissmeyer, 1985, Gellis, 2003). Soil carbon accumulation in the forest ecosystem was probably slightly high as export due to herbivory was not included in the model. However, this would not have a large effect on the carbon budget for the system as most of the carbon would be kept in the system, with a portion lost to respiration or migration by consumers. The dollar value of the ecosystem services is very dependent on the eco-price used to convert from the emergy value. Thus, it is important to use an eco-price that is most representative of society's willingness to pay. The soil erosion model is simple in its construction, thus largely dependent on initial conditions because it lacks feedback from one storage to another. This does not mean the model is not valid; as long as the initial conditions are accurate the model will produce accurate results.

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 was 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. For example, in Forest Hydrology (Chang, 2006) the range of erosion from natural forest lands is listed as between 0 and .05 t/ha/yr. This variability can be attributed to the properties of the soil, topography, and weather of the region. 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.

7.4 Air Pollutant Removal Ecosystem Service

The forests of Maryland play an important role in reducing air pollution in Maryland (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 due to its impact on human health (Mazzeo, 2011).

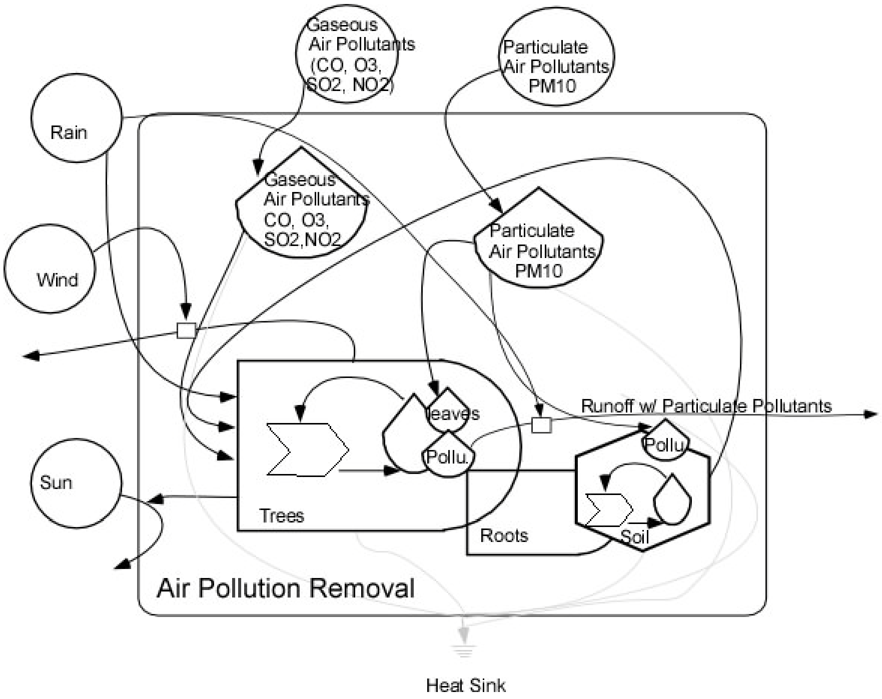


Figure 7.4.1 Energy systems language diagram showing how forests remove air pollutants from the atmosphere.

7.4.1 Data Collection and Parameter Estimate

The Urban Forest Effects Model (UFORE) was created by David Nowak at the USFS to assess the structure and some of the functions (carbon storage, sequestration and air pollutant removal of the urban forest). The original format of the model was data intensive; it requires either a full or partial inventory of the species, size, leaf area, height, and health of all the trees and shrubs in the forest being assessed and from this data estimates carbon storage, sequestration and air pollutant removal of the forest evaluated. Details on the equations used to go from collected data to carbon and air pollutant removal can be found in Nowak (2008). I utilized a spatial variation of this model, i-tree vue, which uses the land-use, tree canopy cover, and impervious area National Land Cover Data along with climatic inputs of a given area to generate annual carbon sequestration and air pollutant removal by the trees and shrubs of the given area. While the numbers generated by i-tree vue are approximations the product had the advantages for our project of not requiring data intensive inputs and being able to model a large area (the state of Maryland).

The i-tree VUE software estimates quantities of CO_2, CO, O_3, SO_2, NO_2, and PM 10 removed from the atmosphere by forests in given location (see Table 7.4.1). This location is defined by the boundary of Maryland, defined in ArcMap (ESRI, 2010) and input to the model. UFORE requires GIS files for land-use and land-cover, impervious surface, and leaf area of the area being studied. The files for land-use, tree canopy cover, and impervious area were obtained from the United States Geology Survey National Land Cover Database (Homer, 2004) online database and clipped to the boundaries of the state of Maryland using ArcMap software. The specific algorithm used by the UFORE model to generate the final values of air pollutant uptake can be found in Nowak (2000).

Table 7.4.1. Sequestration values assumed for Canopy Cover in MD by the i-Tree Vue Model

Air Pollutant	Value (MT/ha/y).	Specific Emergy (sej/g)	Emergy, (sej/yr)
Carbon sequestered	3	-	
CO removed	0.00152	1.20E+09	1.52E+18
NO2 removed	0.00744708	6.84E+09	4.26E+19
O3 removed	0.017443348	6.23E+10	9.08E+20
SO2 removed	0.004159442	5.26E+10	1.83E+20
PM10 removed	0.008190064	2.04E+10	1.39E+20

The emergy value for air pollutants removed was estimated by multiplying mass removed per hectare of forest by the area of forest canopy cover and then by the appropriate specific emergy of the air pollutant. Since there were no previous estimates of the solar transformity of ozone or PM10 in the literature, I estimated new transformities (see Appendix 4).

7.4.2 Results

In sum, the ecosystem service of air pollution removal totaled $172 million annually for the state of Maryland when using the service specific eco-price, with the majority, ($119 million), made up by the ozone removal ecosystem service (see Figure 7.4.2, and Table 7.4.2,). Carbon Monoxide (CO) and Nitrogen dioxide had the lowest values at $0.2 and $5.6 million dollars per year, respectively, when using the service specific eco-price. The Public Return on Ecosystem Investment (PREI) was 19 for the commodity eco-price, 32 for the weighted average eco-price and 3 for the service specific eco-price.

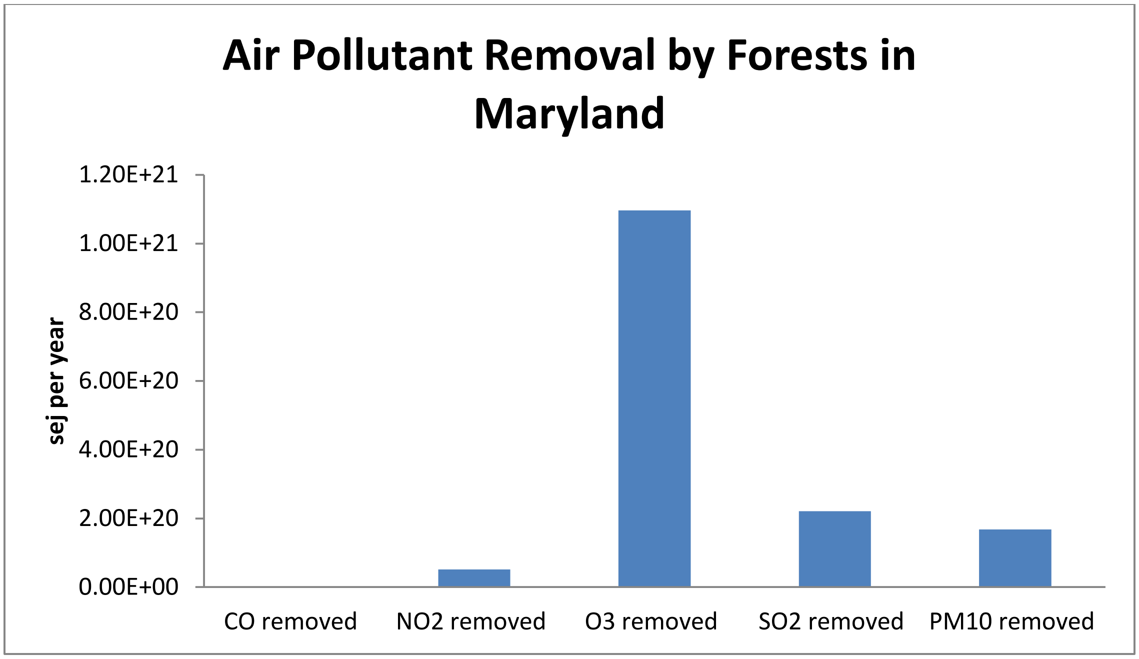


Figure 7.4.2 Emergy value of air pollutant removal ecosystem services per year. CO removal was too small to be displayed.

Table 7.4.2 Public value and fair payment price for Air Pollutants

CO Removal	**Maryland (million $ per yr)**	**Forest ($ per acre per yr)**
Public Value	$ 0.58	$ 0.23
Commodity Fair Payment Price	$ 0.03	$ 0.01
Mean Ecosystem Service Fair Payment Price	$ 0.02	$ 0.01
Specific Ecosystem Service Fair Payment Price	$ 0.20	$ 0.08
NO2 Removal		
Public Value	$ 16.1	$ 6.50
Commodity Fair Payment Price	$ 0.84	$ 0.34
Mean Ecosystem Service Fair Payment Price	$ 0.49	$ 0.20
Specific Ecosystem Service Fair Payment Price	$ 5.6	$ 2.25

Table 7.4.2 Continued

O3 Removal		
Public Value	$ 342.8	$ 138.73
Commodity Fair Payment Price	$ 17.9	$ 7.23
Mean Ecosystem Service Fair Payment Price	$ 10.4	$ 4.22
Specific Ecosystem Service Fair Payment Price	$ 118.9	$ 48.12
SO2 Removal		
Public Value	$ 69.0	$ 27.91
Commodity Fair Payment Price	$ 3.6	$ 1.46
Mean Ecosystem Service Fair Payment Price	$ 2.1	$ 0.85
Specific Ecosystem Service Fair Payment Price	$ 23.9	$ 9.68
PM10 Removal		
Public Value	$ 52.6	$ 21.29
Commodity Fair Payment Price	$ 2.7	$ 1.11
Mean Ecosystem Service Fair Payment Price	$ 1.6	$ 0.65
Specific Ecosystem Service Fair Payment Price	$ 18.2	$ 7.38
Air Pollutant Total		
Public Value	$ 497.1	$ 201.2
Commodity Fair Payment Price	$ 25.9	$ 10.5
Mean Ecosystem Service Fair Payment Price	$ 15.1	$ 6.1
Specific Ecosystem Service Fair Payment Price	$ 172.4	$ 69.8

7.4.3 Discussion

The dollar value of air pollutant ecosystem services varied according to the type of air pollutant considered and the eco-price used to convert emergy value to dollar value. There is a wide range of values for the different air pollutants, with ozone removal being nearly 600 times greater than that of carbon monoxide. Carbon monoxide has both the lowest sequestration rate and specific emergy, yielding the low estimate of value given that the eco-price used was identical for all air pollutants. Ozone removal has the highest value regardless of the eco-price used. This result is a combination of the fact that ozone has the highest physical amount removed by forests (see table 7.4.1) and a relatively high specific emergy value. Ozone is the primary air pollutant of concern for public health in Maryland along with PM10 (MDE, 2009). Consequently, this result is consistent with public policy goals.

7.5 Pollination Ecosystem Service

Wild bees are estimated to pollinate between 15 and 30 percent 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, rather than native wild bees. When assessing the pollination ecosystem service, the emergy value of crops pollinated by wild pollinators was attributed to the ecosystem service of the forests of Maryland.

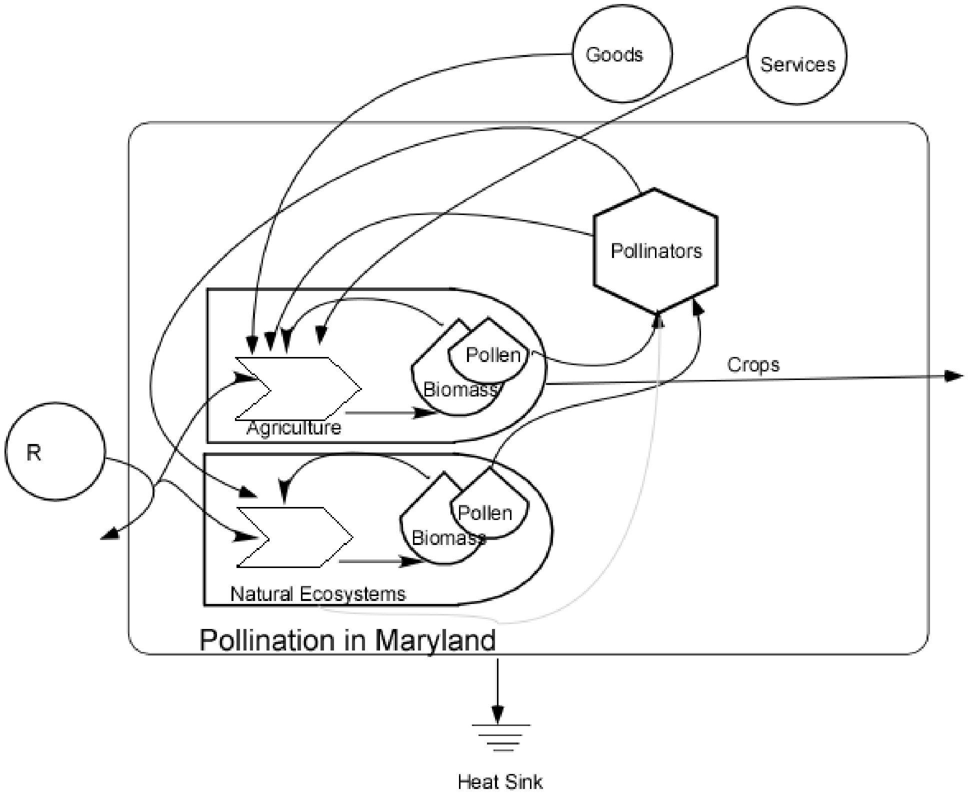


Figure 7.5.1. Energy systems language diagram of pollination in Maryland. Pollinators serve both the natural ecosystems and agricultural lands of Maryland.

7.5.1 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 crops pollinated by wild pollinators was adapted from the calculations in Losey and Vaughn, 2006. They present data on the percentage of crops that are pollinated and the proportion pollinated by wild pollinators. Table 7.5.1 is reprinted from Losey and Vaughn (2006). Data from www.extension.org was used to estimate the number of hives necessary to support 1 ha of crops (5 hives necessary for pollination of all plants), the mass of an individual bee (90 mg) and the number of bees in a hive (40,000).

The transformity of a bee was calculated using the emergy of pollen, which was calculated by multiplying the total emergy driving a hectare of agricultural land in Maryland (this study) by pollen mass divided by the total plant mass and then dividing the resulting emergy value by the joules of bees supported by 1 hectare of agricultural land. This yields a transformity of 4.26E05 sej/J. 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 native bees. The emergy value of the pollination ecosystem service was estimated by calculating the number of acres of cropland supported by native bees (see Table 7.5.1) and the emergy value (as stated above) of native bees necessary to pollinate that cropland. In Maryland, there are 11,000 ha of crops supported by the native pollination of approximately 2 billion bees.

Table 7.5.2, adapted from from Losey and Vaughn (2006), shows the value of various crops, the dependence of the crop on insect pollination and the percentage of pollination by domesticated and native pollinating insects. These values were used to calculate the amount of crops in Maryland pollinated by native pollinators (Table 7.5.1, column four).

Equation 7.7 Emergy of Pollination Calculation

(11,400 ha of agricultural land pollinated by wild pollinators)*(1.84E14 sej/ha)= 2.1E18 sej of agricultural production attributed to wild pollinators

Table 7.5.1 Crop Area in Maryland and Area Supported by Native Pollinators, in Ha

Field & Misc Crop	Area Planted, All Purpose	Harvested Area	Percent of Crop Pollinated by Native Pollinators (from Losey, 2006)	Area attributed to Wild pollination
Corn	189,880	171,955	0	0
Soybeans	196,231	192,185	0	0
Hay	0	84,966	5%	0
Hay	0	68,782	5%	4,248
Wheat	93,058	78,897	0	3,439
Wheat	93,058	78,897	0	0
Hay Alfalfala	0	16,184	5%	0
Barley	22,253	19,421	0%	809
Potatoes summer	971	931	0%	0
Potatoes all	971	931	0%	0
Vegetable Crops	0	28,221	10%	2,937
Principal Crops, total	587,479	564,417		11,434

Table 7.5.2 The value of crop production resulting from pollination by native insects, 2001-2003.
Reproduced from Losey and Vaughn, 2006

Crop	US average value (V) (millions of dollars)	Dependence on Insect pollination (D)	Proportion of pollinators that are domesticated exotic bees (P)	Proportion of pollinators that are native bees (1-P)	Annual value attributable to native bees (millions of dollars) (VxDx(1-P))
Fruit and nuts					
Almond	1120.0	1.0	1.0	0.0	0.0
Apple	1585.1	1.0	0.9	0.1	158.5
Apricot	30.0	0.7	0.8	0.2	4.2
Avocado	382.4	1.0	0.9	0.1	38.2
Blueberry					
Wild	23.1	1.0	0.9	0.1	2.3
Cultivated	192.9	1.0	0.9	0.1	19.3
Boysenberry	3.9	0.8	0.9	0.1	0.3
Cherry					
Sweet	290.6	0.9	0.9	0.1	26.2
Tart	56.3	0.9	0.9	0.1	5.1
Citrus					
Grapefruit	278.4	0.8	0.9	0.1	22.3
Lemon	286.1	0.2	0.1	0.9	51.5
Lime	2.0	0.3	0.9	0.1	0.1
Orange	1713.6	0.3	0.9	0.1	51.4
Tangelo	10.8	0.4	0.9	0.1	0.4
Tangerine	112.0	0.5	0.9	0.1	5.6
Temple	6.1	0.3	0.9	0.1	0.2
Cranberry	159.7	1.0	0.9	0.1	16.0
Grape	2774.8	0.1	0.1	0.9	249.7
Kiwifruit	16.7	0.9	0.9	0.1	1.5
Loganberry	156.0	0.5	0.8	0.2	15.6
Macademia	31.1	0.9	0.9	0.1	2.8
Nectarine	121.2	0.6	0.8	0.2	14.5
Olive	66.5	0.1	0.1	0.9	6.0
Peach	487.9	0.6	0.8	0.2	58.5
Pear	263.9	0.7	0.9	0.1	18.5
Plum	197.8	0.7	0.9	0.1	13.8
Raspberry	95.8	0.8	0.9	0.1	7.7
Strawberry	1187.6	0.2	0.1	0.9	213.8
Vegetables					
Asparagus	154.3	1.0	0.9	0.1	15.4
Broccoli	543.4	1.0	0.9	0.1	54.3
Carrot	575.5	1.0	0.9	0.1	57.6

Table 7.5.2 Continued

Cauliflower	219.8	1.0	0.9	0.1	22.0
Celery	256.5	1.0	0.8	0.2	51.3
Cucumber	379.5	0.9	0.9	0.1	34.2
Cantaloupe	401.0	0.8	0.9	0.1	32.1
Honeydew	94.1	0.8	0.9	0.1	7.5
Onion	808.0	1.0	0.9	0.1	80.8
Pumpkin	75.5	0.9	0.1	0.9	61.2
Squash	192.3	0.9	0.1	0.9	155.8
Vegetable seed	61.0	1.0	0.9	0.1	6.1
Watermelon	315.9	0.7	0.9	0.1	22.1
Field Crops					
Alfalfa					
Hay	7212.8	1.0	1.0	0.1	360.6
Seed	109.0	1.0	1.0	0.1	5.5
Cotton					
Lint	3449.5	0.2	0.8	0.2	138.0
Seed	689.3	0.2	0.8	0.2	27.6
Legume seed	34.1	1.0	0.9	0.1	3.4
Peanut	793.1	0.1	0.2	0.8	63.4
Rapeseed	0.3	1.0	0.9	0.1	0.0
Soybean	15095.2	0.1	0.5	0.5	754.8
Sugar beet	1057.3	0.1	0.2	0.8	84.6
Sunflower	312.7	1.0	0.9	0.1	31.3
Total					3074.1

Note: D and P values are from Morse and Calderone (2000).

a. Rounded to 0.8; the actual value is 0.75.

b. From Morse and Calderone (2000).

7.5.2 Results

Pollination is a relatively minor ecosystem service in Maryland, with only approximately $1.45 million of public value that can be attributed to this service and a value of $300,000 when using the specific ecosystem service eco-price. When using the service specific eco-price the PREI is five, signifying that the suggested fair payment price is five times less than the public value provided by pollination. The low overall value of the service is not unexpected, as most major crops in Maryland are not insect pollinated.

Table 7.5.3 Public value and fair payment price for Pollination by wild insects

Pollination	**Maryland (million $ per yr)**	**Forest Land ($ per acre per yr)**	**PREI**
Public Value	$1.43	$0.58	
Commodity Fair Payment Price	$0.07	$0.03	19
Mean Ecosystem Service Fair Payment Price	$0.04	$0.02	33
Specific Ecosystem Service Fair Payment Price	$0.3	$0.12	5

7.5.3 Discussion

The value of the pollination ecosystem service is the lowest of all ecosystem services considered in this research, regardless of conversion used for emergy to dollars. When all states and all types of crops are considered Losey and Vaughn (2006) estimated that wild pollinators contributed over 3 billion dollars to the United States economy If this study was done in a different state with crops reliant on wild pollinators the value would likely be much larger. None of the three major crops (corn, soybeans and wheat) planted in Maryland are pollinated by insects. Corn and wheat are wind pollinated and the variety of soybeans planted in Maryland is self pollinated (Marla McIntosh, personal communication). Overall, insects play a relatively minor role in pollinating Maryland crops with wild insects playing an even smaller role.

A weakness in this calculation is that the value of pollinators to individual gardeners or community supported agricultural groups was not considered. Further, the service that pollinators provided to wild plants was not considered. The economic impact of pollinators on facilitating reproduction of wild plants has not been quantified and likely is tenuous at best. A potential example of how wild pollinators could impact the economy is the occurrence of wild flowers could be linked to increased recreation activity. However, it is not likely that these values are significant. Regardless, there is not sufficient data available for an assessment. Pollinators do play a major role in facilitating production of wild flora and this value is captured in the biodiversity model (See section 8.2).

Chapter 8. Emergy and Biodiversity

Biodiversity refers to the genetic variety in the flora and fauna of a given area. There is evidence that biodiversity in an ecosystem increases the resilience of the system (Hollings, 1973, Folke, 2004, Bastian, 2013). Previous work has theorized how emergy relates to biodiversity (Campbell, 2009, Odum, 1996). It has been observed that as emergy flow per area increases the number of species per area increases in an exponential way (Odum, 1996 from Keitt, 1991). Renewable emergy is a measure of the resource base available for species and more emergy will support greater complexity; again supporting a greater number of species. The emergy needed to develop genetic material is generally very high because genetic material tends to develop over a long period of time and the emergy of the entire population is necessary to generate new genetic material. Evolution of genetic diversity and economic exchange take place on very different time scales, tens of thousands of years vs. seconds. As such it is difficult to relate the emergy of biodiversity to a dollar flow. Biodiversity is both the most important ecosystem service in terms of facilitating the provision of other ecosystem services and the most difficult to value (Ostfeld, 2002). Figure 8.1 shows how biodiversity has a controlling influence on biomass production, when other factors are held constant (Odum, 1996).

The first portion of this chapter expands on the previous literature, attempts to clarify the relationship of emergy and biodiversity by looking at five forests along the Eastern Seaboard of the United States. Section 8.2 presents an ecological network model that demonstrates how systems with higher biodiversity have increased emergy flow through the system and equates this additional emergy flow to the ecosystem service of biodiversity.

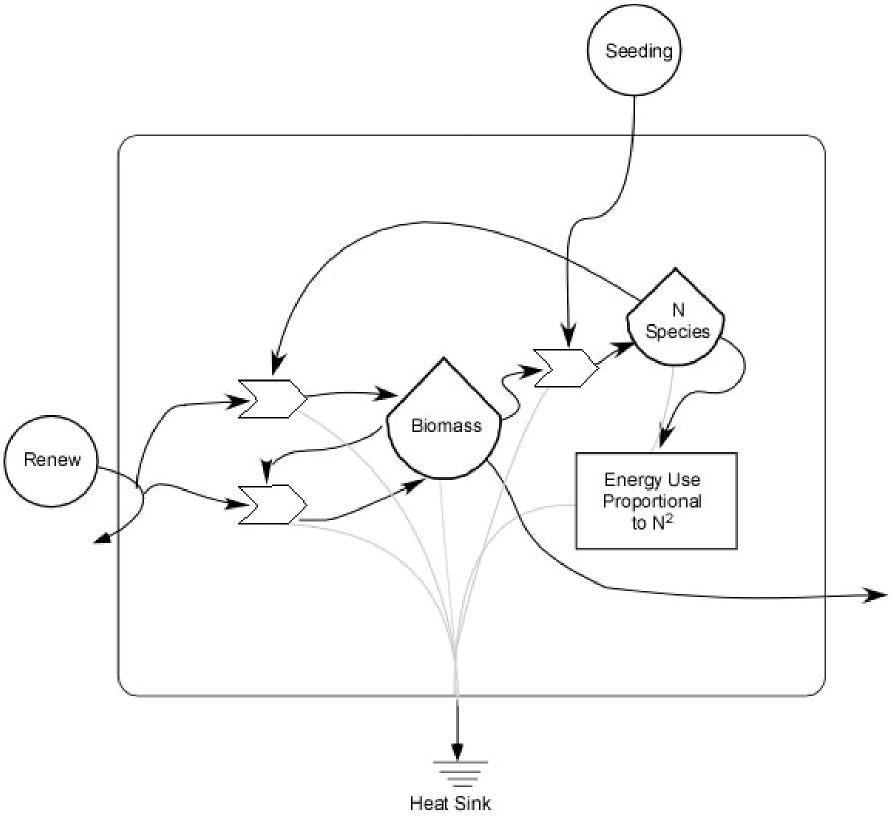


Figure 8.1.1 The number of species (N) is influenced by, and influences, the biomass of flora and fauna in a forested system. Higher biodiversity supports more energy throughput in the system and higher biomass storage when inputs (renewable emergy and seeding) are constant (adapted from Odum, 1996).

The model, ForBioLat (Forest Biodiversity Latitude) relates the quality of habitat to the flow and storage of emergy in forest ecosystems. Total storage of emergy per area (1 ha) was assumed to be indicative of the quality of habitat in each ecosystem considered. The following forest ecosystems were included; Southeastern conifer, Mid-Atlantic coastal hardwood, Northeastern hardwood coastal, New England Acadian Spruce-Fir and Eastern Canadian Black Spruce forests. Emergy and vertebrate biodiversity were assessed for the five forests along the eastern coast of North America, from Florida to Newfoundland at 100 years of age. A focus on the eastern coast of the United States was chosen in order to attempt to control for factors beyond the renewable emergy flow and storage of natural capital in the forest, such as isolation of populations, effect of elevation change and disturbance regime. Some variation in disturbance regime was evident and its consideration was necessary to explain results.

Table 8.1.1 Characteristics Eastern North American Forests included in ForBioLat, Species and Elevation from Olson (2002), Transpiration Rate is calculated

	Dominant Species	Transpiration Rate, cm/yr	Elevation Range, msl
Southeastern Conifer Forest	Longleaf Pine	128.2	0-200
Mid-Atlantic Coastal forest	White Oak/Red Oak/Hickory	106.6	0-30
Northeastern Coastal forests	Sugar Maple/Beech/Yellow Birch	62.0	0-200
New England-Acadian forest	Red Spruce/Balsam Fir	60.0	0-600
Eastern Canadian forest	Black Spruce	46.0	0-700

8.1.1 Data Collection

The ForBioLat model includes data on vertebrate diversity that was taken from the World Wildlife Fund Eco-regions database (Olson, 2001). This database catalogs the known vertebrate diversity in the terrestrial eco-regions of the earth. Rainfall and insolation data, displayed in minute by minute quadrats, was collected from the NASA SSE website. Transpiration in each eco-region was calculated using the Penman-Monteith equation (Ventura, 1999). The Carbon Online Estimator (COLE, USFS, 2011 was used to estimate carbon storage at 100 years for each forested ecoregion. Carbon pools considered by COLE include tree biomass, shrub biomass, standing dead, the forest floor and soil organic matter.

8.1.2 Parameter Estimate

The parameters in ForBioLat were species richness, renewable emergy flow per ha and renewable emergy storage per ha. The renewable emergy per ha was assumed to be the emergy of transpiration per ha, the quantity estimated using the Penman-Monteith equation and multiplied by the appropriate transformity (this study). Renewable emergy input in emergy accounting is taken as the single largest renwable flow, because all renewable flows originate from the same ultimate source, the global emergy baseline (sun+tide+deep heat). It is safe to assume that transpiration will be the largest renewable input in a system with significant primary production as it is the sum of sun, wind and rain. Renewable emergy storage was assumed to be the sum of tree and shrub biomass and soil OM and multiplied by appropriate transformities taken from Tilley (2002) for biomass and Cohen (2007) for soil OM. Detailed calculations for each forest type included in the ForBioLat model are included in Appendix 5.

8.1.3 Results

It was expected that emergy and biodiversity would both increase as latitude decreases (Young, 2010, Campbell, 2012, Wier, 2007). This pattern is supported by the ForBioLat model (fig. 8.1.2), where the regression relationship of renewable emergy flow and biodiversity, has an r^2 value of 0.8. The slope is 6 E9 sej of renewable emergy per vertebrate species; signifying that for every 6 E9 of renewable emergy species richness is expected to increase by one. However, a much less clear pattern is shown in figure 8.1.3 where stored emergy (natural capital, composed of the summed emergy of tree and herbaceous biomass, dead biomass and soil organic matter) and biodiversity are compared over latitude where the r^2 value is only 0.36 and the slope is 2 E14 sej of natural capital per species. Figure 8.1.4 compares latitude and species and supports a negative relationship with an a r^2 value of 0.84 and a slope of -0.0827 degrees of latitude per species. A simple t-test with two tails was run for each relationship (Table 8.1.3) and both the renewable emergy-species richness and latitude-species richness relationships are significant at p=0.005 while the natural capital-species richness relationship was also found to be significant (p=0.015) but the relationship is much less strong (r^2=0.36) and the forest with the highest number of species had one of the lowest storages of natural capital.

Table 8.1.2 Vertebrate species richness, emergy flow and stored emergy of Eastern North American Forests at similar elevation (0-300 msl).

Ecoregion	Vertebrate Species Richness (WWF, 2011)	Renewable Emergy per ha (Appendix 5)	Stored Biomass Emergy (Appendix 5)	Latitude
Southeastern Conifer Forest	427	2.83E+12	2.75E+16	30°
Mid-Atlantic Coastal forest	404	2.31E+12	6.52E+16	38°
Northeastern Coastal forests	373	1.81E+12	6.18E+16	42°
New England-Acadian forest	320	1.75E+12	2.92E+16	44°
Eastern Canadian forest	220	1.34E+12	1.59E+16	50°

Footnote: Representative forest types from each ecoregion were chosen for carbon storages, all at 100 years of age

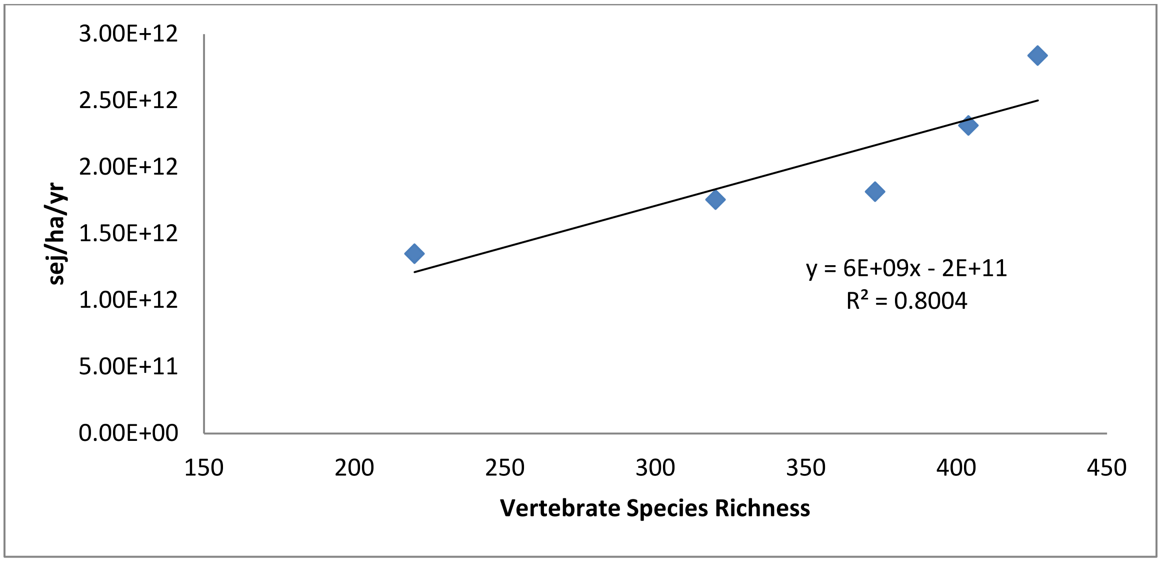


Fig. 8.1.2 Output of ForBioLat, renewable emergy flow (y axis) and species richness (x axis) over five Eastern North American coastal plain forests located along a latitudinal gradient from Florida to Newfoundland.

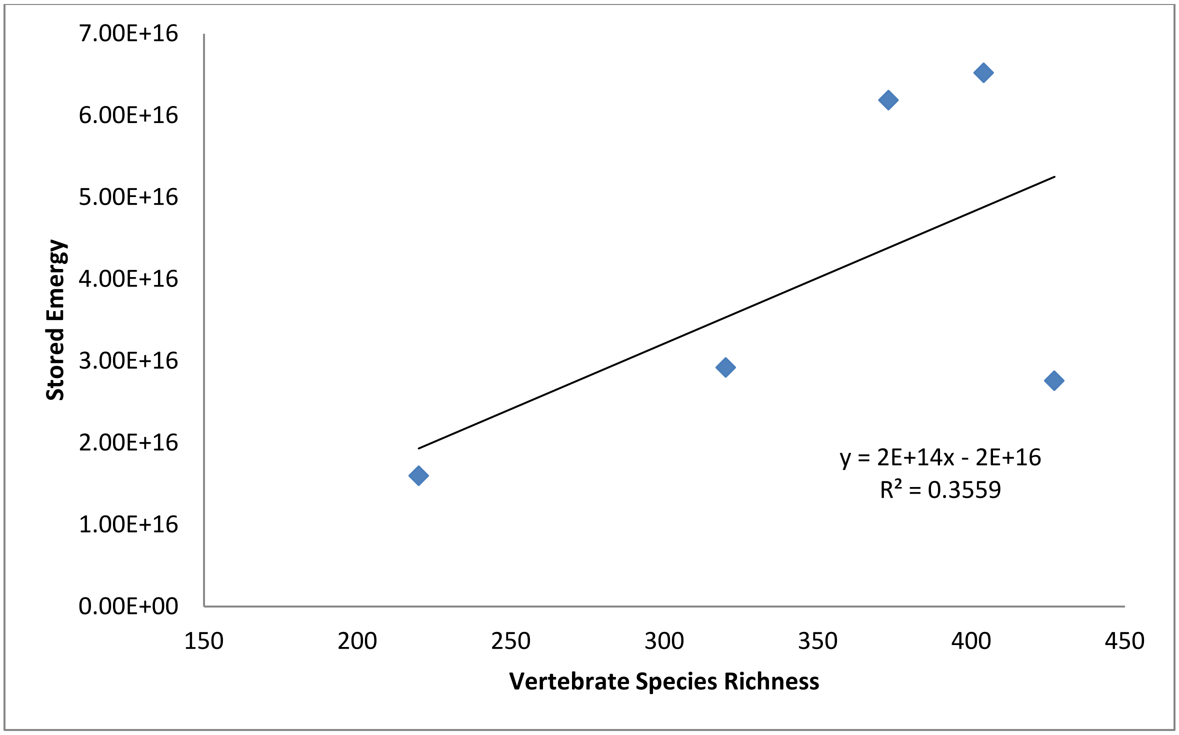


Figure 8.1.3 Output of ForBioLat, stored emergy of forest biomass (y axis) and species richness (x axis) over five Eastern North American coastal plain forests located along a latitudinal gradient.

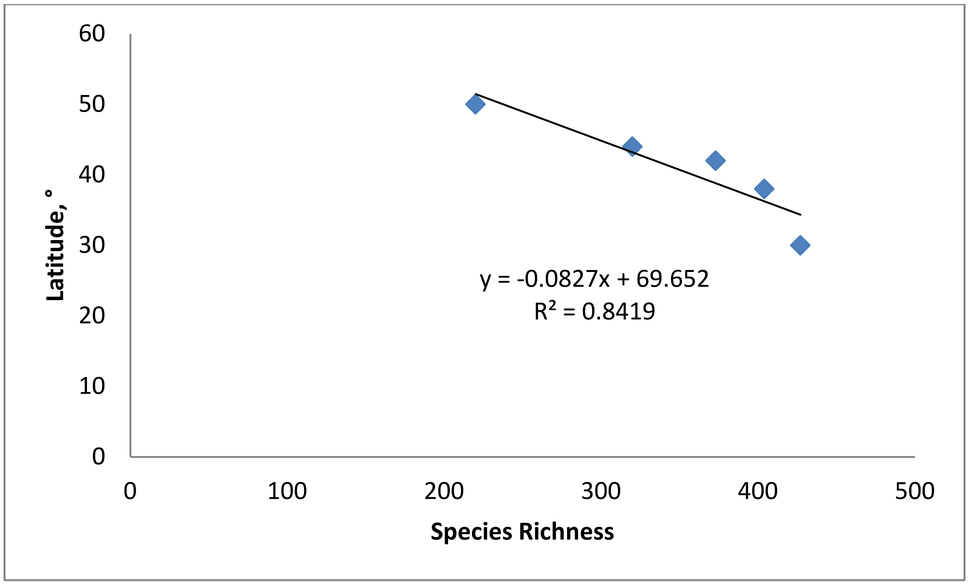


Figure 8.1.4 Relationship between latitude (y axis) and vertebrate species richness (x axis) over five forests along the east coast of North America.

Table 8.1.3 Results of T-Test, two Tails

	p value	Significant, p<0.05
Renewable emergy-Species Richness	0.00142	yes
Natural Capital-Species Richness	0.01563	yes
Latitude-Species Richness	0.00152	yes

8.1.4 Discussion

The Southeastern (SE) Conifer forest ecoregion, located in Northern Florida, had the highest renewable emergy flow and species richness but the second lowest emergy of stored biomass. This was likely due to the fact that this ecoregion has a higher frequency of disturbance (White, 2001), decreasing the ability of the ecosystem to build up natural capital over the long term. A possible explanation of the increase in biodiversity in the Southeastern Conifer forest ecoregion relative to the other eco-regions is the intermediate disturbance hypothesis (Grime, 1973, Connell, 1978). The intermediate disturbance hypothesis (IDH) proposes that diversity will be maximal when disturbance occurs at an intermediate frequency. This could explain the higher diversity in the SE conifer eco-region that has a more frequent disturbance regime than the other ecosystems considered. However, the other ecoregions have similar natural disturbance regimes (infrequent) so the IDH cannot be used to explain the overall trend in vertebrate diversity change over latitude.

The emergy of stored biomass in the other ecoregions decreased as latitude increased. There is a lower renewable emergy flow per year and a slower associated accretion of natural capital in the higher latitude forests. However, as we see in the case of the Southeastern Conifer ecoregion, disturbance regime can have a controlling influence on natural capital (Van Lear, 2005). In longleaf pine forests frequent fire keeps natural capital low but the unique nature of the ecosystem supports a high degree of endemism and, as suggested by this model, the high yearly flow of renewable emergy has an influence in supporting more species richness. Given the results of the ForBioLat model a definitive statement on the relationship between natural capital and vertebrate species richness cannot be made. A stronger relationship is seen between latitudinal renewable emergy per year and diversity. This relationship is less influenced by disturbance regime because it is on a shorter time scale. Renewable emergy flow is not influenced by disturbance unless the scale of interest is very small, such as an individual forest plot. Even on a small areal scale only transpiration would be affected by disturbance, particularly if the renewable flows are multi-year averages as is advised when conducting an emergy analysis (Odum, 1996). It would have potentially been informative to include the emergy of periodic disturbance (e.g. hurricanes, fires) when evaluating the forests; including this pulse of emergy may have explained the observed trend.

It can be stated that an increased flow of annual renewable emergy correlates with an increase in observed vertebrate diversity. This stands to reason as it can be assumed that an increased emergy base (greater empower) will support a greater number of species according to the maximum empower principle. More empower will support a greater number of ecological niches, thus more species will occur to occupy those niches. Greater empower (transpiration in the ForBioLat model) is also associated with increased average temperatures and a greater ability for flora and fauna species to survive and flourish through winter conditions, again promoting niche specialization and further speciation (Odum, 1996, Turner, 2004). The aspect of the latitude-biodiversity relationship not addressed in this model is that of the degree of freedom in species movement (Turner, 2004) where it is theorized that land masses in lower latitudes are less connected and thus less facilitative to species movement, promoting greater niche specialization resulting in more species. However, the ForBioLat model avoids this potentially confounding effect by only including forest sites on the east coast of North America. While causality cannot be inferred because these are observational relationships the results of the ForBioLat model support the hypothesis that renewable emergy flow is positively correlated with species richness.

8.2 Synthesis of Emergy and Ecological Network Analysis: Evaluation of Hubbard Brook Forest, NH and a theoretical Northeastern Suburban Hardwood Forest

Genetic diversity within existent life has a tremendous value, both to the global ecosystem and humanity. Biodiversity is vital to the resilience of global systems and is perhaps the most important supporting ecosystem service; facilitating the provision of virtually all others (Diaz, 2005, Thompson, 2009). The previous section supported the relationship of higher renewable emergy with increased biodiversity but, also perhaps that biodiversity is the most difficult ecosystem service to value. Past ecological economic studies assign value based on potentially economically viable products from ecosystems (Costanza et al, 1997) but this value omits the supporting and regulating services that biodiversity provides.

I approached the problem from a systems perspective to provide an inclusive estimate of the value of biodiversity. A practical application of emergy to valuing biodiversity was done by Brown et al (2006) for the Florida Everglades. This study is the first example of the integration of environmental accounting and ecosystem network analysis. The transformity of species and Shannon diversity indices were compared across trophic levels to assess conservation value and inform policy decisions (see chapter 2 for review of Brown et al, 2006). The ecological network data for the Everglades was established by a previous study, Heymans (2002). Our research expands upon their research by using similar matrix models simulating biodiversity in the Hubbard Brook Experimental Forest ecosystem and a theoretical suburban hardwood forest. Comparisons were made between species and trophic guilds for Shannon diversity and transformity. The difference in the emergy flow-through of the biota of the two systems is the ecosystem service of biodiversity. Figure 8.2.1 shows an energy systems language (ESL) representation of the Hubbard Brook Experimental Forest and Figure 8.2.2 is an ESL diagram of a theoretical suburban hardwood forest. The stocks and flows shown in these diagrams correspond to those in the natural forest and suburban forest models.

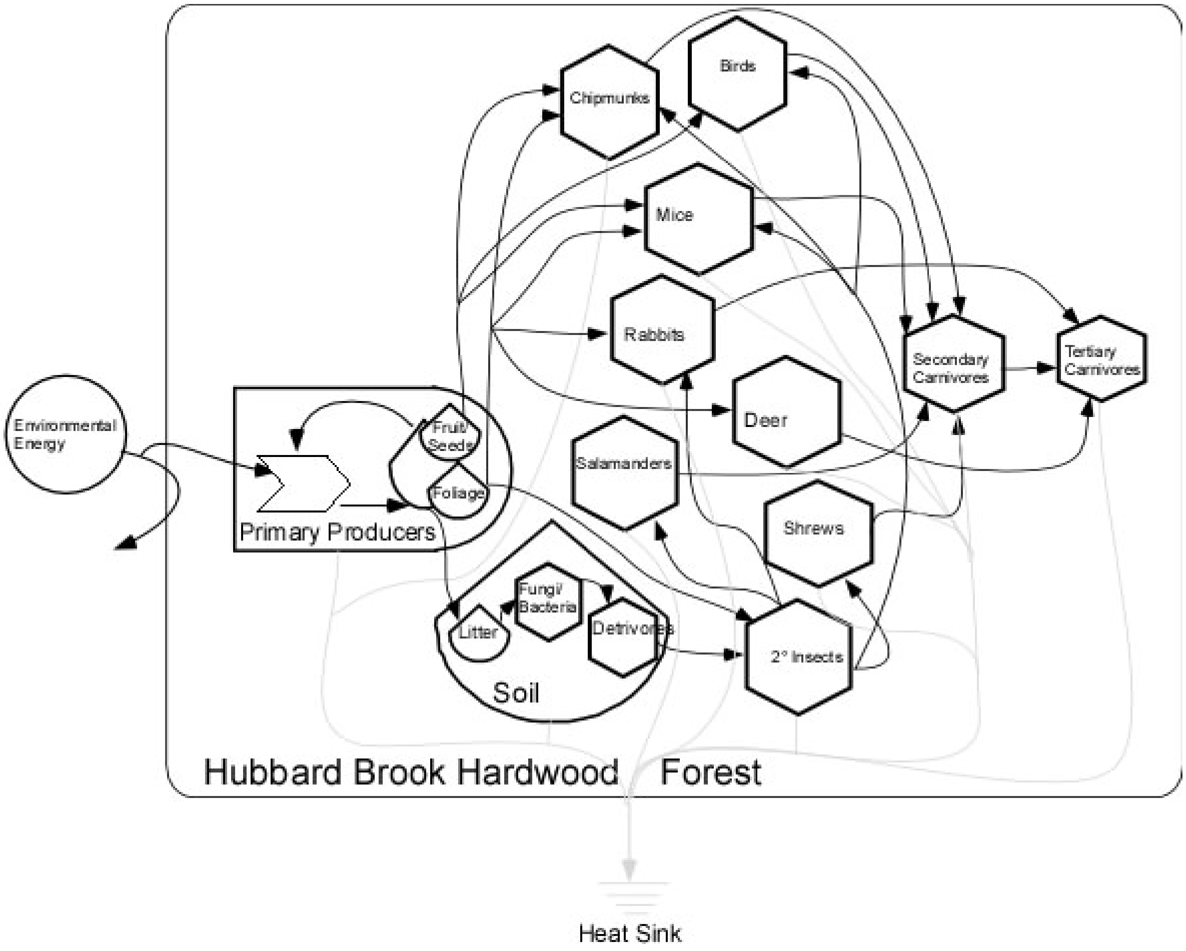


Figure 8.2.1 Energy Systems Language diagram of Hubbard Brook Experimental forest, adapted from Gosz, 1978.

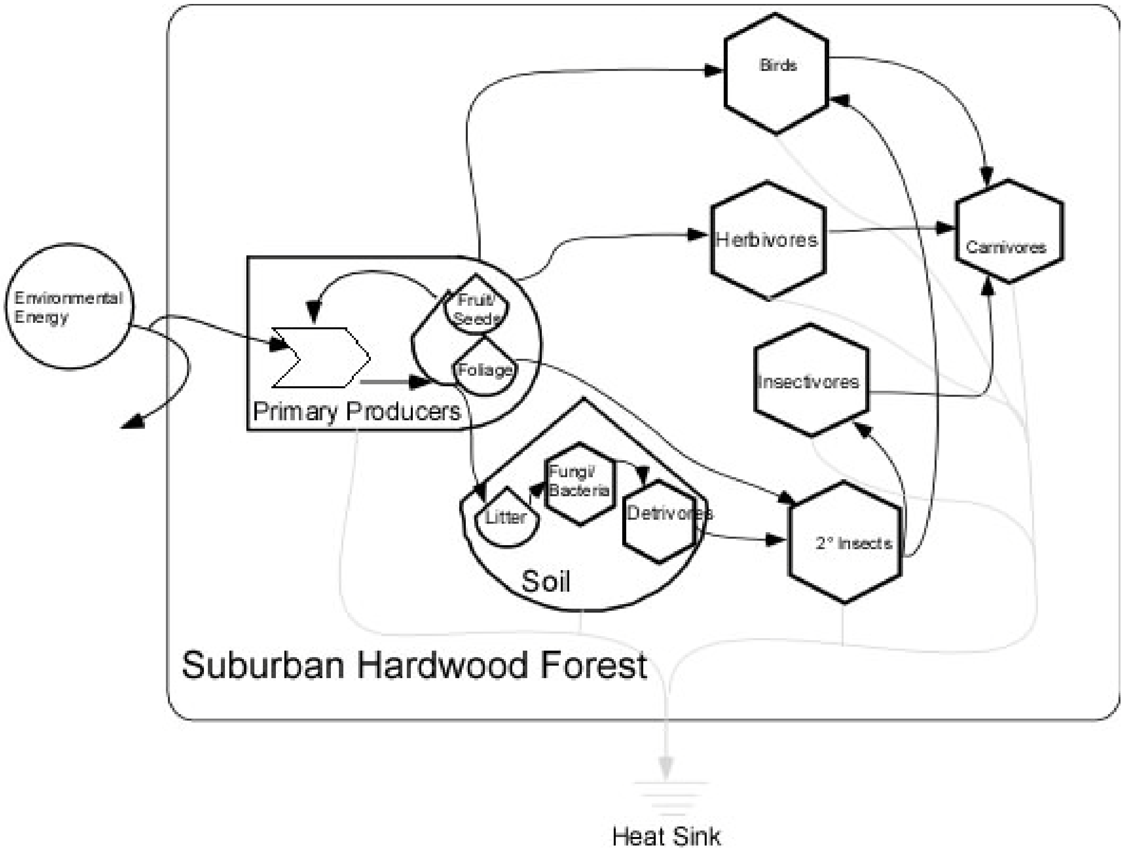


Figure 8.2.2 Energy Systems Language diagram of a suburban hardwood forest. Some network components were aggregated and the tertiary consumers were assumed to be absent.

8.2.1 Emergy Ecological Network Model Methodology

The natural forest and suburban forest models are constructed by first putting the available data in an ecological network model, as proposed by Ulanowicz (2004). The ecological network model (in this case done in Microsoft Excel™) shows the quantity of energy (sometimes nutrients or carbon) that flows from one compartment to another over the defined time period, a year in our models (see Appendix 5 Table 8 for the Ecological Network of Hubbard Brook Experimental Forest). Each compartment represents a species or nonliving storage such as detritus. From the Ecological Network model indices can be calculated that give information on dominance of species, recycle pathways, and complexity of the network (Ulanowicz, 2004). In Bardi (2004) methods are presented for calculating transformities using a transformed Ecological Network model (termed here an Emergy Ecological Network). These methods were followed in designing the natural forest and suburban forest Emergy Ecological Network models. A

Ecological Network model has the receiving compartments as rows and the exporting compartments as columns with exports being positive numbers and net production being the difference of flows in minus flow out; when adapting the network for an emergy ecological network the rows and columns are inverted, net production is made to be a negative number through addition of a negative sign to the equation, an additional row for transformities is added and two additional columns, titled sum products and constraint are added to meet the requirements of the Microsoft Solver™ add-on to solve for transformities in excel. Cells in the sum products column are the sum of the row times the transformity and the constraint column is 0. Solver™ is run to solve the transformity values for each category (species and non-living) with the constraint that the sum products column should equal the constraint column (0). Because net production is negative and inflows are positive the emergy of the network component must equal the sum of the input emergy, satisfying the rules of emergy algebra (the emergy of a system component is equal to the sum of the emergy of all the inputs).

8.2.2 Data Collection

The data regarding the energy flow within a forest trophic network, originally in kcal/m2/yr and converted to j/m2/yr, for the model came from Gosz (1978). Comprehensive studies of the flow of energy in an ecosystem are extremely rare (Ulanowitz, 2004), and this was the only example found of a near complete energy network for a temperate hardwood forest. The energy flow of primary production, herbivores and detrivitores was quantified but secondary and tertiary carnivore energy flow was assumed based on a trophic efficiency rate of 10% transfer between prey species and carnivores. No comprehensive energy flow data set exists for an urban or suburban ecosystem so assumptions were made for the degree to which suburban flows were less than flows observed in the forest system, relying on support from literature sources. It was assumed that salamanders and tertiary carnivores were absent from the suburban forest. Some species were aggregated based on trophic role (into herbivores, insectivores and carnivores) due to data limitations. Specific sources include McDonald et al 1997, Mitchell et al 2006, Laundre and Hernandez, 2006, Falk 1976 and Fisk et al 2010. Table 8.2.3 shows the percentage that the flow between model compartments was reduced for the suburban forest model from the flows observed in the natural forest model.

8.2.3 Parameter Estimate

Total emergy flow-through for the system was calculated by summing the net production of each system component multiplied by its transformity (as calculated by the Solver™ application). The following indices were calculated from the model output: Ecosystem Importance Value (EIV), Expected and Observed Emergy Throughput and Ecosystem Biodiversity (an adjusted form of the Shannon Diversity Index). The Ecosystem Importance Value (EIV), representing the relative contribution of each component to the total emergy flow-through, is formulated as Net Production of the ith network component (NPi) * transformity of the ith component (Ti) divided by the sum of net production times the associated transformity for all components (EIV=NPi*Ti/∑NPj*Tj). Ecosystem Biodiversity is the negative of the sum of each EIV times its log (EB= -∑EIVi*log(EIVi)), and is a quality adjusted, whole ecosystem, formulation of the Shannon-Weiner Index. The average EOET is the average of the expected and observed emergy throughput, formulated as the total emergy throughput divided by the number of biotic compartments (TET/N) divided by the ith network component times its associated transformity (NPi*Ti) (EOET=(TET/N)/(NPi*Ti)). The average EOET indicates how much variance occurs in the network. Emergy per bit is the total emergy throughput of the network component divided by the Shannon-Wiener Diversity Index, emergy per species is the total empower divided by the total diversity observed in the network, where the Shannon-Wiener Diversity Index is formulated as $H = (j) -\sum pi * \log_2[p_i]$ where p_i the probability of observing component i in a system of j components.

Emergy of Biodiversity Calculation –

((2.37E11 sej/m2/yr, sum of natural forest biota j*calculated sej/j)-(0.457E11 sej/m2/yr, sum of suburban forest biota j* calculated sej/j))*(1.01E10 m2 of forest in MD)= 1.93E21 sej/yr

Table 8.2.1 The Emergy Forest Network Model, data from Hubbard Brook Forest Ecological Network, Gosz (1978) in $J/m^2/yr$

	Sun (sej)	Photosynthesis	Fruit and Seeds	Foliage/Woody	Litter	Detritus	Fungi and Bacteria	Insects	Birds	Chipmunks
Photosynthesis	2.00E+03	-1	0	0	0	0	0	0	0	0
Fruit and Seeds		1673600	-1550799.6	0	0	0	0	0	0	0
Foliage/Woody		1.76E+07	0	-4.95E+06	0	0	0	0	0	0
Litter	3.00E+03	0	0	0	-1	0	0	0	0	0
Detritus		0	0	1.26E+07	2.90E+05	-5.01E+06	5.00E+06	60000	1500	6000
Fungi and Bacteria		0	0		0	1.23E+07	-1.23E+06	0	0	0
Insects		0	0	16736	0	627600	627600	-127194	0	0
Birds		0	5857.6	0	0	0	0	25104	-3096.16	0
Chipmunks		0	89537.6	20920	0	12552	0	6276	0	-12928.6
Mice		0	25104	9204.8	0	5439.2	0	6694.4	0	0
Deer		0	0	18828	0	0	0	0	0	0
Rabbits		0	0	4184	0	0	0	0	0	0
Salamanders		0	0	0	0	0	0	4602.4	0	0
Shrews		0	0	0	0	0	0	29706.4	0	0
Secondary Carnivores		0	2301.2	0	0	0	0	0	3096.16	12928.56
Tertiary Carnivores		0	0	0	0	0	0	0	120	120

Table 8.2.1 Continued

	Mice	Deer	Rabbits	Salamanders	Shrews	Secondary Carnivores	Tertiary Carnivores
Photosynthesis	0	0	0	0	0	0	0
Fruit and Seeds	0	0	0	0	0	0	0
Foliage/Woody	0	0	0	0	0	0	0
Litter	0	0	0	0	0	0	0
Detritus	2000	900	200	500	1500	1300	52
Fungi and Bacteria	0	0	0	0	0	0	0
Insects	0	0	0	0	0	0	0
Birds	0	0	0	0	0	0	0
Chipmunks	0	0	0	0	0	0	0
Mice	-4644.24	0	0	0	0	0	0
Deer	0	-1882.8	0	0	0	0	0
Rabbits	0	0	-418.4	0	0	0	0
Salamanders	0	0	0	-920.48	0	0	0
Shrews	0	0	0	0	-2970.64	0	0
Secondary Carnivores	4644.24	400	200	460.24	2970.64	-2700.104	0
Tertiary Carnivores	120	1482.8	218.4	120	120	334.72	-263.592

Table 8.2.2 The Emergy Suburban Forest Network Model, a North East Hardwood Forest in Suburban Conditions, J/m^2/yr

	Sun (sej)	Photosynthesis	Primary Production	Litter/food waste	Detritus	Fungi and Bacteria	Insects	Birds	Herbivore	Insectivor	Carnivore
Photosynthesis	2.00E+03	-1	0	0	0	0	0	0	0	0	0
Foliage/Woody		9.46E+06	-3.10E+06	0	0	0	0	0	0	0	0
Litter	4.00E+03	0	0	-1	0	0	0	0	0	0	0
Detritus		0	6.28E+06	7.74E+05	-4.40E+06	1.00E+05	20000	1200	4400	1300	500
Fungi and Bacteria		0	0	0	2.45E+06	-4.90E+05	0	0	0	0	0
Insects		0	10041.6	0	313800	376560	-70040.16	0	0	0	0
Birds		0	3514.56	0	0	0	20083.2	-2359.78	0	0	0
Herbivores		0	67110.4	0	10794.72	0	10376	0	-8828.11	0	0
Insectivores		0	0	0		0	27447.04	0	0	-2744.7	0
Carnivores		0	920.48	0	0	0	0	1857.696	7861.824	2058	-1269.8

Table 8.2.3 The Emergy Suburban Forest Network Model, showing the percentage each flow was reduced from Hubbard Brook Flow data found in Gosz (1978)

	Sun (sej)	Photosynthesis	Primary Production	Litter/food waste	Detritus	Fungi and Bacteria	Insects	Birds	Herbivores	Insectivore	Carnivores
Photosynthesis	0	-	-	-	-	-	-	-	-	-	-
Foliage/Woody	-	50.00%	-	-	-	-	-	-	-	-	-
Litter	0	-	-	-	-	-	-	-	-	-	-
Detritus	-	-	50.00%	40.00%	-	-	-	-	-	-	-
Fungi and Bacteria	-	-	-	-	80.00%	-	-	-	-	-	-
Insects	-	-	40.00%	-	50.00%	40.00%	-	-	-	-	-
Birds	-	-	40.00%	-	-	-	20.00%	-	-	-	-
Herbivores	-	-	60.00%	-	40.00%	-	20.00%	-	-	-	-
Insectivores	-	-	-	-	-	-	20.00%	-	-	-	-
Carnivores	-	-	60.00%	-	-	-	-	40.00%	40.00%	40.00%	-

8.2.4 Results

Figure 8.2.3 and 8.2.4 compare the emergy throughput of the natural forest system and the suburban forest system. In all cases the emergy throughput of the natural forest is higher than that of the suburban forest. The difference in throughput generally increases as the trophic level increases, although fungi and bacteria emergy is the exception. Figure 8.2.5 compares the transformities for each trophic level in Hubbard Brook Experimental Forest “natural forest” and a theoretical suburban hardwood forest, “suburban forest”. Transformities are significant because they quantify the emergy necessary to generate a quantity observed in the model and are indicative of the quality of something; its ability to perform work and exert influence in a system. The transformity indicates that top level carnivores have a greater influence in the system than herbivores. This is a conclusion supported by the top down regulation ecological theory (Miller, 2001).

The total emergy throughput of the flora and fauna in one year over 1 m^2 of the Hubbard Brook Experimental Forest was estimated to be 2.37E11 sej while emergy flow for the suburban forest system was 0.46E11 sej, with the difference being 1.92E11 sej. The additional emergy (1.92E11 sej) flowing through the natural system is the ecosystem service of biodiversity being provided by the forest.

Table 8.2.4 contains several indices calculated for the two ecological networks. The two networks have similar values for the Ecosystem Importance Value and Ecosystem Biodiversity, with the suburban forest having a slightly higher EIV and the natural forest having a slightly higher Ecosystem Biodiversity.

They diverge significantly with the EOET, where the natural forest has an EOET of 60.3 and the suburban forest has an EOET of 0.9. This indicates that the natural forest has more variance between system components. This is easily observed by looking at the emergy flows in the natural forest, particularly the small flows for rabbits and deer. Comparing these indices is not a completely fair comparison as the suburban forest model aggregates several of the system components, naturally biasing the model to have greater equality between flows. For example, the greatest divergence from the average observed in the natural forest system is seen in the deer and rabbits but these are averaged together with chipmunks and mice for the suburban forest model, evening out the EOET index.

Figure 8.2.6 displays the dollar value of the ecosystem service, using the three eco-prices for fair payment and public value. The service specific eco-price is greater than double the other fair payment estimates because this eco-price is larger than the average. People value biodiversity more highly, given the economic exchanges found to be representative of payments for biodiversity (see Chapter 5 on the eco-price).

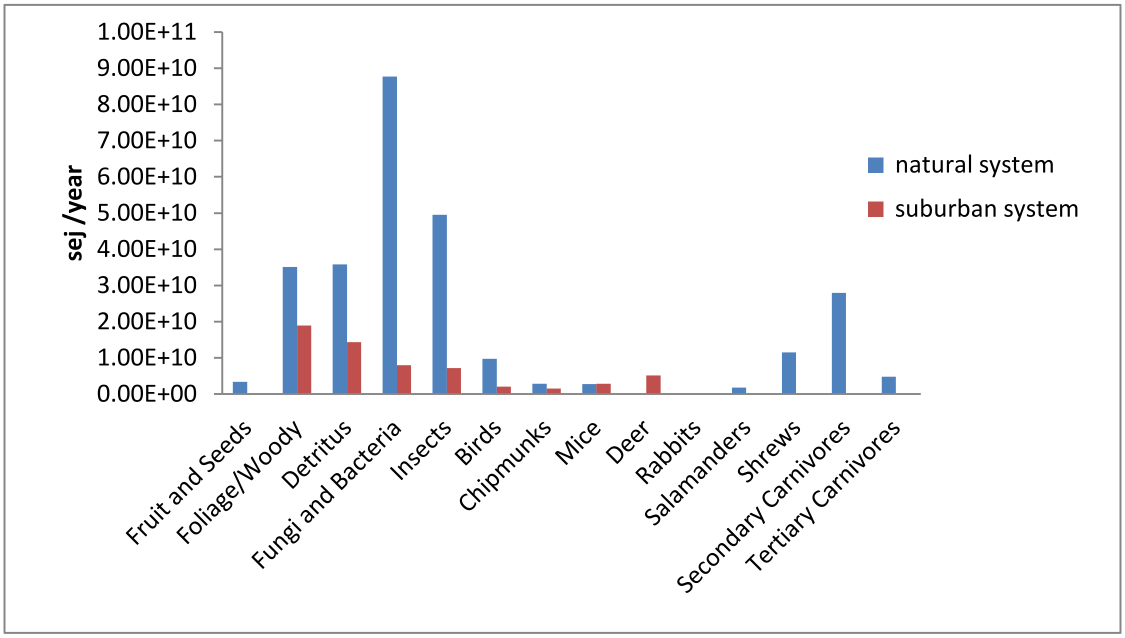


Figure 8.2.3 The emergy of annual throughput for each biodiversity model component.

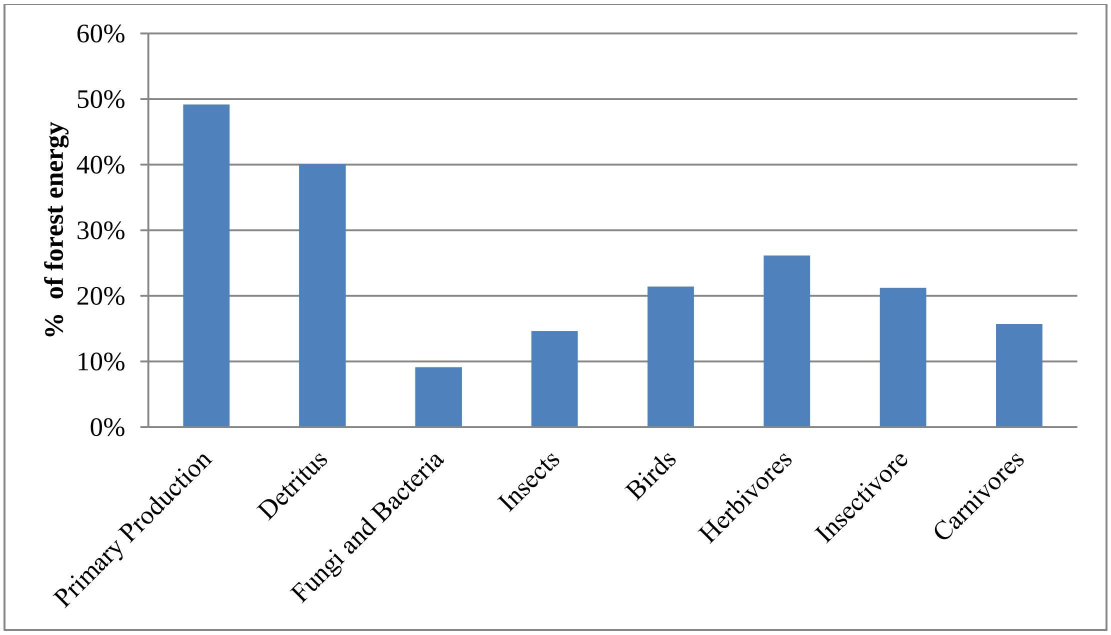


Figure 8.2.4 Suburban system throughput as a percentage of the natural system emergy throughput, natural system categories summed for comparison.

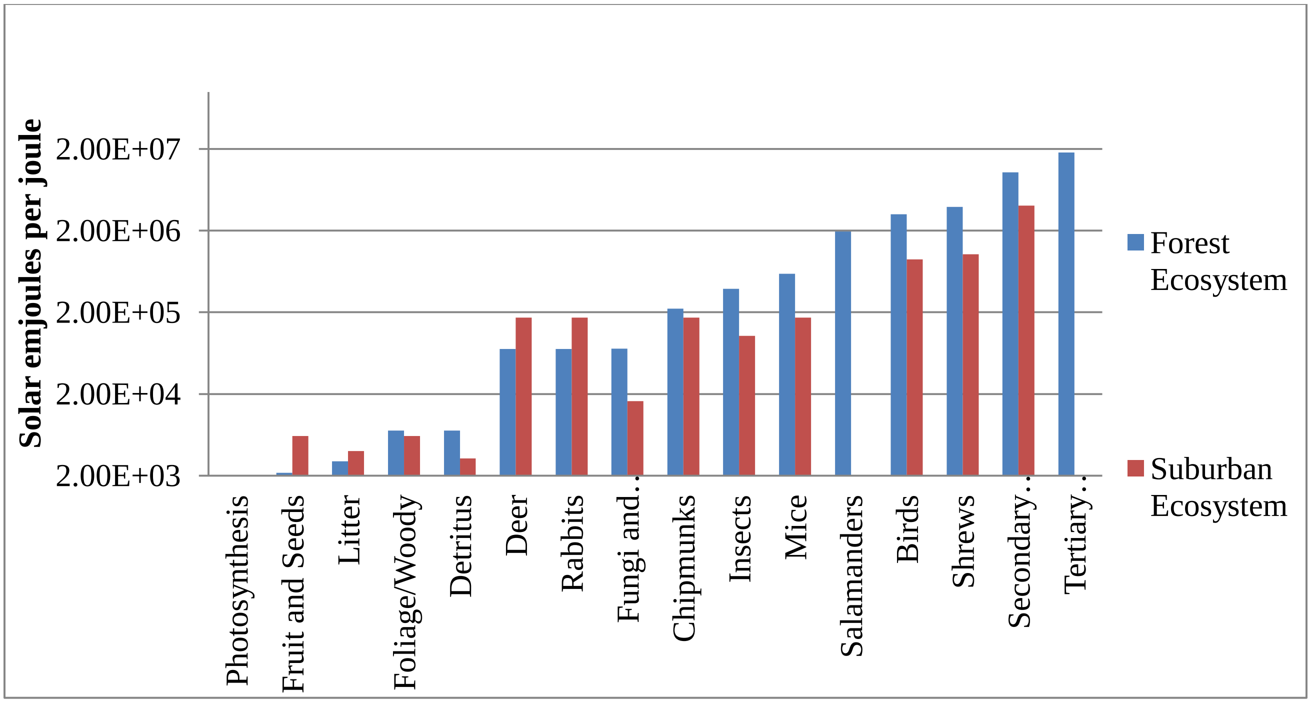


Figure 8.2.5 The transformities of the components of undisturbed and suburban forest ecosystems, determined through quality adjusted ecological network models. If the suburban forest model aggregates a category the same transformity is displayed for each category aggregated in the model.

Table 8.2.4 Indices for Quality Adjusted Ecological Network	Hubbard Brook	Suburban Forest
EIV (ecosystem importance value)= (Npi*Ti)/(∑NPj/Tj)	1.15	1.31
Ecosystem BioDiversity=-∑EIVi*log(EIVi)	0.90	0.87
Avg. EOET(expected and observed emergy throughput)= (TET/N)/(Npi*tri)	60.31	0.91
emergy per bit	1.06E+11	*
Emergy per Species	8.51E+08	1.98E+07
Shannon Diversity Index	2.24	*
Total emergy throughput, sej/m^2/yr	2.37E+11	4.57E+10
* Diversity data by trophic level not available for suburban forest		

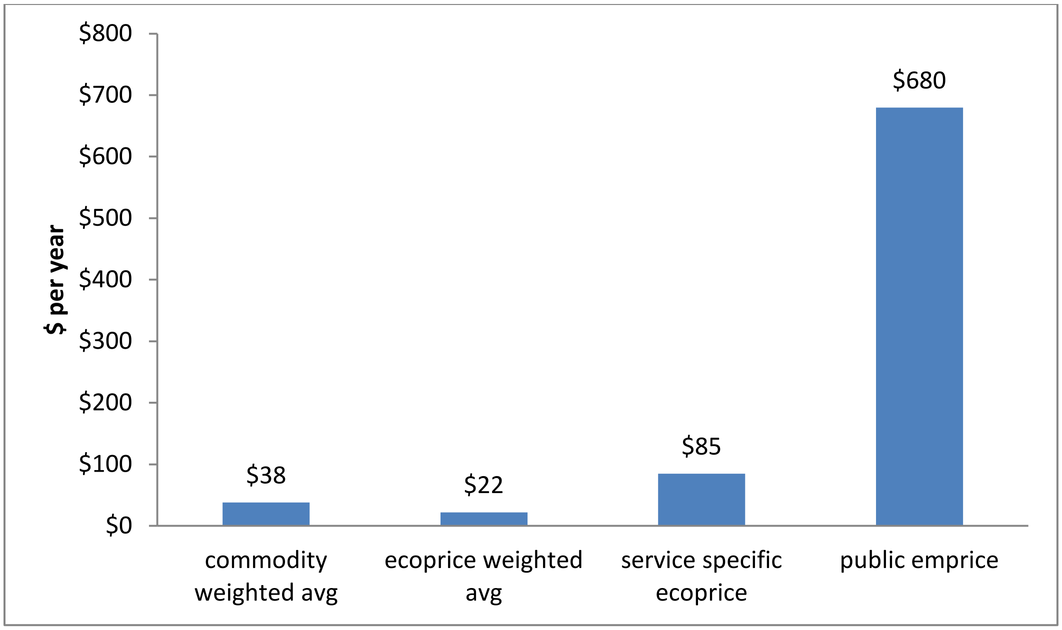


Figure 8.2.6 The annual dollar value of the biodiversity ecosystem service. The commodity weighted average, eco-price weighted average and service specific eco-price are all estimates of fair payment price.

Table 8.2.5 Public value and fair payment price for the Biodiversity Ecosystem Service

	Maryland (million $ per yr)	**Forest Land ($ per acre per yr)**	**PREI**
Public Value	$680	$272	
Commodity Fair Payment Price	$38	$15	18
Mean Ecosystem Service Fair Payment Price	$22	$9	31
Specific Ecosystem Service Fair Payment Price	$85	$34	8

8.2.5 Discussion

The ecosystem service of biodiversity was quantified through incorporation of the ecological network modeling methodology into emergy synthesis. The value stated here for the public value of biodiversity is an underestimate. Biodiversity is essential for the provision of nearly all of the other ecosystem services. If biodiversity were to be completely eliminated the other aspects of the system would suffer and potentially collapse; for example, a large scale ecological disaster like instances of extreme acid mine drainage, large scale clear cutting or nuclear fallout that eliminate a high percentage or all flora and fauna in an area; the affected area subsequently experiences decreased water quality, increased erosion, and decreased soil fertility, all directly a result of the lack of flora and fauna (biodiversity). A case can be made that the public value of biodiversity should be the sum of the value of all ecosystem services, especially when viewed from a large spatial or long temporal scale where intra- and inter-species genetic variety becomes more important for the long term sustainability of a system (Berkes, 1995). However, this would involve double counting and is not appropriate for the scale of analysis used in this research.

The emergy throughput is more than five times higher in the natural forest system (2.37E+11 sej/m^2/yr) than the suburban forest system (0.46E+11 sej/m^2/yr). Generally the difference increases as trophic level increases (Figure 8.2.4) but fungi and bacteria, having a low trophic level, has the greatest difference in emergy throughput. The difference in net production is not the cause of the large discrepancy (40% NPP difference, see Table 8.2.3) but the transformity calculated by the model is 1.63E+4 for the suburban forest system and 7.15E+4 for the natural forest system, accounting for the large discrepancy in emergy throughput. The forest model has more feedbacks from higher trophic to detritus which then feed the fungi and bacteria. The higher quality emergy feedback from upper trophic levels increases the emergy value of fungi and bacteria through a higher transformity.

Odum (1970) presented a similar study, quantifying the difference in net primary production (NPP) of a plantation forest and a natural rainforest in Puerto Rico. The rainforest has 32 g biomass/m^2/day and the plantation has a NPP of 20 g biomass/m^2/day. Odum attributes the increase in NPP to the “value to the total system’s competitive role” of the increased diversity observed in the rainforest.

The estimates for suggested fair payment provided are representative of the increase in emergy flow in a naturally forested system compared to a suburban system. This increase in flow can be attributed to more than one factor but I attribute the increase to the umbrella term of “Biodiversity Ecosystem Service”. However, if exotic and introduced species are considered a suburban system actually has higher biodiversity than a natural forest system (particularly Hubbard Brook which has almost no exotic species). These species often exist in degraded systems or are supported by anthropogenic work so the emergy flow through and the ability to support upper trophic level species is more representative of how a system is functioning than raw species richness numbers. Emergy flow through is less in a suburban system because a portion of the area is allocated to infrastructure and not available for biota and because suburban systems have a decreased ability to support upper trophic species. Human activity disturbs many of these species, making it less likely they will occur in a suburban ecosystem (McDonnell, 1997, Pita, 2009). Human dominated systems have less renewable emergy flow and a decreased ability to support natural systems (less available area, more negative anthropogenic distrubance) and this results in a detrimental effect on the ability of an ecosystem to support renewable emergy throughput. Analyzing an energy flow network through the lens of emergy reveals the degree to which anthropogenic activity negatively affects biota, and conversely the additional amount of emergy flowing through a forested system. This additional emergy represents the additional ability of an ecosystem to function compared to a human impacted to system, i.e. the ecosystem service of supporting biodiversity performed by the forest.

The constructed quality adjusted ecological network models demonstrate the ability of the forest to support a more robust ecosystem, particularly at higher trophic levels. The tertiary carnivore species (black bear Ursus americanus, fishers *Martes pennant*, Broad Winged Hawk Buteo platypterus) and ecologically sensitive salamander species are assumed to be absent in the suburban forest. The energy flow of secondary carnivores and some herbivores are reduced significantly in the suburban system. A choice, based on literature evidence, (McDonnell, 1997 and Pita, 2009) was made to eliminate the tertiary carnivores and salamaders in the suburban forest model. Tertiary carnivore and salamander emergy makes up only 2% of the total emergy flow in natural forest model (Table 8.2.4) so eliminating them in the suburban model only made a small impact on the difference observed. The reduction in total energy flow in the suburban model is chiefly a product of the reduced energy base of the system. There is less primary production (assumed to be 50% of forest primary production) due to the footprint of development (model assumes 40% impervious cover) and the managed nature of a suburban system (model assumes 20% lawn cover).

The calculated indices do not show a large difference between the systems; the EIV and Ecosystem Biodiversity indices are very similar. This can be attributed to outliers in the Hubbard Brook network model that had much less associated emergy than expected, leading to a poor measure of flow-through evenness, as exemplified by the very high EOET index. The best measure of how forest biodiversity is beneficial to society is the total emergy throughput and forests have an emergy throughput per year five times greater than that of a suburban forest.

Chapter 9: Summary of Ecosystem Service Values

If the entire 2.5 million acres of MD forest participated in the EIC the estimated fair payment price would be a minimum of $178 million, and as much as $744 million per year to provide payment commensurate to the value of forest ecosystem services. The range in values is dictated by the eco-price chosen. I recommend that the higher estimate be the goal when implementing the EIC, as it is judged to be the best estimate of societal willingness to pay for forest ecosystem services. However, a case can also be made for the commodity eco-price. Ecosystem services can be seen as playing an analogous role in the economy to primary inputs such as commodities, so valuing them as such may be appropriate. In their current condition and extent the forests of MD provide $5 billion (this is the total estimate based on sej/GDP, the public value, see Table 9.2) to the economy and society of the State. Thus, even when the higher estimate of $744 million is used, suggested payment to the EIC is only 15% of the total ecological-economic value. The additional value can be thought of as a societal consumer surplus of investing in the forests of Maryland.

A synthesis of results from the ecosystem service specific fair payment evaluation is presented in Table 9.1. The largest ecosystem services are stormwater mitigation ($238 million per year), groundwater recharge ($142 million), ozone removal ($119 million) and biodiversity ($87 million). Together these make up over 75% of the total dollar value of ecosystem services provided. On average, each acre of forest in Maryland provides $298 of ecosystem services every year. Divided evenly among the population of Maryland, the value of ecosystem services per capita is $124.

9.1 Comparison of Valuation Methodology

The dollar values listed in Table 9.1 and reported in previous sections of the document labeled as the specific ecosystem service fair payment price are generated using the average eco-price for each category of ecosystem service. Figure 9.1 displays these values in a graph for ease of distinguishing their relative magnitudes. These values were determined to be the best representation of what Maryland would be willing to pay for ecosystem services, and totaled $744 million. However, other options for estimating an appropriate emergy to dollar ratio were considered and are reported here.

On average in the Maryland economy for every dollar spent there are 2.82E 12 sej exchanged, in 2000 dollars. If this ratio is used to convert the emergy of ecosystem services to dollars the value of ecosystem services is much higher, at $5 billion (aforementioned as the public value of ecosystem services, see Table 9.2). If ecosystem services were completely integrated into the economy of Maryland and valued the same as human work based goods/services this would be their value. This is an estimate of the total benefit that ecosystems are providing to society. The public receives more value (>5 times) than the cost of funding the EIC program in promoting and perpetuating ecosystem services. In other words, when a dollar is invested in the EIC it returns more than 5 dollars in benefits to society (the societal consumer surplus). Consumer surplus is defined as the benefit or “welfare” a consumer gets from the consumption of goods or services and is the difference between the price a consumer is willing to pay and the price actually paid. Ecosystem services are essential for the survival of society so the price society is willing to pay would be the cost to replace ecosystem services with anthropogenic work/services. The public value can be seen as a first order approximation of this cost, but it would likely be much higher than this value. The initial cost and upkeep of providing services like clean water, stormwater control, and sediment retention would be very high. Certain ecosystem services, like biodiversity protection, would not be possible to replicate using human work. Obtaining a more accurate estimate of the cost of replacing ecosystem services with infrastructure and human labor and the extent that would be possible should be the subject of future research.

In order to provide a range of possible eco-prices and to explore how variability in the eco-price affects the total value of ecosystem services, two weighted average eco-prices were calculated. In both cases the average of eco-prices was weighted by magnitude of emergy flow. In the first case (results displayed in Table 9.3) the seventeen eco-prices used in Table 9.1 were averaged based on the percent contribution to the total emergy flow. This method yielded an estimate for the dollar value of ecosystem services of $178 million dollars per year. The weighted emdollar ratio (eco-price) was found to be 8.71E13 sej/$. The service specific eco-price for each ecosystem service was the average of the eco-prices relevant to the particular ecosystem service, see Table 9.1. Table 9.3 displays the resulting ecosystem service values when using the weighted average eco-price

A weighted average was taken of eight commodities in Maryland (weighting based on the magnitude of the emergy flow of the commodity). The weighted average was 5.08E13 sej/$, resulting in a total annual value for ecosystem services of $268 million (see table 9.4). Figure 9.3 is a bar graph comparing ecosystem services by eco-price method used.

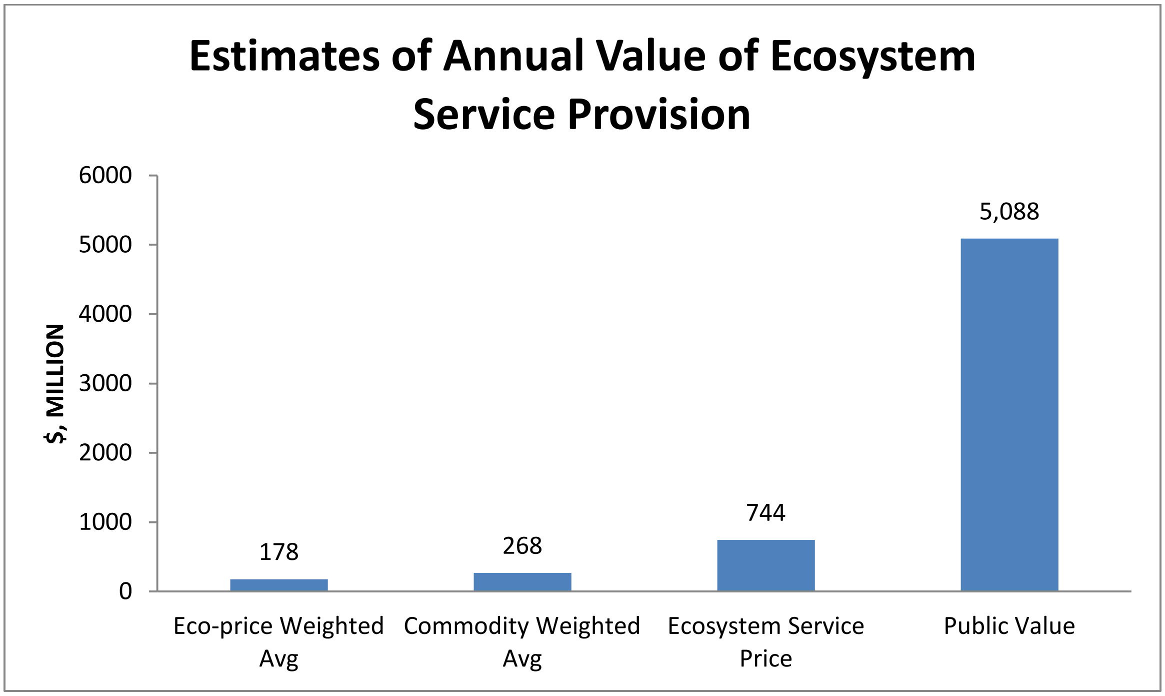


Figure 9.1 Values for ecosystem services provided by all forests of Maryland.

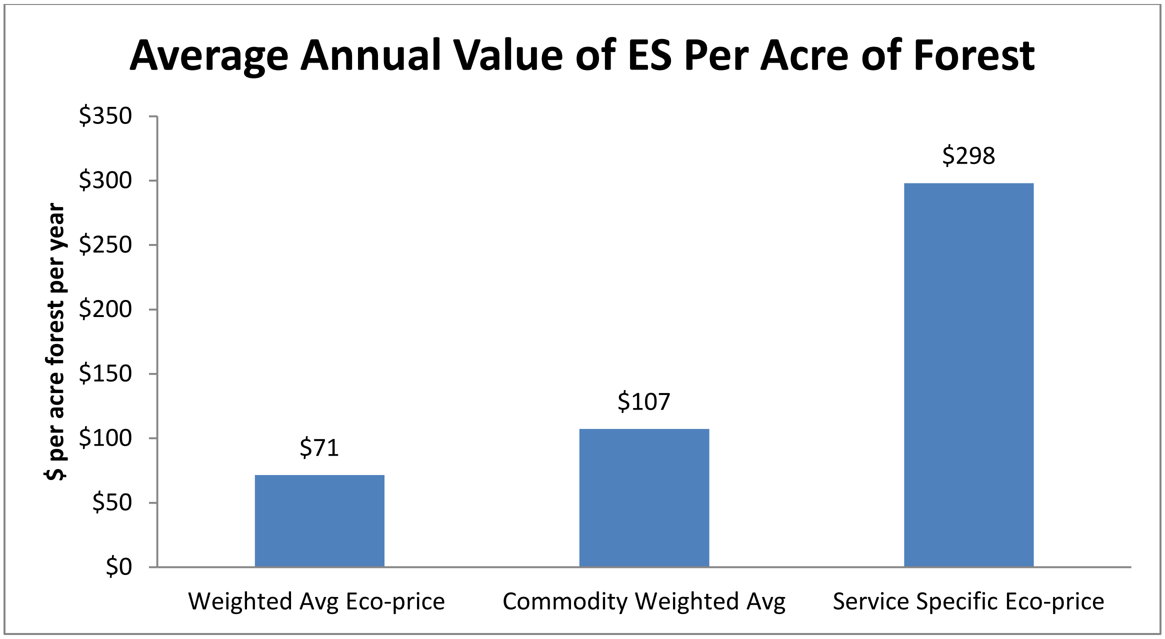


Figure 9.2 The annual value of forest ecosystem services per acre by eco-price used to convert emergy to dollars.

Table 9.1 Ecosystem Services of MD and service specific emergy to dollar ratios

Note	Item	Units	Quantity	Unit Emergy Values [1]. (sej/unit)	Solar Emergy ($x10^{18}$sej)	Emprice (Sej/$)	$'s ($x10^6$ $)
1	Carbon Sequestration	J	2.22E+16	3.62E+04	8.02E+02	1.82E+14	4
	Stormwater mitigation						
2	Stormwater, Piedmont	J	7.96E+15	1.24E+05	9.87E+02	8.95E+12	110
3	Stormwater, Coastal Plain	J	7.37E+15	1.55E+05	1.14E+03	8.95E+12	128
	Groundwater recharge						
4	GW Recharge, Piedmont	J	4.64E+14	1.50E+06	6.96E+02	8.95E+12	78
5	GW Recharge, Coastal Plain	J	4.35E+14	1.32E+06	5.75E+02	8.95E+12	64
	Nutrient Uptake	J					
6	Nitrogen Uptake	g	1.10E+10	4.10E+09	4.52E+01	8.95E+12	5
7	Phosphorus Uptake	g	9.68E+09	2.16E+10	2.09E+02	8.95E+12	23
8	Soil Building	J	4.06E+15	1.43E+05	5.81E+02	8.01E+13	7
9	Erosion Prevention	g	3.33E+12	1.68E+09	5.60E+03	8.01E+13	70
	Air Pollutant Removal						
10	CO Removal	g	1.27E+09	1.20E+09	1.52E+00	7.64E+12	0.2
11	NO_2 Removal	g	6.22E+09	6.84E+09	4.26E+01	7.64E+12	6
12	O_3 Removal	g	1.46E+10	6.23E+10	9.08E+02	7.64E+12	119
13	SO_2 Removal	g	3.48E+09	5.26E+10	1.83E+02	7.64E+12	24
14	PM10 Removal	g	6.84E+09	2.04E+10	1.39E+02	7.64E+12	18
15	Biodiversity Protection	J	4.21E+10	mixed	1.93E+03	2.23E+13	87
16	Pollination by Wild Insects	ha	1.14E+04	1.84E+14	2.10E+00	7.19E+12	0.3
	Total				1.38E+22		743.7
	Dollars per Acre of Forest		$298.4				
	Dollars per Capita		$130.5				

See Appendix 2 for footnotes detailing calculations

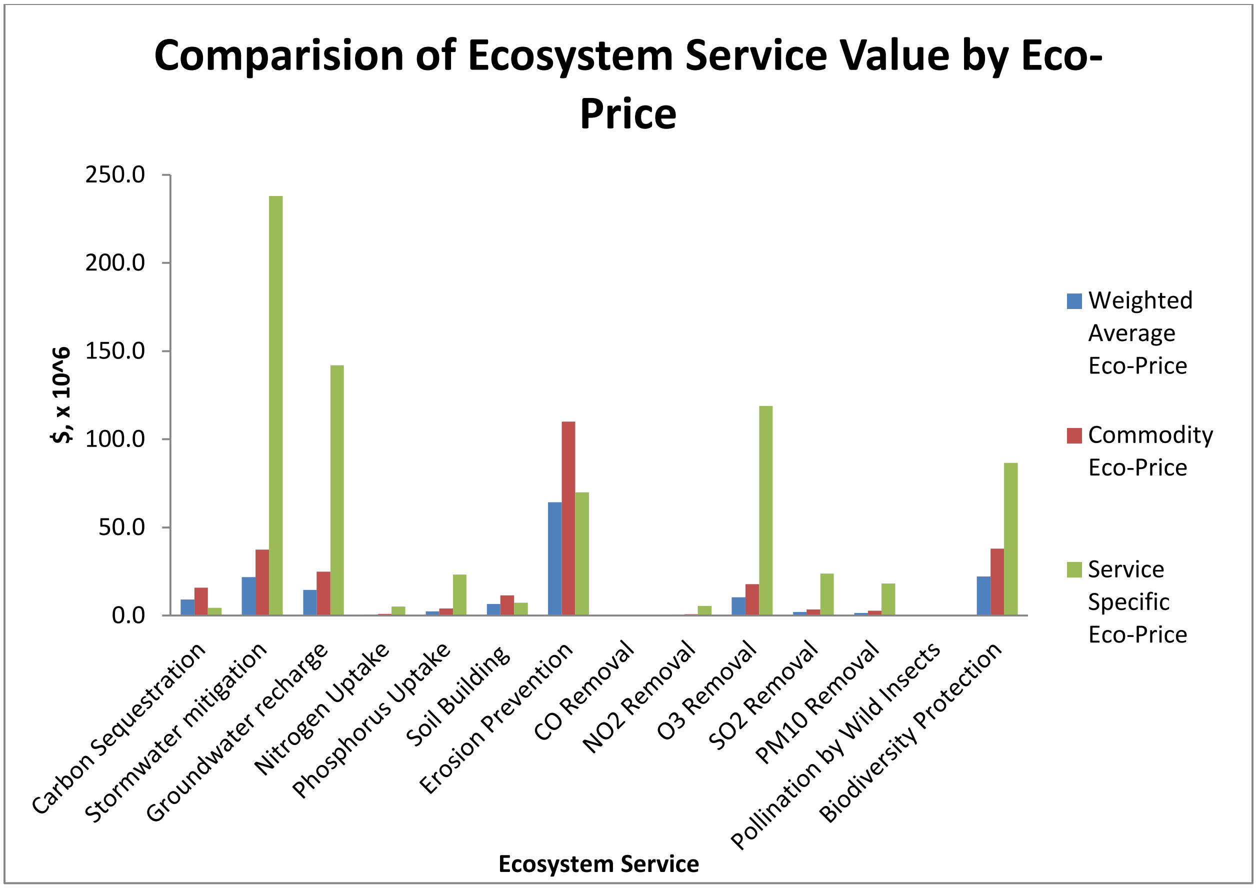


Figure 9.3 Fair Payment Value of Forest Ecosystem Services in MD based on eco-prices. (million $ per year)

Table 9.2 Public value of Forest Ecosystem Services in MD mean eco-price for state economy

Item	Units	Quantity	Unit Emergy Values	Solar Emergy	Eco-price (1E12 sej/$)	Public Value (Million $)
Carbon Sequestration	J	2.22E+16	3.62E+04	802.3	2.65	$303
Stormwater mitigation	J	1.53E+16	1.24E+05	1901	2.65	$717
Groundwater recharge		8.99E+14	1.41E+06	1268.2	2.65	$479
Nitrogen Uptake	g	1.10E+10	4.10E+09	45.2	2.65	$17
Phosphorus Uptake	g	9.68E+09	2.16E+10	209.2	2.65	$79
Soil Building	J	4.06E+15	1.43E+05	580.6	2.65	$219
Erosion Prevention	g	3.33E+12	1.68E+09	5596.8	2.65	$2,112
CO Removal	g	1.27E+09	1.20E+09	1.5	2.65	$1
NO2 Removal	g	6.22E+09	6.84E+09	42.6	2.65	$16
O3 Removal	g	1.46E+10	6.23E+10	908.5	2.65	$343
SO2 Removal	g	3.48E+09	5.26E+10	182.8	2.65	$69
PM10 Removal	g	6.84E+09	2.04E+10	139.4	2.65	$53
Biodiversity Protection	J	4.21E+10	mixed	1933	2.65	$730
Pollination by Wild Insects	ha	2.07E+04	1.84E+14	3.8	2.65	$1

Total Value for Fair Payments to Land Stewards		$5,139
Value per Acre of Forest Land	$2,055	
Value per capita	$856	

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

Table 9.3. Fair Payment Value of Ecosystem Services based on Mean Eco-price of services.

Item	Units	Quantity	Unit Emergy Values (sej/unit)	Solar Emergy (x1018sej)	Emprice (Sej/$)	Dollars (Million $)
Carbon Sequestration	J	2.22E+16	3.62E+04	802.3	8.71E+13	9.21
Stormwater mitigation	J	1.53E+16	1.24E+05	1901.0	8.71E+13	21.83
Groundwater recharge		8.99E+14	1.41E+06	1268.2	8.71E+13	14.56
Nutrient Uptake	J					
Nitrogen Uptake	g	1.10E+10	4.10E+09	45.2	8.71E+13	0.52
Phosphorus Uptake	g	9.68E+09	2.16E+10	209.2	8.71E+13	2.40
Soil Building	J	4.06E+15	1.43E+05	580.6	8.71E+13	6.67
Erosion Prevention	g	3.33E+12	1.68E+09	5596.8	8.71E+13	64.26
Air Pollutant Removal						
CO Removal	g	1.27E+09	1.20E+09	1.5	8.71E+13	0.02
NO2 Removal	g	6.22E+09	6.84E+09	42.6	8.71E+13	0.49
O3 Removal	g	1.46E+10	6.23E+10	908.5	8.71E+13	10.43
SO2 Removal	g	3.48E+09	5.26E+10	182.8	8.71E+13	2.10
PM10 Removal	g	6.84E+09	2.04E+10	139.4	8.71E+13	1.60
Biodiversity Protection	J	4.2E+10	mixed	1933	8.71E+13	22.20
Pollination by Wild Insects	ha	2.07E+04	1.84E+14	3.8	8.71E+13	0.04
Total Value for Fair Payments to Land Stewards					sum	$156.32
Value per Acre of Forest Land		$63				
Value per capita		$26				

Table 9.4 Fair Payment Value of Ecosystem Services based on Mean Eco-prices of Commodities.

Item	Units	Quantity	Unit Emergy Values (sej/unit)	Solar Emergy (1018sej)	Eco-price (1E12 sej/$)	Estimate of Fair Payment (Million $)
Carbon Sequestration	J	2.22E+16	3.62E+04	802	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	50.8	$25.0
Nitrogen Uptake	g	1.10E+10	4.10E+09	45	50.8	$0.9
Phosphorus Uptake	g	9.68E+09	2.16E+10	209	50.8	$4.1
Soil Building	J	4.06E+15	1.43E+05	581	50.8	$11.4
Erosion Prevention	g	3.33E+12	1.68E+09	5597	50.8	$110.1
CO Removal	g	1.27E+09	1.20E+09	2	50.8	$0.0
NO2 Removal	g	6.22E+09	6.84E+09	43	50.8	$0.8
O3 Removal	g	1.46E+10	6.23E+10	909	50.8	$17.9
SO2 Removal	g	3.48E+09	5.26E+10	183	50.8	$3.6
PM10 Removal	g	6.84E+09	2.04E+10	139	50.8	$2.7
Pollination by Wild Insects	ha	2.07E+04	1.84E+14	4	50.8	$0.1
Biodiversity Protection	J	4.21E+10	mixed	1933	50.8	$38.1
Total Value for Fair Payments to Land Stewards						$230.0
Value per Acre of Forest Land		$92				
Value per capita		$38				

9.2 Discussion of Ecosystem Service Value

The three methods of calculating an eco-price used to convert emergy to dollars have advantages and disadvantages. An advantage of using weighted averages is that it mitigates the effect that any one erroneous or outlier eco-price could have on the overall estimate of annual ecosystem service value. The downside of using weighted averages is that information is lost, in particular the estimates of the willingness to pay for particular services. When weighted averages are used one cannot observe the differences in willingness to pay (reflected in the eco-price) across ecosystem services. Using a weighted average yielded a decrease in the annual value of ecosystem services of 79% for the ES weighted average and 65% for the commodity weighted average from the service specific estimate. Ecosystem services like stormwater mitigation and O_3 mitigation had the largest changes in value; the calculation of their value went from using below average eco-prices to a median value. Society places a high value on controlling stormwater (this service by forests would be costly for society to replicate through infrastructure) and on controlling O_3 (ozone has the potential to be detrimental to human health) and thus they have low eco-prices (low emergy per $, high $ per emergy). Using a weighted average loses this information. For this reason I recommend the service specific ecosystem service values to be used by the EIC program to most accurately reflect societal willingness to pay for individual ecosystem services. The caveat to this is that the service specific total ES value is higher (4 times greater than when using the weighted average and 2.75 times greater than using the commodity derived eco-price value) and this may prevent the EIC from being enacted in the current economic and political climate. Therefore, I present results using all three eco-prices.

9.3 Dynamic Eco-Pricing of Ecosystem Services via Natural Resource Commodity Markets

The pricing of ecosystem services should be responsive to supply and demand. The ecosystem services equivalency pricing explained and used above does not have an obviously easy mechanism for correcting the eco-price of services on a daily, weekly, or monthly basis. Likely, implementation of the equivalency pricing would require that an expert committee convene to reset the eco-prices of the equivalent services on an annual basis. Thus, this is one shortcoming of employing the equivalency method.

One way to overcome this limitation of non-dynamic pricing would be to tie the eco-price to actively traded, allied resources or goods. The Commodity Eco-Price uses the emergy-to-dollar ratio (i.e., eco-price) of ubiquitous and highly traded commodities, such as electricity, gasoline, crude oil, natural gas, copper, timber, corn and wool, to translate the emergy flow of ecosystem services to dollar values. Once the value of ecosystem services are in terms of dollars, then the payments to land stewards can be estimated. The dollar enumeration also provides a baseline for what should be collected from or paid by consumers of ecosystem services.

The justification for the Commodity Eco-Price is that both ecosystem services and natural resource commodities are generated from nature. When natural resources are extracted from the earth that is the 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-price provides a proxy pricing mechanism.

The basic equation for the Commodity Eco-Price is given as:

Dollar value of ecosystem service ($) = emergy flow of ecosystem service (sej) x 1/eco-price ($/sej) (1)

9.3.1 Eco-prices for Commodity Weighted Average Eco-Price

Copper had the highest eco-price of the natural resources used in the Natural Resources Equivalency Comparison (Figure 9.3.1). The commodity trading value of copper was $4.09 per lb on June 2, 2011, which provided an eco-price of 35.4E12 sej/$.

Timber had the lowest eco-price of the natural resources used in the Commodity Eco-Price Comparison (Figure 9.3.1). The commodity trading value of timber was $235 per 1000 board feet (MBF) on June 2, 2011, which provided an eco-price of 4.8E12 sej/$.

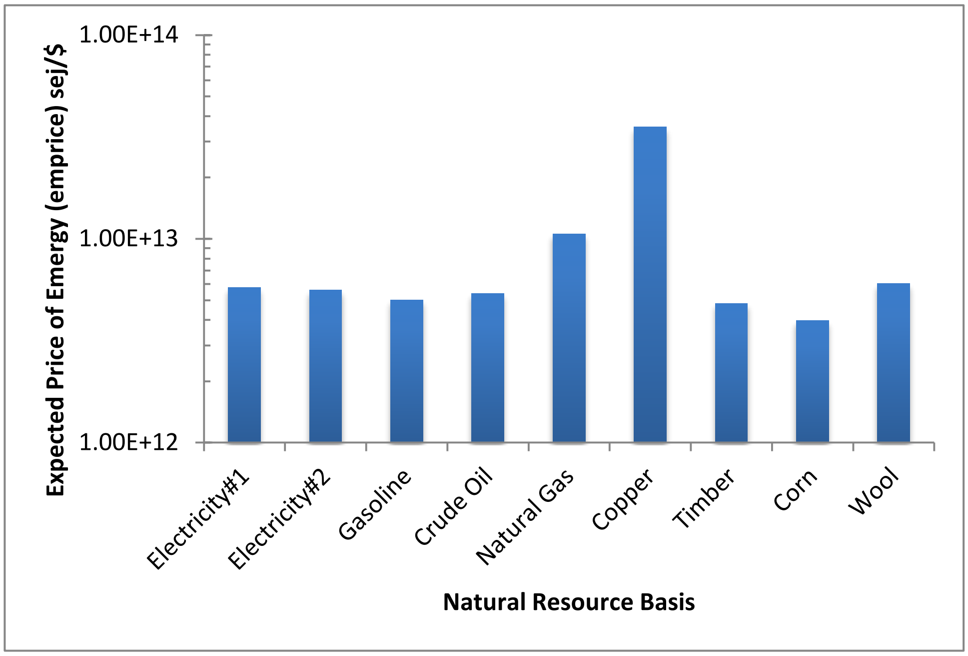


Figure 9.3.1 Expected eco-prices (sej/$) for various commodities (June 2011) used in the Commodity Eco-Price.

9.4 Sensitivity Analysis of the Commodity Eco-Price

9.4.1 Value of Forest Productivity

The annual dollar value of forest productivity, when it was 4 MT/ha/y, was estimated to be between $27 and $199 per ha (Figure 9.4.1). These estimates were based on the Commodity Eco-Price comparison, whereby the expected price of the emergy of common natural resources (sej/$) was used to transform the emergy flow of forest productivity to dollars. The natural resources chosen for comparison were electricity, gasoline, crude oil, natural gas, copper, timber, corn and wool. All of these, with the exception of electricity, are traded freely and at high volume on commodity exchanges. The trading prices change by the minute every business day. With the exception of electricity, all of the prices were based on

June 2, 2011 commodity market trading prices. The expected price of electricity was based on 2006 US prices and consumption rates.

When forest productivity was valued at the price of copper on an emergy equivalency basis, then it was worth $27/ha/y. Using the lower eco-price of timber indicated that forest productivity was worth $199/ha/y.

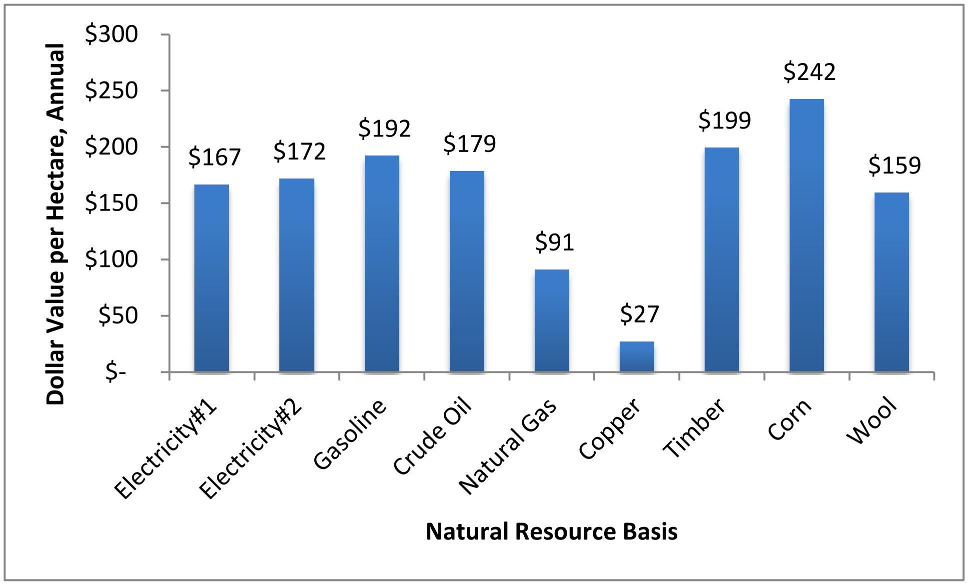


Figure 9.4.1 Dollar value of MD forests based on equivalency with primary energy sources, electricity, minerals and agricultural commodities.

The implication for the EIC is that selection of the commodity to represent the proxy eco-price 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. One alternative would be to estimate a mean eco-price for all commodities as a basket of goods and use it to translate the emergy of the ecosystem service to a dollar value.

The net primary productivity of forests varies with geography, age, climate and forest type. The sensitivity of the value of forest productivity to its rate of production (Figure 9.4.2) shows that the value is 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.

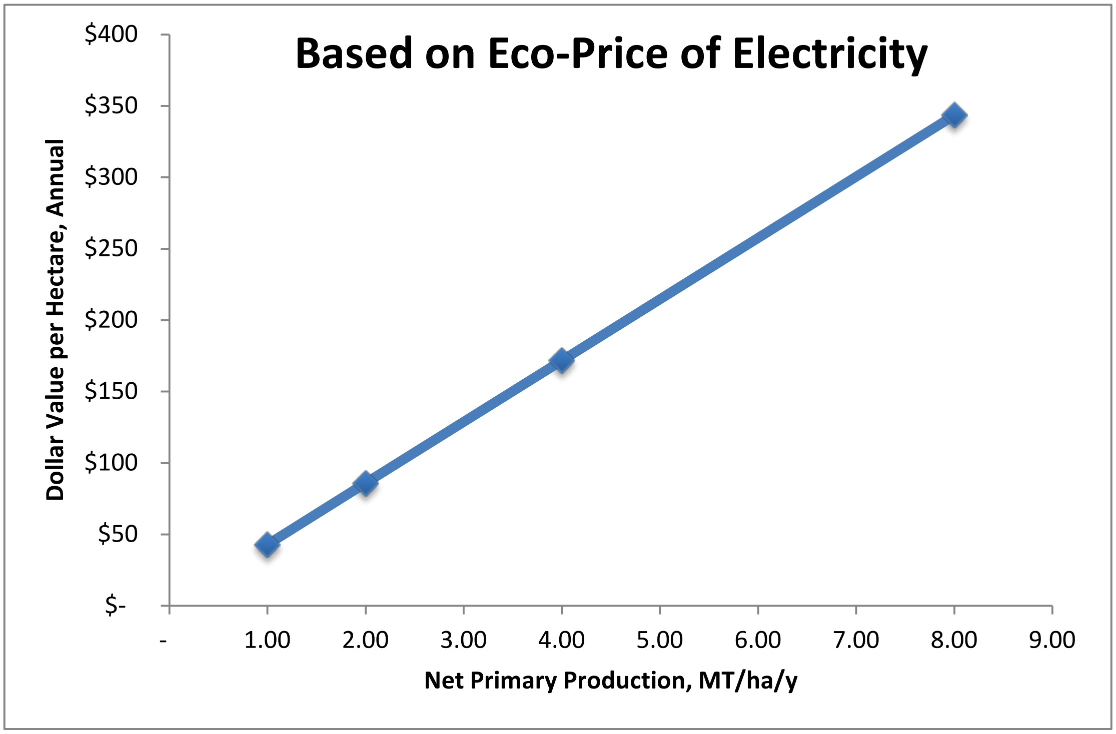


Figure 9.4.2 Sensitivity of the value of forest productivity to net primary production.

The emergy produced by a forest also varies with geography, age, climate and other factors. The sensitivity of the value of forest productivity to the natural variability in its emergy was explored by varying the solar transformity of forest productivity (Figure 9.4.3). The annual dollar value 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 is expected for young, fast growing forests, whereas a solar transformity of 55,000 sej/J is expected for an old-growth stand (Tilley 1999). That is, there is more emergy accumulated in an old-growth forest than an immature one. Thus, a young forest that is less than 50 years old would produce ecosystem services annually at about \$70 per ha. 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.

The implication for the EIC would be that Land Stewards that preserve old-growth forests would be paid more than Stewards that preserve immature forests. It also implies that Land Stewards should be paid more each year because their forest is 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.

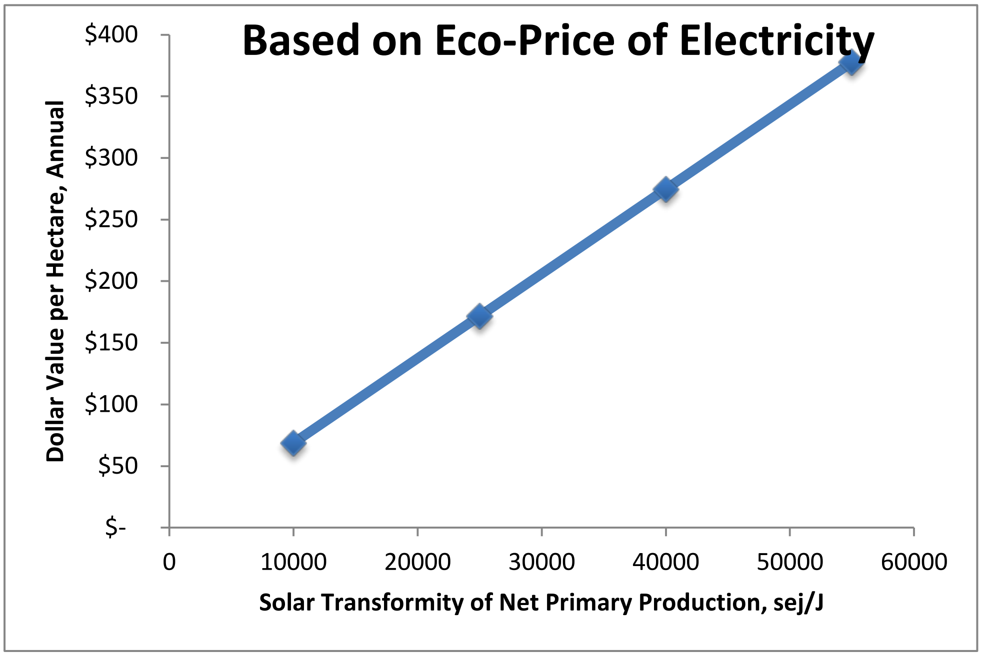


Figure 9.4.3 Sensitivity of the value of forest productivity to solar transformity of productivity.

The Present Value of future dollar flows for ecosystem services is affected by the Discount Rate chosen (Figure 9.4.4). A higher discount rate lowers the Present Value of future payments. Annual dollar flows of $172 had a PV of $5400/ha at a 2% Discount Rate, but only $2100/ha at an 8% rate (Figure 9.4.4). A Land Steward with forest enrolled in the EIC for 50 years could be paid a one time fee of $5400 assuming the 2% Discount Rate was justified.

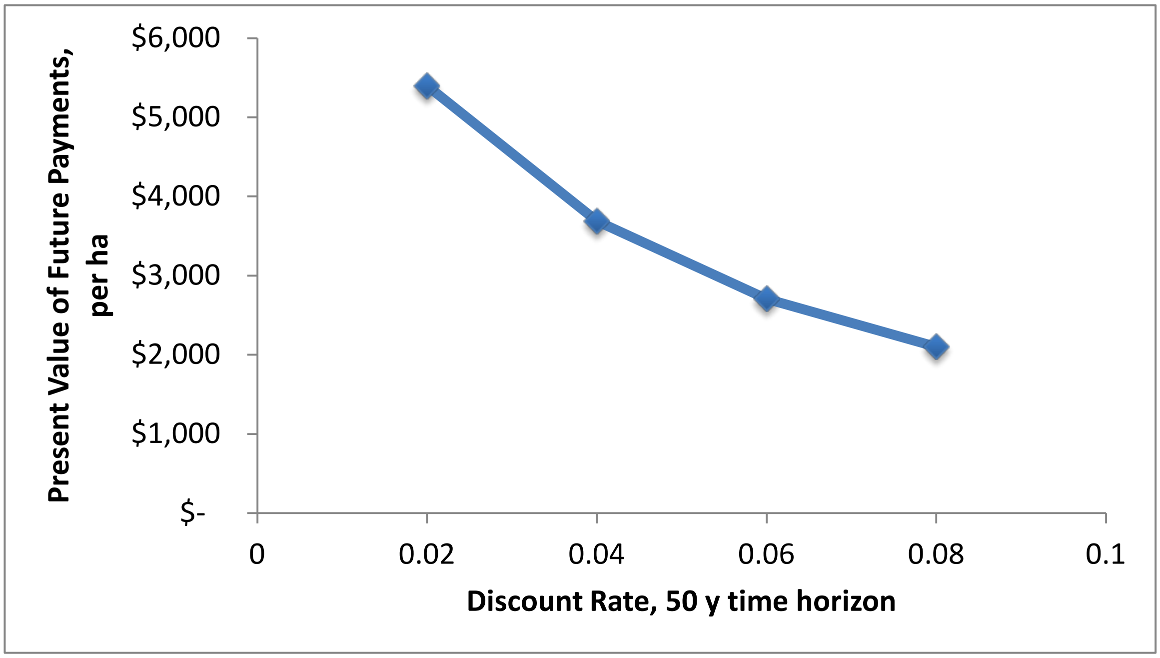


Figure 9.4.4 Effect of Discount Rate on Present Value of 50 years of future annual ecosystem service payments.

The time horizon over which the annual payments are made also affects the PV. The longer the time horizon the higher the PV (Figure 9.4.5). For a 50 year time horizon, annual payments of $172/ha/y have a PV of $5400/ha, assuming a 2% discount rate. A 30 year or 10 year period has a PV of $3850 and $1500/ha, respectively.

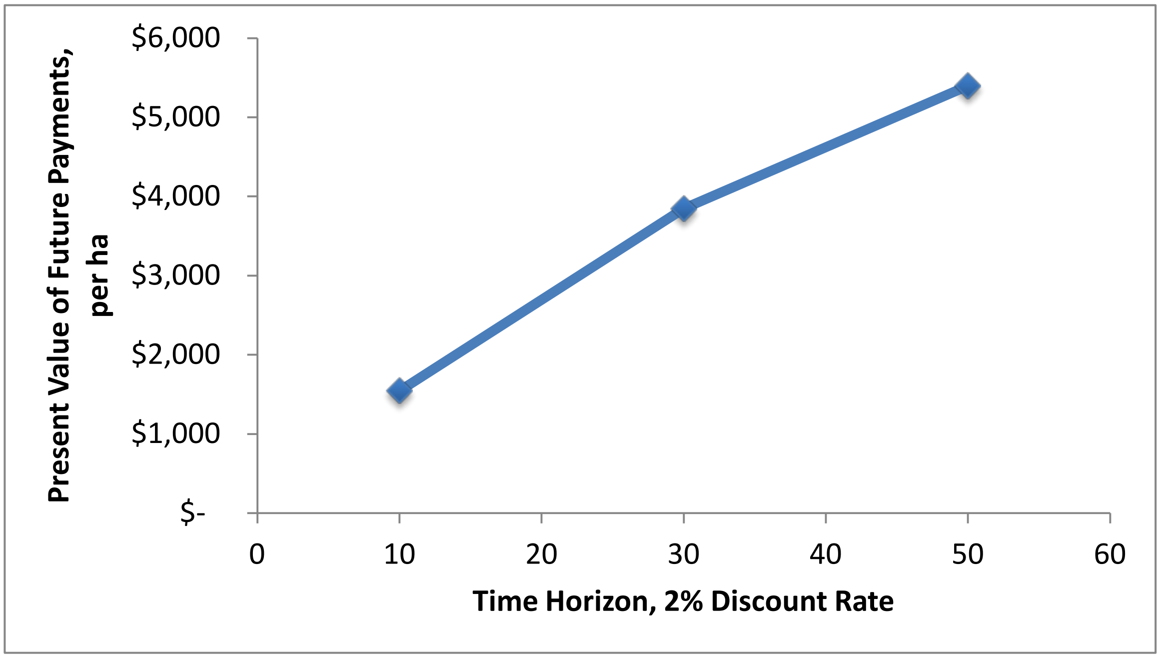


Figure 9.4.5 Effect of Time Horizon on Present Value of future annual ecosystem service payments assuming a Discount Rate of 2%.

Chapter 10: Implementing Payment for Ecosystem Services in Maryland– The EcoInvest Model

EcoInvestCorp is a dynamic simulation model that shows how a Maryland Ecological Investment Corporation (EIC) will collect flows of money generated from consumers of ecosystem services (**N**) and distribute to Stewards (**M**) and Stockholders (**V**) (Figure 10.1). The EIC is eligible to receive consumer fees in proportion to how much ecosystem service value (**S**) it has 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 they paid to Stewards (**M)** and collect administrative costs (**F**) in proportion to the amount of ecosystem services they paid to Stewards. The dividend rate, **v**, and administrative cost rate, f, will be controlled by a State Authority or NGO. The EIC accumulates assets, **E**, as a balance of these inflows (**K, N)** and outflows **(V, M, F**).

EcoInvestPub is a dynamic simulation model that simulates how a government payment for ecosystem services (PES) program would impact Maryland. The flows and symbology are the same as in the *EcoInvestCorp* but Stockholders (**V**), Dividends (**V**), and Assets (**E**) and their associated rates are not included in this model. The number of stewards and consumers is constant, I varied the amount of land between enrollment of all forest lands both publically and privately owned and just privately owned lands and evaluated the return on investment using revenue generated from four eco-prices (public value, commodity price, service specific price and weighted average price).

<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**) through a third party. Thus, Steward Income is M–R (Figure 1). The Steward's Revenue (**M**) will be the amount (**S**) of ecosystem services provided times the fair payment price (i.e., eco-price) (**P_m**) for their basket of ecosystem services.

How are Ecosystem Service Production (S) and Fair Payment Prices (P_m) measured? Emergy synthesis, as a systems ecology-based method, allows the multitude of ecosystem services to be quantified in an integrated fashion as a unified unit. 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 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 energy joules (sej). In *EcoInvestCorp* and *Pub*, the amount of ecosystem services (**S**) provided by Land Stewards was estimated to be different rates based on the above work. Under each Scenarios S was 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 2 for list of eco-prices). See Chapter 4 for a more detailed explanation of eco-prices and their derivation.

What is the basis for collecting money from consumers of ecosystem services? Consumers do not directly consume ecosystem services, but they do consume goods that have measurable quantities of embodied solar energy, just as ecosystem services do. Thus, an ideal and energetically consistent framework for selecting collecting payments from consumers would be to base their payments on their total consumption of solar emergy. The payment per a type of good 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 in *EcoInvestCorp* the amount of money collected by the EIC was more simplistic. It was taken as a function of a basic monthly rate per participant and a fraction of state population that participated. In *EcoInvestPub* the amount of money collected is determined by the eco-price used to determine the dollar value per sej of ecosystem service provided (the monthly rate) and the full participation of the citizens of Maryland.

How much public value is generated relative to payments made? 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 (**P_n**), which was 2.82E12 sej/$ (i.e., **B** = **S/P_n)**. This mean statewide price of solar embodied energy has been calculated for other states (North Carolina, Tilley 1999; West Virginia, Campbell et al. 2004; Maine, Campbell 1998; Texas, Odum and Odum, 1987), the U.S. (Tilley 2006) and mostly recently for every country in the world as part of a United Nations study (Cohen 2006).

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

How will impartiality be assured? An impartial third party panel should be employed to review both the ecosystem services being provided and the eco-prices used to convert emergy to dollars. This panel should be made up by a mix of professionals, government employees and academics without financial interest in the EIC to assure impartiality. This panel could also be responsible for the periodic update of the eco-price database, at least once per year.

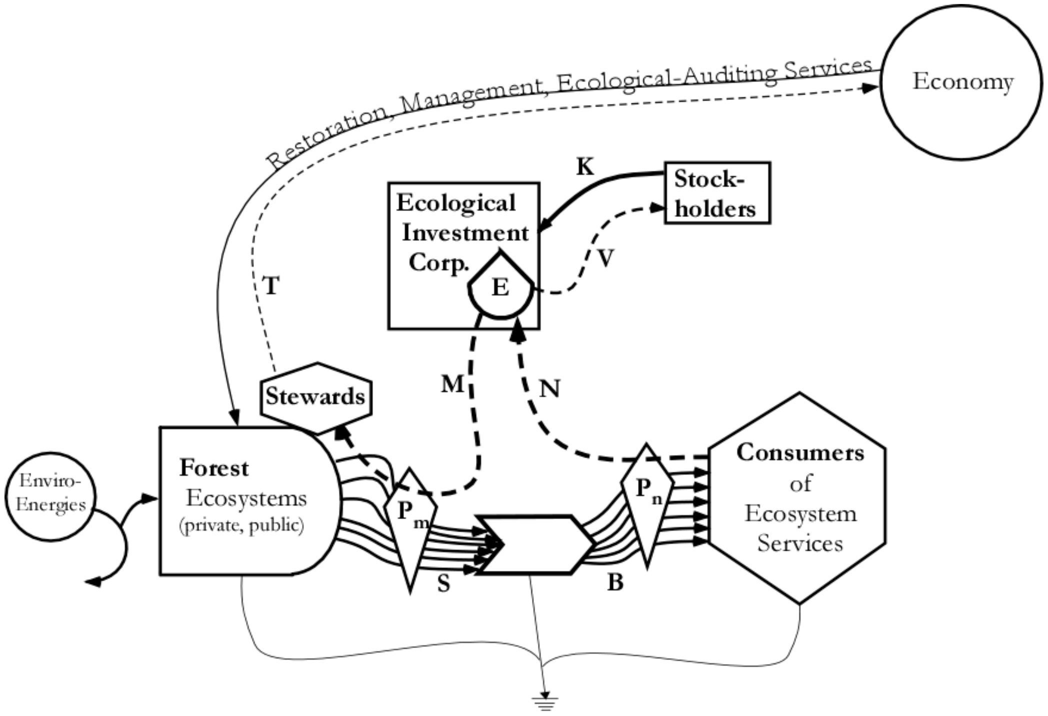


Fig. 10.1 Simulation model for operating a statewide Ecological Investment Corporation. (*EcoInvestCorp*).

$dE/dt = K + N - M - F - V$

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 (%);

$S=a\sigma A$ where a is participation rate of land stewards (%),

σ 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)

10. 1 Parameter Estimates

Table 10.1 contains the descriptions and values estimated or assumed for the parameters in *EcoInvestCorp* and *EcoInvestPub* parameters are shown in Table 10.1. Estimated parameter values were based on the work presented above. Three parameters are shown as variable because they took on various values for the Scenarios run below. Assumed parameter values were based on best guesses.

I 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 project.

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. *EcoInvestPub* does not contain the investment portion of the model, as it would be a government entity.

Table 10.1 Parameter descriptions, values, units and formulas for EcoInvestCorp. Parameters in **bold** were treated as variables in Six Scenarios, while the one underlined (n) was solved to make the EIC profitable in the EcoInvestCorp model.

Parameter	*Description*	*Value*	*Units*	*Source*
a	**Participation rate of Land Stewards**	**variable**	**%**	
A	Forested area in MD	1.01E06	ha	Table 5.1
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/$	Figure 4.6.1
P_n	Public emprice	2.82E12	sej/$	Table 5.4
r	Management/restoration costs	$10	$/ha	Assumed
σ	Per area ES delivered from forest	1.20E16	sej/ha	Calculated from Table 5.2
U	**Number of people donating**	**variable**	**participants**	
v	Dividend rate to stockholders	0.5%	%	Assumed
Formulas				
B	Public value of ES 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□A	sej	

10.2 Scenarios

Six scenarios in *EcoInvestCorp* and four scenarios in *EcoInvestPub* were used to explore what the range of consumer payments should be using the parameter values given in Table par1 and 2. Under the assumptions and estimates used, land stewards were paid $241/ha/y in *EcoInvestCorp* scenarios and payments were varied from $2.89-$11.17 in *EcoInvestPub* scenarios. Each *EcoInvestCorp* 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 *EcoInvestCorp* 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. *EcoInvestPub* assumes participation of all 6 million people in Maryland and enrollment of either all 1 million ha of forest land or only the privately owned lands; approximately 700,000 ha.

Table 10.2 shows 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 per the $1,000,000 invested as capital. The Public Value per Payment index indicates how much public value ($) was generated by the ecosystem services for each dollar donated by consumers.

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.

Table 10.2 The Six Scenarios Run in EcoInvestCorp, Varying Land and Consumer Participation

Consumers/Land Owner Participation	**Low/Low**	**Medium/Low**	**High/Low**	**Low/High**	**Medium/High**	**High/High**
Monthly Per Capita Donation	**$30.00**	**$6.00**	**$3.00**	**$118.00**	**$23.50**	**$11.75**
Dividend Rate	0.50%	0.50%	0.50%	0.50%	0.50%	0.50%
Administrative Costs	2.00%	2.00%	2.00%	2.00%	2.00%	2.00%
Participant Consumers	**50,000**	**250,000**	**500,000**	**50,000**	**250,000**	**500,000**
Forest Area, ha	**50,000**	**50,000**	**50,000**	**200,000**	**200,000**	**200,000**
Land Steward Revenue	$18,571,429	$18,571,429	$18,571,429	$74,285,714	$74,285,714	$74,285,714
Land Steward Costs	$6,500,000	$6,500,000	$6,500,000	$26,000,000	$26,000,000	$26,000,000
Land Steward Income	$12,071,429	$12,071,429	$12,071,429	$48,285,714	$48,285,714	$48,285,714
Income per hectare	$241	$241	$241	$241	$241	$241
Capital Investment	$1,000,000	$1,000,000	$1,000,000	$1,000,000	$1,000,000	$1,000,000
EIC Revenue	$19,500,000	$19,500,000	$19,500,000	$76,700,000	$76,375,000	$76,375,000
EIC Payments	$18,571,429	$18,571,429	$18,571,429	$74,285,714	$74,285,714	$74,285,714
Dividends	$92,857	$92,857	$92,857	$371,429	$371,429	$371,429
Admin. Costs	$371,429	$371,429	$371,429	$1,485,714	$1,485,714	$1,485,714
EIC Net Income	$464,286	$464,286	$464,286	$557,143	$232,143	$232,143
Public Value	$230,496,454	$230,496,454	$230,496,454	$921,985,816	$921,985,816	$921,985,816
Return on Capital	9.29%	9.29%	9.29%	37.14%	37.14%	37.14%
Public Value per Payment ($/$)	11.8	11.8	11.8	12.1	12.1	12.1

Table 10.3 EcoInvestPub Enrollment of All Maryland Forest Lands with Varying Eco-Price

Item	Weighted Average Eco-price	Commodity Eco-price	Service Specific Eco-price	Public Value
Emprice Used, sej/$	8.71E+13	5.08E+13	7E12-1E14	2.82E+12
Monthly Per Capita Payment	3.81	5.7	12.51	59.75
Dividend Rate	-	-	-	-
Administrative Costs, % of total Revenue	0.02	0.02	0.02	0.02
Participant Consumers	5.83E+06	5.83E+06	5.83E+06	5.83E+06
Forest Area, ha	1.01E+06	1.01E+06	1.01E+06	1.01E+06
Land Steward Revenue	$49,894,925	$169,607,981	$685,586,406	$5,391,521,793
Land Steward Costs	$131,134,117	$131,134,117	$131,134,117	$131,134,117
Land Steward Income	$181,029,042	$300,742,098	$816,720,523	$5,522,655,910
Income per hectare	$179	$298	$810	$5,475
Revenue	$312,163,159	$431,876,215	$947,854,640	$5,653,790,027
Payments	$49,894,925	$169,607,981	$685,586,406	$5,391,521,793
Dividends	-	-	-	-
Admin. Costs	$3,011,116	$3,011,116	$3,011,116	$3,011,116
Public Value	$4,977,975,711	$4,977,975,711	$4,977,975,711	$4,977,975,711
Public Value per Payment ($/$)	16	12	5	1

Table 10.4 EcoInvestPub, Participation of Privately Owned Forest Land

Item	Weighted Average Eco-price	Commodity Eco-price	Service Specific Eco-price	Public Value
Emprice Used, sej/$	8.71E+13	5.08E+13	7E12-1E14	2.82E+12
Monthly Per Capita Payment	3.14	5.25	12.06	74.17
Dividend Rate	-	-	-	-
Administrative Costs, % of total Revenue	2%	2%	2%	2%
Participant Consumers	5.83E+06	5.83E+06	5.83E+06	5.83E+06
Forest Area, ha	7.67E+05	7.67E+05	7.67E+05	7.67E+05
Land Steward Revenue	$27,952,374	$175,524,651	$651,812,428	$4,995,752,786
Land Steward Costs	$99,661,929	$99,661,929	$99,661,929	$99,661,929
Land Steward Income	$127,614,303	$275,186,580	$751,474,357	$5,095,414,715
Income per hectare	$180	$389	$1,062	$7,200
Revenue	$219,609,930	$367,182,207	$843,469,984	$5,187,410,342
Payments	$27,952,374	$175,524,651	$651,812,428	$4,995,752,786
Dividends	-	-	-	-
Admin. Costs	$2,653,930	$2,653,930	$2,653,930	$2,653,930
Public Value	$4,098,533,336	$4,098,533,336	$4,098,533,336	$4,098,533,336
Public Value per Payment ($/$)	19	11	5	1

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 10.5). 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 both a high, medium, or low consumer participation rate and 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 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 10.5).

Table 10.5 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 50,000	High 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 10.1). Tying dividends to payments to land stewards 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 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 annual dividends were $371,429 (Table 10.6). 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 10.6). 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 10.6 Mean annual dividend to stockholders Land Stewards to receive $241/ha/y and for the EIC to be profitable.

Consumer Participation		**Land Steward Participation (ha)**	
		Low 50,000	High 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 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 10.7). 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 10.7). Obviously, if costs were higher, income would be less.

In the EcoInvestPub model revenue varied dependent on the amount of land participating in the program (all forest land in Maryland, Table 10.2, or only privately owned forest land, Table 10.3) and by the eco-price used to convert the emergy value of ecosystem services to dollars. Revenue for forest landowners was $26 million for the weighted average eco-price, 125 for the commodity eco-price and $584 million for the service specific eco-price. When only privately owned forest lands are considered revenue was $10,467,507 for the weighted average eco-price, $134,959,760 for commodity eco-price and $558,093,541 for the service specific eco-price.

Table 10.7 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 50,000	High 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 10.1). Six scenarios were used to explore what the range of public value would be. Each scenario assumed 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 10.2). 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 10.8). 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. Public value is dependent on the amount of land area enrolled in the EIC, so in EcoInvestPub it is either $3.5 billion in the private forest land only scenario or $4.3 billion in the all forest lands of Maryland scenario.

When placed in the context of the State of Maryland as a whole the EIC would represent a relatively minor investment, between 0.5%-2.3% of the state budget and only 0.06%-0.26% of the Gross State Product.

Table 10.8 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

Table 10.9 Placing the EIC in the Context of State Monetary Flow and State Government Budget

	Percent of MD Gross State Product	**Percent of MD State Budget**
Commodity weighted avg	0.06%	0.56%
Weighted avg eco-price	0.09%	0.83%
Service Specific eco-price	0.26%	2.32%
public emprice	1.75%	15.85%

10.3 Discussion of EcoInvestCorp and EcoInvestPub

The current study did not inquire as to how many consumers of ecosystem services would be willing to donate to the EIC. However, for EcoInvestCorp I assumed that 4% of Marylanders could be persuaded into donating $6 per month. This would be approximately 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, using the commodity eco-price.

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 forest land in MD is owned as tracts of less than 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 land owners. Certainly, if a land owner 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 possibly through an easement.

Participation of 250,000 consumers and 50,000 ha (5% of forested land) would require donation of $6 per month. 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 donors from participating without a tax deduction.

When the EIC is considered to function as a governmentally mandated payment for ecosystem services program, *EcoInvestPub*, the people of Maryland would be asked to pay between $200 and $850 million dollars to forest land stewards and potentially, for the state to invest in conservation/restoration of forest lands. While this would be a significant investment for the people of Maryland (<1% of total state governmental budget and <.01% of Gross State Product, see table 10.9) it would go a long way towards preserving ecosystem services for future and provide a blueprint for other state governments to follow in enacting PES programs. It should be noted that I did not take property tax into account in this model, which would affect the amount of net revenue to the forest landowner. The EIC could treat property tax in a number of different ways: property tax could be waived, the tax could be subtracted from the EIC payment, or the tax could be used for restoration/conservation/preservation of forest lands. The *EcoInvestCorp/Pub* models revenue streams for one year and does not consider if the participating landowners would be required to enter into a stewardship agreement for an agreed upon amount of time. While the *EcoInvestPub* model assumes all forest lands would be enrolled in the program this would not necessarily be the case, particularly if the program were to require forest landowners to enter into an agreement to manage their land in a certain way over a given amount of time. A potential revenue source for the EIC would be private capital from firms like GreenVest (www.greenvestus.com) or private investors interested in contributing to sustainable actions.

10.4 Designing and Implementing the Ecosystem Investment Corporation

The ecosystem investment corporation will reconcile investment by society in perpetuating ecosystem services with the value being provided by forests in Maryland. However, there are many different forms the Ecological Investment Corporation (EIC) could take in accomplishing this. Several options for how the EIC could be organized, revenue generation and how funds could be invested are presented. The following are options for generating revenue for the EIC.

1. The EIC is funded by a progressive income tax. The tax would scale to match the total amount of ecosystem services provided from forests, feasibly for the previous year. A weakness to this method is that it would likely be politically unfavorable.

2. An additional land transfer tax or a replacement for current land transfer taxes that fund land conservation programs in Maryland. The tax would increase if the land being transferred was forest being sold for development. Again, rate of taxation should be determined by the rate that matches the value of ecosystem services provided. Weaknesses are that this method may not be politically favorable and

revenue is only generated when land is sold, likely for development, the very trend the EIC program seeks to slow.

3. A tax on high impact goods, such as gasoline, fertilizers, and fuel 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 ecosystem services (ES) provided by forests. In addition, this tax could potentially have a disproportionate cost for lower income individuals and small businesses.

4. An ecosystem services market. The question of how ecosystem services can be “bundled” so that one market can trade all ES provided has been an important one within the ES research and practitioner community. Valuing ES using emergy provides an answer for this question. All ES are in the same units so can be grouped together (bundled) and sold as ES credits. Either a cap on consumption of ecosystem services could be implemented or it could be required that an entity that causes a decrease in ecosystem services would have to purchase a correspondent value in ES credits. It would likely be difficult to implement on the level of the individual consumer, except perhaps for land purchasing/developing. A positive for this option is that markets are generally politically favorable, although installing the legislation necessary for them to function properly is less so.

5. A voluntary contribution system is an option to generate a limited amount of revenue for the EIC. This could be in the form of a market, similar to the Bay Bank or could be an option on state income tax returns or during land transfers. Information on the value of ES provided in Maryland would be provided and the consumer would have the option to donate. This would be the easiest option to enact politically but would very likely generate the least revenue and have the least effect on perpetuating the provision of ES from the forests of Maryland.

Once revenue is generated it would then be divided between the forest landowners of Maryland and forest preservation and restoration investment. Forest landowners would need to enroll in the EIC, necessitating some cost. It is imperative to keep the cost of enrollment at a minimum as previous literature

(Rueben, 2010) has shown that cost of enrollment is the most significant deterrent for small landowners. Maryland has a very high percentage of small forest landowners, with over 80% of forest landowners owning less than 10 acres, totaling 20% of the forest land in Maryland. These landowners are much less likely to participate in a program like the EIC (Fletcher, 2009) so a low barrier of entry is essential to getting at least a portion of small parcel landowners to enroll.

If the EIC program is able to generate revenue commensurate with the value of ES, provided the proportion of revenue distributed to landowners, preservation and restoration could be determined based on the following priorities— distribution of appropriate funds to enrolled forest landowners, funding applicable restoration projects, and lastly purchasing priority lands to be preserved. Providing incentive for landowners to keep their land in forest is the primary goal of the EIC with promoting Forest ES through restoration and preservation being secondary. A major concern of forest landowners in Maryland is property taxes (NWOS, 2006), applying the ES benefit in the form of a tax break would likely be favorable with landowners.

The EIC has the potential to dramatically change not only the ability of forest landowners to be economically viable but the perception of ecosystem services in 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 is 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 the mechanism has the potential to strengthen the long term sustainability for the people and forests of Maryland.

10.5 Tool for Land Steward to use to estimate forest value in EIC

There are three proposed options for tools to be used by land stewards for evaluating ecosystem provision by forest lands. They are as follows:

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, limiting 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.

3. **Landowner Worksheet Assessment (LWA):** Table 11.1 is an example worksheet that could be accessed online by forest landowners. It is proposed that the following inputs; location of the land, forest acreage, the dominant forest type, and the average age range of the forest, and the best management practices currently being implemented, can be used to obtain an accurate estimate of the ecosystem services being provided by the forest. Currently the worksheet only has the functionality of returning the provision of ecosystem services for an average acre of forest land in Maryland but expanding the functionality is certainly possible and part of the future work to be done in this project.

Table 11.1 Ecosystem Investment Corporation Enrollment Worksheet

Location:	
Number of Acres:	1
Dominant Species:	
Age Range:	
Best Management Practices	

		Ecosystem Service	**$ per Ton**	**Eco-Price emergy per $**	**Dollar Value of Land**
	1	Carbon Sequestration	$2.92	1.82E+14	$1.8
Input		Area, Dominant Species, Age			
	2	Stormwater mitigation	$0.08	7.26E+12	$131.6
Input		Location, Area			
	3	Groundwater recharge	$0.90	7.26E+12	$66.2
Input		Location, Area			
	4	Nitrogen Uptake	$0.0002	7.26E+12	$2.5
Input		Area			
	5	Phosphorus Uptake	$0.0012	7.26E+12	$11.6
Input		Area			
	6	Soil Building	$26.19	8.01E+13	$2.9
Input		Area, Dominant Species, Age			
	7	Erosion Prevention	$20.98	8.01E+13	$28.0
Input		Area			
	8	CO Removal	$63.56	8.01E+13	$0.10
	9	NO2 Removal	$362.27	8.01E+13	$2.70
	10	O3 Removal	$3,301.61	8.01E+13	$57.59
	11	SO2 Removal	$2,785.88	8.01E+13	$11.59
	12	PM10 Removal	$1,079.04	8.01E+13	$8.84
Input		Area			
	13	Pollination by Wild Insects	$786.64	1.30E+13	$5.7
	14	Biodiversity	-	2.23E+13	$34.7
Input		Area, surrounding land use			
		Total $			$331.1

Chapter 11: Synthesis Discussion

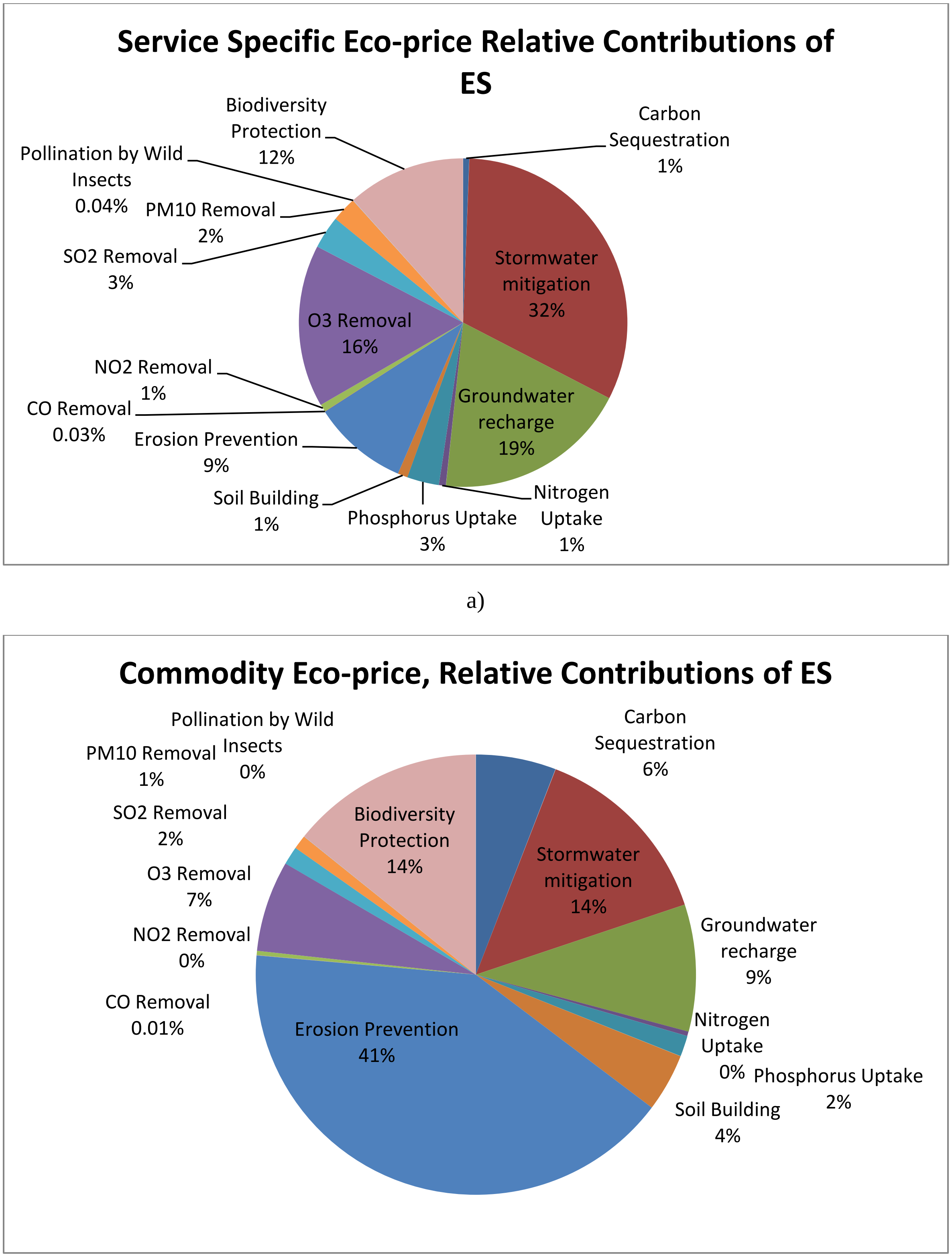
11.1 What is the “right” eco-price?

This research presents novel methodology for valuing ecosystem services from forest lands, using environmental accounting of the emergy flows from forest lands compared to typical suburban conditions in Maryland; valuation consistent with the ecological debt concept. This method produces an estimate of the additional ecosystem services provided by forest lands vs. their most likely alternative land-use. The question of the best way to convert the emergy value of ecosystem services to dollars still remains, but upon completion of this study the commodity eco-price and specific service price seem to be more valid than simply taking a weighted average. When weighting the eco-prices by emergy flow the ecosystem services with high emergy flow dominates the averaged eco-price, these tended to be higher eco-prices and thus a high average eco-price was generated. The commodity eco-price was also a weighted average but the eco-price values tended to be more similar and a more representative averaged eco-price was generated.

Both the commodity eco-price and service specific eco-price have certain advantages. The commodity eco-price relies on the rational that ecosystem services function much in the same way as primary inputs to the economy, forming the base of a functioning society. The commodity eco-price averages eight primary inputs and in the future more commodities considered to be primary economic inputs could be added to improve the estimate. The fair payment value for forest ecosystem services in Maryland, when they are valued like primary inputs to the economy, is $268 million per year.

The service specific eco-price attempts to assess a willingness to pay specific to each ecosystem service, rather than a weighted average. Between two to five eco-prices were average for each ecosystem service, and the average ES eco-price was used to convert the emergy of the ecosystem service to dollars. Society values individual ecosystem services at different rates and the service specific eco-price attempts to capture this. The area where the differing rates are most evident is hydrologic and soil ecosystem services. Hydrologic ecosystem services have an average emergy value but a lower average eco-price (lower eco-price equates to more money per sej of emergy) while soil ecosystem services have a high emergy value but a lower than average eco-price (society does not highly value soil). The service specific ecosystem service captures this variability; hydrologic ecosystem services comprise 51% of the total and soil ecosystem services are only 10% using this method (see Fig. 11.1). The other two methods that use weighted averages value hydrologic ecosystem services at 21% and soil ecosystem services at 44% of the total ecosystem service yearly value (see fig. 11.1).

The increased specificity of the specific eco-price does have a draw back in that because there are fewer eco-prices being averaged an outlier that may be an error has a greater affect on the end value. The total ecosystem service value generated using the service specific eco-price was $744 million dollars per year, more than $400 million more than the value generated using the commodity eco-price. The model *EcoInvestPub* shows how monetary flows to forest landowners and the state would change dependent on the eco-price chosen. It stands to reason that there would be trade-offs between choosing between lower and higher investment in the ecosystem. Higher values provide more incentive for preservation and restoration of ecosystems but a program demanding a greater investment would be more difficult to enact. The service specific eco-price should be further refined, through calculating more eco-prices and identification of outliers (e.g. eco-prices that deviate several orders of magnitude from the mean, especially within a service specific eco-price), to increase the accuracy of the estimated willingness to pay for an ecosystem service. The commodity eco-price is consistent with the logic that ecosystem services should be valued similarly to primary inputs to the economy and yields a value that may be more feasible for action in Maryland.



a)

b)

Figure 11.1 Relative contribution to the total value made by each Ecosystem Service using the (a) service specific and (b) commodity eco-prices

11.2 Connections between the EIC and other Conservation Programs

An important implication of enacting the EIC in Maryland is the potential effect it would have on the logging industry or forest landowners that sell timber. Firstly, EIC are not meant to replace income from timber, but to supplement it. The EIC would encourage sustainable rotations and best management practices— if the forest is cut in such a way where soil/water functions remain high the EIC payment would decrease less. If a forest was shown to be a net producer of erosion the ecosystem service payment would be zero. Payments for some ecosystem services, such as carbon sequestration, would be higher for younger, more rapid growing forests.

A number of tax incentive and cost share programs for forest stewards exist at both the state and federal level. The degree to which the EIC could replace or substitute for these programs would be dependent on whether it was a voluntary or compulsory program. If voluntary, it would exist as a complementary mechanism for the encouragement of forest conservation without replacing existing programs. If compulsory, payment for ecosystem services could be integrated into the tax incentive programs. Requirements for enrollment in the tax programs, like having a forest stewardship plan and a minimum enrollment period (15 years in the case of FCMA and Woodland Assessment) should be necessary to participate in the EIC program. Recommended changes to the existing structure of these programs would be to eliminate the upfront cost of enrollment and decrease the minimum acreage from 5 to 1 acres of contiguous forest land to minimize the barrier to entry. Currently, the tax rate in Maryland for woodlands is $50 per acre if not enrolled in FCMA or WA. This study suggests the fair payment for forest ES be $71, $107 or $298 per acre. Therefore, net payment to the landowner would be $21, $57 or $248 per acre after taxes. It would stand to reason that increasing the rate of payment would create higher incentive both for enrollment in the EIC and conservation of forest land. Enrollment in the EIC should not restrict forest landowners from participating in eligible cost share programs, such as CREP, WIP, or EQIP.

There are certainly implications of the enaction of an EIC (either public or private) for the state of Maryland that are not revealed in the models I have proposed. It is difficult to predict how people would respond to the introduction of the EIC, in either its voluntary contribution/investment form or the government program alternative. Volunteer PES (Payment for Ecosystem Services) markets, like the Chicago Carbon Exchange, have been proposed in the past and were not successful. Others show signs of limited success but have some major flaws, like emissions trading and the clean development mechanism under the Kyoto Protocol, that were not predicted prior to implementation. When setting up the EIC care must be taken to ensure that the barrier of entry is low enough that a small landowner will be interested in participating. Having the option to apply payments to property tax may help with this, as surveys have shown that property taxes are a chief concern among small land owners (Rueben, 2010). Any PES program should be set up to ensure that the tax is progressive as those of higher income have a larger impact on the environment.

11.2.1 Implications of Maryland's Ecological Debt

As shown in chapter 6 of this dissertation, Maryland is carrying a tremendous debt to the ecological system. While this is the first instance of using environmental accounting to quantify ecological debt, it can be surmised that Maryland is on the high end in terms of ecological debt by US State. Maryland has higher wetland and forest loss than the average State in the US and a higher population density, all indicative of a high ecological debt. While total recompense is not possible in the current socio-economic system, it is possible to "pay down the debt" by investing in conservation and restoration of natural systems. There is a "minimum ecological debt" that should be the goal of preservation/restoration efforts. The desired minimum ecological debt could be established by ascertaining the lowest support area necessary for the population of Maryland to be completely reliant on renewable emergy. This goal could also be progressed towards through a reduction in population or a reduction in emergy use per person, lessening the burden on the environment. It is important to note that the implementation of a PES program in Maryland would not necessarily reduce ecological debt, as ecosystem services represent the "interest" on the debt. Investment in building natural capital is necessary to reduce debt, which is a recommended component of the EIC. The rate that ecological debt should be paid down in order to meet sustainability goals should be the topic of future research. Ecological debt would be a suitable metric to monitor the progress towards minimizing human impact on the environment. It is an appropriate companion metric to the Genuine Progress Indicator (GPI) a tool of ecological economics, already calculated for Maryland by the Maryland Department of Natural Resources (http://www.green.maryland.gov/mdgpi/).

11.3 Comparison of Ecosystem Service Values with Previous Estimates

This research is the first case of ecosystem services being evaluated based on the difference between forest and most likely alternative land-use and the first instance of the eco-price being used to convert emergy values to dollars. There has not been a comprehensive study of forest ecosystem services with the intention of asking people to pay the values generated from either the biophysical or ecological economic disciplines. Thus, there are not direct comparisons to be made. Perhaps the most appropriate comparison of my results would be to previous ecological economic studies where price for ecosystem services is suggested. However, ecological economic evaluations of multiple ecosystem services are uncommon.

When this research is compared to my master's research (Campbell, 2012) which evaluated the ecosystem services from USFS lands, the results are quite different. For comparison purposes I consider only supporting, regulating and water provision ecosystem services from the USFS study. Campbell (2012) found that USFS lands provide $544 per ha per year (using the emdollar ratio for the US of 1.9E12 sej/$) while this dissertation found a value over $5000 per ha per year of public value. The difference in emdollar ratio used (1.9E12 sej/$ vs. 2.82E12 sej/$) would make the USFS estimate higher given the same amount of emergy. Fewer ecosystem services are considered in the prior study (water provision, gross primary production, clean air, carbon sequestration and clean water) compared to this study (erosion, soil building, groundwater promotion, pollination, and biodiversity are additionally considered) so a lower value is expected, but even without these services the value for MD forest ES is $1345 per ha per year. This dissertation research was a more detailed study of both the biophysical and emergy aspects of the ecosystem services so it is likely this research captured more complexity and function of the forest than the previous study, leading to a better understanding of ecosystem provision and a higher estimate for value.

Costanza et al (1997) consider the global value of many ecosystem services including provisioning, regulating, supporting and cultural ES's and estimate the total value of ES's from temperate/boreal forests to be $302 per ha per year. Many ecosystem services I considered are not included in this estimate (the water ES, biodiversity, air pollutant removal, erosion prevention), others are included that I did not consider (waste treatment, biological control, food production, recreation, cultural), and some are included in both but likely valued differently (climate control vs. carbon sequestration). Interestingly, Costanza et al value nutrient cycling as the highest ES for tropical forests ($922 per ha per yr) but do not value it for temperate forests. The $302 per ha per yr is very close to the median value I suggest as a fair payment price ($268 per ha per yr) although the ES's valued and methodology used were very different.

A recent study by Wu (2010) of the ecosystem services, goods, and natural capital of the forests surrounding Beijing (totaling 1.1 million ha, very similar to area of the forests of Maryland, 1.01 million ha) valued water conservation, agricultural protection, carbon sequestration and oxygen supply, biodiversity conservation, air purification/temperature regulation, soil protection, forest ecotourism, job opportunities, products of economic forests, and science and education at $4791 per ha per year. Unfortunately the individual ecosystem service values are not presented for a direct comparison to be made and this study includes many different ES than considered in my research but it is compelling that they came up with a similar number. Many of the ES they consider are made up of human work (education, jobs) so it makes sense the value generated is close to what I found for the public value (a lower emdollar ratio would be used to convert these ES's to dollars).

11.4 Limitations to the Study

It is important to have high resolution data for the models because of the variability in ecosystem services, dependent on change in climatic factors, geology, elevation, and degree of anthropogenic influence. I attempted to partially capture this by analyzing some ecosystem services by physiographic region but a physiographic region is a coarse approximation of traits. While our numbers for the state of Maryland are likely reasonably accurate, it would be difficult to assign ES values to an individual plot of land with a high degree of certainty without additional research and data collection. Previous studies have shown that forest fragmentation has a significant effect on many forest ecosystem functions, and consequently ecosystem service provision (Kupfer, 2006, Wulder et al 2009, Fisher et al, 2006, Aerts and Honney, 2011, Foley et al, 2007). For example, forest biodiversity has been shown to increase as parcel size and degree of connectedness to other parcels increases (Fischer et al, 2006). The location of a forest within a watershed and the surrounding land-use is also influential in the ecosystem function of a forest (Lowrance, 1997, Defries et al, 2004). Because forest ecosystem services in Maryland were considered primarily at the level of the state as a whole I could not consider the effect that surrounding land-use or forest fragmentation has on the provision of ecosystem services. These factors should be considered in future research (see section 11.6 Next Steps).

A limitation to this study is simply the unpredictable nature of human behavior. Meaning, the valuation of ecosystem services is not constant from individual to individual, instance to instance and ecosystem service to ecosystem service. This limitation is evident in the calculation of the eco-price, although an attempt to limit its effect is made through averaging the eco-prices, and in the *EcoInvestCorp* and *Pub* models. I know neither if the public has a demand for the preservation of ecosystem services or the rate at which they would be willing to pay for them. Previous polling studies have shown that simply asking people what they are willing to pay is not sufficient; you do not really know what behavior a group of people will exhibit until they actually are required to make a utility choice with their dollar. I can predict the feasibility of the EIC but will not truly know the societal response until the program is begun in Maryland. An example of this is the Maryland Nutrient Trading Program which is yet to have a nonpoint source nutrient trade consummated although it was predicted to succeed and makes economic sense for some potential participants (http://nutrientnet.mdnutrienttrading.com/trade/projects.app?view=implemented).

11.4.1 Uncertainty Calculation in Emergy Analysis

A limitation to this study is that I was not able to supply an uncertainty measure for our data and consequently, the estimates of ecosystem service value. Calculation of uncertainty in environmental accounting is still developing and a suitable method was not available, given our data limitations (Ingwerson, 2011). Ingwerson (2011) proposes a method for calculating uncertainty in emergy analysis but this method is both time and data intensive. When assessing uncertainty in an emergy evaluation it is necessary to quantify the uncertainty for the input data as well as the transformities. This can be very difficult if estimates of input data are sparse or if examples of previous transformity calculations are rare or do not exist. Hudson's (unpublished) work on uncertainty reveals that the most importance should be placed on estimating uncertainty for the largest emergy flows and that uncertainty of small emergy flows is not significant on total system emergy flow. Her proposed method may make future incorporation of uncertainty into emergy analysis more feasible as currently uncertainty analysis for emergy research is almost never done (Hau and Bakshi, 2004).

A potential limitation were the EIC to be enacted is that there likely would not be time/money available for monitoring of each forest stand so the management plan and models, based on measured data, would be used to determine the change in ecosystem service flows rather than direct measurement. Again, this would bring into question the level of uncertainty associated with the model.

11.5 Conclusions

The overarching goal of this study was to design a method for assessing the value that forests provide to the society of Maryland and returning a commensurate value to be invested in perpetuating these services. This method uses values for ecosystem services determined using environmental accounting to suggest prices for the consumers of ecosystem services (the public of Maryland) to pay to a intermediary organization that would then reinvest in forest landowners or the forest itself. Thus, a positive feedback mechanism previously absent in the current ecosystem service production-consumption paradigm is provided. The following goals and resulting conclusions were achieved through this research—

- The emergy baseline for the State of Maryland was quantified, placing Maryland forests into the context of the overall system
    - Maryland forest renewable emergy comprises 0.2% of the total emergy throughput in Maryland in a given year.
    - The emergy of ecosystem services from forests would make up 2.5% of the total emergy throughput in Maryland.
- The emergy value of soil generation, carbon sequestration, air pollutant removal, stormwater runoff prevention, groundwater recharge promotion, water quality improvement, pollination and biodiversity protection from the forests of Maryland was successfully.
    - The value of ecosystem services from the forests of Maryland totaled $5 billion per year of public value.
    - The highest individual ecosystem service was erosion prevention, totaling over $2 billion of public value followed by biodiversity protection at $730 million, stormwater mitigation at $717 million and groundwater recharge at $479 million.
- The emergy value of MD forest ecosystem services was converted to dollars using the novel method for determining the appropriate emergy to dollar ratio for ecosystem service s that I term the “eco-price” (see chapter 4).

    - Depending on the eco-price used it was suggested that the people of Maryland pay between 33 and 5 times less for ecosystem services than the public value provided.
- The EcoInvest model was developed to simulate the potential impact of the implementation of both a private and publically run Ecosystem Investment Corporation/Program. This model found—
    - If only 4% of Marylanders voluntarily invest $7 per month ($84/yr, our median estimate) in the EIC it would be economically feasible, given the participation of 7% of privately owned forest lands.
    - If the EIC was a public program the average Maryland citizen would be responsible for $3-$12 per month, or $36-$144 per year for the program to be successful in its goal of returning commensurate value for ecosystem services provided by all of Maryland's forests.
- The ecological debt carried by Maryland was determined.
    - Maryland currently has an ecological debt of $17.5 billion when our median eco-price was used to convert emergy to dollars and $316 billion if the emdollar ratio for the state of Maryland is used.
    - If the reduction of ecological debt, through restoration or conservation, is part of the overall goal for the EIC or a similar PES program it would be necessary to allocate a portion of the collected revenue toward the building of natural capital.
- The EIC would provide more financial compensation to forest landowners than is currently available through existing programs.
    - This would provide a greater incentive for landowners to implement BMP's and manage their land in an ecologically sustainable way.

Currently there is interest from several states, federal government and non-profit organizations (www.thebaybank.org, USDA Farm Bill, 2008, www.willamettepartnership.org, http://www.oregon.gov/OWEB/ecosystem_services) in creating markets for ecosystem services. However, the current dialogue lacks a consistent metric for both measuring the service and valuing ecosystem services in dollars. Emergy can both measure the service and provide a method to convert the measurement to dollars. This study provides the methodology for both valuing ecosystem services and developing a sustainable relationship between the land that provides ecosystem services and consumers.

This research is novel in the fields of environmental accounting and ecosystem services. While ecosystem services have been addressed in the emergy literature (Odum and Odum, 2002, Campbell, 2009, Pulselli, 2011) a consistent methodology had not been previously developed. This research is an example of how environmental accounting can be used to inform policy for the mutual benefit of humanity and the environment. While many details remain in how the EIC would ultimately be set up and function in Maryland the EIC has the potential to enhance the long term sustainability of ecosystem services and the benefits they provide for the people of Maryland.

11.6 Next Steps

To operationalize the EIC I suggest a pilot test whereby a region of Maryland 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 (22%) of the forest land in Maryland. The change in value and function of ecosystem services spatially would be further explored. An acre of forest in the urban/suburban Montgomery County has different functions and associated ecosystem services than an acre of forest in rural Allegany County. The effect of forest patch size and degree of connectedness on ecosystem service provision would be analyzed as part of future work and would be achievable at a finer scale. This study would be organized around studying how forest function changes over a rural-urban gradient and assessing how this affects the value of ecosystem services to the local population vs. society as a whole.

The EIC needs to be marketed to both consumers and land stewards. Consumers could be enticed to donate once they become knowledgeable of how little they can contribute to be participants and 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. It is likely that a pilot program such as this would need to be established and demonstrated to be successful before the state as a whole would consider adopting a payment for ecosystem services program.

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.

Ideally, a large scale effort would be made to further characterize the ecosystems and their associated services in Maryland. The monitoring of hydrology, forest production, biodiversity information, soil dynamics, and air pollution in the state should either be established or expanded as the values I have presented are either generalized over the entire state or over a physiographic region. Increasing the resolution of data in the state would allow more accurate values to be assigned for ecosystem services from specific land parcels.

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 Energy (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	2.00 E-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 unit= 1470 (Odum, 1996)

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(_____k g/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+03 J/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

			1.9924 E+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 River	1.18E+08	96	4.73	5.58E+14	Station: 01491000
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
Youghiogheny 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	An Overview of Maryland Wetlands and Water Resources, Maryland Department of Environment, 2000
Rainfall =	1.10	m	
Avg. Elev =	182.88	m	Elevations obtained from USGS
Energy(J) =	1.28E+16	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
Energy(J) =	7.80E+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
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

elevation = 320.04 m

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

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

elevation = 655.32 m

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

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 m^3/yr**	**Height In m**	**Height out m**	**Energy J/yr**	USGS Water Resources Data Maryland and 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 2000

g/metric ton = 1.00E+06 g/ton

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**		MT	
	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 http://minerals.usgs.gov/minerals/pubs/state/md.html

g/metric ton = 1.00E+06 g/ton

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	*1.8374E+20*

			.8674	
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-

Production =	108790	pounds/yr	$ value from Manufacturing survey 2000 and tons calculated from 1997 commodity flow survey.
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.

2 NOAA's Marine Fisheries Services Report Data for 2000

4 **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

MEAT,
2 **DAIRY,**
5 **EGGS**

Data on from Maryland Agricultural Statistic for 2000

Porduct	***g/yr***	***j/yr***	***Emergy/Unit***	***sej/yr***
Poulty	5.77E+09	5.72 10E		

		+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

Appendix 2. Ecoprices

Footnotes for Table 9.1- Eco-priceEco-prices for Ecosystem Services

	Carbon Sequestration Eco-priceEco-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	
	emergy=	1.86E+12	sej	Avg. for N forms from from D.E. Campbell, 2009
	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	Soi 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	8.2	mill tons

	SO2			
	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	Polination 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 3.2 Maryland Commodities

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

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/$	

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/$	

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	$/bdft	
solar transformity	50000	sej/J	This study
Eco-price Timber	4.82E+12	sej/$	

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/$	

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/$	

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/$	

Appendix 3. Maryland Ecosystem Services

Footnotes for Table 10.1- 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			
5	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
6	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			
8	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
9	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	
9	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		
10	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				
11	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	
12	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	
13	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	
14	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	
15	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	
16	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	

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	$/yr	MDE, 2009
Urban Area of MD	2.80E+09	m^2	
Air Shed Height	1000	m of ozone formation	Fatogoma, 1996
Avg Days Exceeding Air Qual. Stds (2000-2010)	22.7	days/yr	MDE, 2009
Avg Ozone Concentration	0.32	mg/m^3	MDE,2009
Ozone on Exceeding days=	Urban Area*Ht of Air Shed*O3 Concentration*.001 g/mg		
=	9.01E+08	g O3	
specific emergy	6.23E+10	sej/g O3	This document
emergy on exceeding day	5.62E+19	sej/day	
emergy per year	1.27E+21	sej/yr	
Eco-price of PM10			
Avg concentration per day	1.60E-05	g m^3	MDE, 2009
PM in MD=	Urban Area*Ht of Air Shed*PM10 Concentration/day*365 days/yr		
=	1.64E+10	g yr	
specific emergy	2.04E+10	sej g-1	This research
emergy per year	3.33E+20	sej yr	
eco-price for O3 and PM10 in MD	3.88E+12	sej/$	

Appendix 5: Biodiversity

Table A5.1. Southeastern Conifer Forest- Long leaf pine @ 100 years from afforestation

Note	Item	Units	Quantity	Unit Emergy Values [1]. (sej/unit)	Solar Emergy ($x10^{12}$sej)	EmDollars ($x10^3$ Em$)
RENEWABLE RESOURCES:						
1	Sunlight	J	4.90E+13	1.00E+00	49.0	0.0
2	Rain Chemical Potential	J	6.33E+10	3.10E+04	1963.3	2.0
3	Transpiration	J	4.78E+10	5.94E+04	2837.5	2.8
4	Rain Geopotential	J	0.00E+00	4.70E+04	0.0	0.0
5	Wind, Kinetic	J	4.73E+07	2.45E+03	0.1	0.0
6	Earth Cycle	J	1.01E+10	1.20E+04	121.1	0.1
EMERGY STORAGES						
7	Soil Organic Matter	J	2.30E+12	1.43E+05	328528	328.5
8	Forest Biomass	J	7.63E+11	3.62E+04	27600	27.6
9	Standing/Dead Biomass	J	6.86E+10	2.52E+04	1728	1.7
				sum	357855	

Footnotes

RENEWABLE RESOURCES:

1 Solar Insolation — Source

Land Area 10000 m^2

Insolation 4.55 kwh/m^2/day — Stackhouse 2011

= (kwh)*(J/kwh)*(days/yr)

= 5978700000

Albedo 1.80E-01 (% given as a decimal)

Energy = (area)*(avg insolation)*(1-albedo)

= 4.90E+13 J

Transformity 1.00E+00 sej/J — Odum et.al, (2000)

2 Rain

Chemical Potential

	Land Area	1.00E+04	m^2	
	Rain	1.282	m/yr	Stackhouse 2011
	Total Volume Rain	1.28E+04	m^3	
	Energy=	(volume)*(1000kg/m^3)*(4940J/kg)		
	=	6.33E+10	J/yr	
	Transformity	3.10E+04	sej/J	Odum et.al, (2000)
3	Transpiration	9.67E-01	m/m^2/yr	Gholz and Clark, 2000
		9.67E+03	m3	
	Energy=	(Volume)*(1000Kg/m^3)*(4940J/kg)		
	=	4.78E+10	J/yr	
	Transformity	5.94E+04	sej/J	Modeled
4	Rain Geopotential			
	Runoff		m/m^2/yr	modeled
	Mean Elevation Change	0.00E+00	m	
	Land Area	1.00E+04	m^2	
	Energy =	(area)(rainfall)(avg change in elevation)(density)(gravity)		
	=	0.00E+00	J	
	Transformity	4.70E+04	sej/J	Odum et.al, (2000)
5	Wind, Kinetic			
	Area	1.00E+04		
	air density	1.30E+00	kg/m^3	
	avg annual wind velocity	4.02E-01	mps @ 50 m	Stackhouse, 2011
	Geostrophic wind	6.70E-01	observed winds are about 0.6 of geostrophic wind	
	Drag Coeff.	2.00E-03		
	Energy=	(area)*(density)*(dragcoef)*(Geos-grndVel)^3*(31500000sec/yr)		
	=	4.73E+07		
	Transformity	2.45E+03	sej/J	Odum (2000)
9	Earth Cycle			
	Heat Flow	3.20E+01	miliwatts/m^2	IHFC, 2005
	area	1.00E+04	m^2	
	energy=	(miliwatts/m^2)*(area*sec/yr)		
		1.01E+06	J/m^2	
	energy=	1.01E+10	J/yr	
	Transformity	1.13E+04	sej/J	Odum (2000)
Emergy Storages				
10	Soil OM	109.73	mt	COLE, 2011

mass OM= 1.10E+08 g
Energy= massOM* 5.0 kcal/g of OM * 4186 j/kcal
2.30E+12 J
Transformity 1.43E+05 sej/J Cohen, 2007

11 Tree and Shrub Biomass 52.05 mt of C
= 5.21E+07 g
3.50E+00 Kcal/g of Biomass
energy= g*3.5kcal/g*4186J/kcal
= 7.63E+11 J
Transformity 3.62E+04 sej/J

12 Standing and Down Dead Trees 4.68 mt of C
= 4.68E+06 g
3.50E+00 Kcal/g of Biomass
energy= g*3.5kcal/g*4186J/kcal
= 6.86E+10 J
Transformity 2.52E+04 sej/J Tilley, 2002

Table A.5.2. Mid-Atlantic Coastal Forest

Note	Item	Units	Quantity	Unit Emergy Values [1]. (sej/unit)	Solar Emergy ($x10^{12}$sej)	EmDollars ($x10^3$ Em$)
RENEWABLE RESOURCES:						
1	Sunlight	J	4.15E+13	1.00E+00	41.5	0.0
2	Rain Chemical Potential	J	5.27E+10	3.10E+04	1633.7	1.6
3	Transpiration	J	3.89E+10	5.94E+04	2312.6	2.3
4	Rain Geopotential	J	0.00E+00	4.70E+04	0.0	0.0
5	Wind, Kinetic	J	9.38E+10	2.45E+03	229.7	0.2
6	Earth Cycle	J	1.74E+10	1.20E+04	208.4	0.2
EMERGY STORAGES						
7	Soil Organic Matter	J	1.11E+12	1.43E+05	158171	158.2
8	Forest Biomass	J	1.80E+12	3.62E+04	65216	65.2
9	Standing/Dead Biomass	J	1.51E+11	2.52E+04	3807	3.8
				sum	227193	

Footnotes

RENEWABLE RESOURCES:

1	Solar Insolation			Source
	Land Area	10000	m^2	
	Insolation	3.85	kwh/m^2/day	Stackhouse, 2011
	=	(kwh)*(J/kwh)*(days/yr)		
	=	5.06E+09		
	Albedo	1.80E-01	(% given as a decimal)	
	Energy =	(area)*(avg insolation)*(1-albedo)		
	=	4.15E+13	J	
	Transformity	1.00E+00	sej/J	Odum et.al, (2000)
2	Rain			
	Chemical Potential			
	Land Area	1.00E+04	m^2	
	Rain	1.0668	m/yr	Stackhouse, 2011
	Total Volume Rain	1.07E+04	m^3	
	Energy=	(volume)*(1000kg/m^3)*(4940J/kg)		
	=	5.27E+10	J/yr	
	Transformity	3.10E+04	sej/J	Odum et.al, (2000)
3	Transpiration	0.79	m/yr	
		7.88E+03	m3	
	Energy=	(Volume)*(1000Kg/m^3)*(4940J/kg)		
	=	3.89E+10	J/yr	
	Transformity	5.94E+04	sej/J	Modeled
4	Rain Geopotential			
	Runoff	0.30	m/m^2/yr	modeled
	Mean Elevation Change	0.00E+00	m	
	Land Area	1.00E+04	m^2	
	Energy =	(area)(rainfall)(avg change in elevation)(density)(gravity)		
	=	0.00E+00	J	
	Transformity	4.70E+04	sej/J	Odum et.al, (2000)
5	Wind, Kinetic			
	Area	1.00E+04		
	air density	1.30E+00	kg/m^3	
	avg annual wind velocity	5.05E+00	mps @ 50 m	Stackhouse, 2011
	Geostrophic wind	8.42E+00	observed winds are about 0.6 of geostrophic wind	
	Drag Coeff.	2.00E-03		
	Energy=	(area)*(density)*(dragcoef)*(Geos-grndVel)^3*(31500000sec/yr)		

	=	9.38E+10		
	Transformity	2.45E+03	sej/J	Odum (2000)
9	Earth Cycle			
	Heat Flow	5.51E+01	miliwatts/m^2	IHFC, 2005
	area	1.00E+04	m^2	
	energy=	(miliwatts/m^2)*(area*sec/yr)		
		1.74E+06	J/m^2	
	energy=	1.74E+10	J/yr	
	Transformity	1.13E+04	sej/J	Odum (2000)
Emergy Storages				
10	Soil OM	52.83	mt	COLE, 2011
	mass OM=	5.28E+07	g	
	Energy=	massOM* 5.0 kcal/g of OM * 4186 j/kcal		
		1.11E+12	J	
	Transformity	1.43E+05	sej/J	Cohen, 2007
11	Tree and Shrub Biomass	122.99	mt of C	
	=	1.23E+08	g	
		3.50E+00	Kcal/g of Biomass	
	energy=	g*3.5kcal/g*4186J/kcal		
	=	1.80E+12	J	
	Transformity	3.62E+04	sej/J	
12	Standing and Down Dead Trees	10.31	mt of C	
	=	1.03E+07	g	
		3.50E+00	Kcal/g of Biomass	
	energy=	g*3.5kcal/g*4186J/kcal		
	=	1.51E+11	J	
	Transformity	2.52E+04	sej/J	Tilley, 2002

Table A.5.3. Northeastern Coastal Forest-Sugar maple/beech/yellow birch @ 100 yrs

Note	Item	Units	Quantity	Unit Emergy Values [1]. (sej/unit)	Solar Emergy ($x10^{12}$sej)	EmDollars ($x10^3$ Em$)
RENEWABLE RESOURCES:						

1	Sunlight	J	4.11E+13	1.00E+00	41.1	0.0
2	Rain Chemical Potential	J	6.67E+10	3.10E+04	2067.4	2.1
3	Transpiration	J	3.06E+10	5.94E+04	1815.2	1.8
4	Rain Geopotential	J	0.00E+00	4.70E+04	0.0	0.0
5	Wind, Kinetic	J	1.84E+11	2.45E+03	450.2	0.5
6	Earth Cycle	J	1.76E+10	1.20E+04	211.0	0.2
EMERGY STORAGES						
7	Soil Organic Matter	J	1.51E+12	1.43E+05	215655	215.7
8	Forest Biomass	J	1.71E+12	3.62E+04	61875	61.9
9	Standing/Dead Biomass	J	1.87E+11	2.52E+04	4711	4.7
				sum	282242	

Footnotes

RENEWABLE RESOURCES:

1 Solar Insolation

			Source
Land Area	10000	m^2	
Insolation	3.81	kwh/m^2/day	Stackhouse, 2011
=	(kwh)*(J/kwh)*(days/yr)		
	500634000		
=	0		
Albedo	1.80E-01	(% given as a decimal)	
Energy =	(area)*(avg insolation)*(1-albedo)		
=	4.11E+13	J	
Transformity	1.00E+00	sej/J	Odum et.al, (2000)

2 Rain

Chemical Potential

Land Area	1.00E+04	m^2	
Rain	1.35	m/yr	Stackhouse 2011
Total Volume Rain	1.35E+04	m^3	
Energy=	(volume)*(1000kg/m^3)*(4940J/kg)		
=	6.67E+10	J/yr	
Transformity	3.10E+04	sej/J	Odum et.al, (2000)

3 Transpiration

	0.62	m/yr	
	6.19E+03	m3	
Energy=	(Volume)*(1000Kg/m^3)*(4940J/kg)		
=	3.06E+10	J/yr	
Transformity	5.94E+04	sej/J	Modeled

4 Rain Geopotential

	Runoff		m/m^2/yr	modeled
	Mean Elevation Change	0.00E+00	m	
	Land Area	1.00E+04	m^2	
	Energy =	(area)(rainfall)(avg change in elevation)(density)(gravity)		
	=	0.00E+00	J	
	Transformity	4.70E+04	sej/J	Odum et.al, (2000)
5	Wind, Kinetic			
	Area	1.00E+04		
	air density	1.30E+00	kg/m^3	
	avg annual wind velocity	6.32E+00	mps @ 50 m	Stackhouse, 2011
	Geostrophic wind	1.05E+01	observed winds are about 0.6 of geostrophic wind	
	Drag Coeff.	2.00E-03		
	Energy=	(area)*(density)*(dragcoef)*(Geos-grndVel)^3*(31500000sec/yr)		
	=	1.84E+11		
	Transformity	2.45E+03	sej/J	Odum (2000)
9	Earth Cycle			
	Heat Flow	5.58E+01	miliwatts/m^2	IHFC, 2005
	area	1.00E+04	m^2	
	energy=	(miliwatts/m^2)*(area*sec/yr)		
		1.76E+06	J/m^2	
	energy=	1.76E+10	J/yr	
	Transformity	1.13E+04	sej/J	Odum (2000)

Emergy Storages

10	Soil OM	72.03	mt	COLE, 2011
	mass OM=	7.20E+07	g	
	Energy=	massOM* 5.0 kcal/g of OM * 4186 j/kcal		
		1.51E+12	J	
	Transformity	1.43E+05	sej/J	Cohen, 2007
11	Tree and Shrub Biomass	116.69	mt of C	
	=	1.17E+08	g	
		3.50E+00	Kcal/g of Biomass	
	energy=	g*3.5kcal/g*4186J/kcal		
	=	1.71E+12	J	
	Transformity	3.62E+04	sej/J	
12	Standing and Down Dead Trees	12.76	mt of C	
	=	1.28E+07	g	

3.50E+00 Kcal/g of Biomass
energy= g*3.5kcal/g*4186J/kcal
= 1.87E+11 J
Transformity 2.52E+04 sej/J Tilley, 2002

Table A.5.4. New England Acadian Forest- Spruce/balsam fir @ 100 years

Note	Item	Units	Quantity	Unit Emergy Values [1]. (sej/unit)	Solar Emergy ($x10^{12}$sej)	EmDollars ($x10^3$ Em$)
RENEWABLE RESOURCES:						
1	Sunlight	J	3.89E+13	1.00E+00	38.9	0.0
2	Rain Chemical Potential	J	6.24E+10	3.10E+04	1934.2	1.9
3	Transpiration	J	2.96E+10	5.94E+04	1755.3	1.8
4	Rain Geopotential	J	0.00E+00	4.70E+04	0.0	0.0
5	Wind, Kinetic	J	1.06E+11	2.45E+03	259.6	0.3
6	Earth Cycle	J	1.80E+10	1.20E+04	215.7	0.2
EMERGY STORAGES						
7	Soil Organic Matter	J	2.04E+12	1.43E+05	292031	292.0
8	Forest Biomass	J	8.07E+11	3.62E+04	29217	29.2
9	Standing/Dead Biomass	J	8.79E+10	2.52E+04	2215	2.2
				sum	323464	

Footnotes

RENEWABLE RESOURCES:

1 Solar Insolation Source
Land Area 10000 m^2
Insolation 3.61 kwh/m^2/day Stackhouse, 2011
= (kwh)*(J/kwh)*(days/yr)
= 4.74E+09
Albedo 1.80E-01 (% given as a decimal)
Energy = (area)*(avg insolation)*(1-albedo)
= 3.89E+13 J
Transformity 1.00E+00 sej/J Odum et.al, (2000)

2 Rain

Chemical Potential
Land Area 1.00E+04 m^2
Rain 1.263 m/yr Stackhouse, 2011

		Total Volume Rain	1.26E+04	m^3	
		Energy=	(volume)*(1000kg/m^3)*(4940J/kg)		
		=	6.24E+10	J/yr	
		Transformity	3.10E+04	sej/J	Odum et.al, (2000)
3	Transpiration		0.60	m/yr	
			5.98E+03	m3	
		Energy=	(Volume)*(1000Kg/m^3)*(4940J/kg)		
		=	2.96E+10	J/yr	
		Transformity	5.94E+04	sej/J	Modeled
4	Rain Geopotential				
		Runoff		m/m^2/yr	modeled
		Mean Elevation Change	0.00E+00	m	
		Land Area	1.00E+04	m^2	
		Energy =	(area)(rainfall)(avg change in elevation)(density)(gravity)		
		=	0.00E+00	J	
		Transformity	4.70E+04	sej/J	Odum et.al, (2000)
5	Wind, Kinetic				
		Area	1.00E+04		
		air density	1.30E+00	kg/m^3	
		avg annual wind velocity	5.26E+00	mps @ 50 m	Stackhouse, 2011
		Geostrophic wind	8.77E+00	observed winds are about 0.6 of geostrophic wind	
		Drag Coeff.	2.00E-03		
		Energy=	(area)*(density)*(dragcoef)*(Geos-grndVel)^3*(31500000sec/yr)		
		=	1.06E+11		
		Transformity	2.45E+03	sej/J	Odum (2000)
9	Earth Cycle				
		Heat Flow	5.70E+01	miliwatts/m^2	IHFC, 2005
		area	1.00E+04	m^2	
		energy=	(miliwatts/m^2)*(area*sec/yr)		
			1.80E+06	J/m^2	
		energy=	1.80E+10	J/yr	
		Transformity	1.13E+04	sej/J	Odum (2000)

Emergy Storages

10	Soil OM	97.54	mt	COLE, 2011

mass OM= 9.75E+07 g
Energy= massOM* 5.0 kcal/g of OM * 4186 j/kcal
2.04E+12 J
Transformity 1.43E+05 sej/J Cohen, 2007

11 Tree and Shrub Biomass 55.1 mt of C
= 5.51E+07 g
3.50E+00 Kcal/g of Biomass
energy= g*3.5kcal/g*4186J/kcal
= 8.07E+11 J
Transformity 3.62E+04 sej/J

12 Standing and Down Dead Trees 6 mt of C
= 6.00E+06 g
3.50E+00 Kcal/g of Biomass
energy= g*3.5kcal/g*4186J/kcal
= 8.79E+10 J
Transformity 2.52E+04 sej/J Tilley, 2002

Table A5.5. Eastern Canadian Forest- Black Spruce

Note	Item	Units	Quantity	Unit Emergy Values [1]. (sej/unit)	Solar Emergy (x10^{12}sej)	EmDollars (x10^3 Em$)
RENEWABLE RESOURCES:						
1	Sunlight	J	3.52E+13	1.00E+00	35.2	0.0
2	Rain Chemical Potential	J	4.51E+10	3.10E+04	1397.4	1.4
3	Transpiration	J	2.27E+10	5.94E+04	1349.2	1.3
4	Rain Geopotential	J	0.00E+00	4.70E+04	0.0	0.0
5	Wind, Kinetic	J	6.37E+10	2.45E+03	156.1	0.2
6	Earth Cycle	J	1.74E+10	1.20E+04	208.4	0.2
EMERGY STORAGES						
7	Soil Organic Matter	J	2.06E+12	1.43E+05	294816	294.8
8	Forest Biomass	J	4.42E+11	3.62E+04	15992	16.0
9	Standing/Dead Biomass	J	5.39E+10	2.52E+04	1359	1.4
				sum	312167	

Footnotes

RENEWABLE RESOURCES:

1 Solar Insolation Source
Land Area 10000 m^2

	Insolation		3.27	kwh/m^2/day	Stackhouse, 2011
		=	(kwh)*(J/kwh)*(days/yr)		
		=	4.3E+09		
	Albedo		1.80E-01	(% given as a decimal)	
		Energy =	(area)*(avg insolation)*(1-albedo)		
		=	3.52E+13	J	
		Transformity	1.00E+00	sej/J	Odum et.al, (2000)
2	Rain				
	Chemical Potential				
		Land Area	1.00E+04	m^2	
		Rain	0.9125	m/yr	Stackhouse, 2011
		Total Volume Rain	9.13E+03	m^3	
		Energy=	(volume)*(1000kg/m^3)*(4940J/kg)		
		=	4.51E+10	J/yr	
		Transformity	3.10E+04	sej/J	Odum et.al, (2000)
3	Transpiration		0.46	m/yr	
			4.60E+03	m3	
		Energy=	(Volume)*(1000Kg/m^3)*(4940J/kg)		
		=	2.27E+10	J/yr	
		Transformity	5.94E+04	sej/J	Modeled
4	Rain Geopotential				
		Runoff		m/m^2/yr	modeled
		Mean Elevation Change	0.00E+00	m	USGS, 2007
		Land Area	1.00E+04	m^2	
		Energy =	(area)(rainfall)(avg change in elevation)(density)(gravity)		
		=	0.00E+00	J	
		Transformity	4.70E+04	sej/J	Odum et.al, (2000)

5	Wind, Kinetic			
	Area	1.00E+04		
	air density	1.30E+00	kg/m^3	
	avg annual wind velocity	4.44E+00	mps @ 50 m	Stackhouse, 2011
	Geostrophic wind	7.40E+00	observed winds are about 0.6 of geostrophic wind	
	Drag Coeff.	2.00E-03		
	Energy=	(area)*(density)*(dragcoef)*(Geos-grndVel)^3*(31500000sec/yr)		
	=	6.37E+10		
	Transformity	2.45E+03	sej/J	Odum (2000)
9	Earth Cycle			
	Heat Flow	5.51E+01	miliwatts/m^2	IHFC, 2005
	area	1.00E+04	m^2	
	energy=	(miliwatts/m^2)*(area*sec/yr)		
		1.74E+06	J/m^2	
	energy=	1.74E+10	J/yr	
	Transformity	1.13E+04	sej/J	Odum (2000)
Emergy Storages				
10	Soil OM	98.47	mt	COLE, 2011
	mass OM=	9.85E+07	g	
	Energy=	massOM* 5.0 kcal/g of OM * 4186 j/kcal		
		2.06E+12	J	
	Transformity	1.43E+05	sej/J	Cohen, 2007
11	Tree and Shrub Biomass	30.16	mt of C	
	=	3.02E+07	g	
		3.50E+00	Kcal/g of Biomass	
	energy=	g*3.5kcal/g*4186J/kcal		
	=	4.42E+11	J	
	Transformity	3.62E+04	sej/J	
12	Standing and Down Dead Trees	3.68	mt of C	
	=	3.68E+06	g	

	3.50E+00	Kcal/g of Biomass	
energy=	g*3.5kcal/g*4186J/kcal		
=	5.39E+10	J	
Transformity	2.52E+04	sej/J	Tilley, 2002

Table A5.6 Hubbard Brook Temperate Forest Ecological Network, units are J/m^2/yr, rows are flows out, columns consumers

	Sun (sej)	Fruit and Seeds	Foliage/Woody	Fungi and Bacteria	Insects	Birds	Chipmunks	Mice	Deer	Rabbits	Salamanders	Shrews	Secondary Carnivores	Tertiary Carnivores
Fruit and Seeds		0	0	0	0	5857.6	89537.6	25104	0	0	0	0	2301.2	334.72
Foliage/Woody		0	0	12552000	16736	0	20920	9204.8	18828	4184	0	0	0	0
Fungi and Bacteria		0	0	0	1255200	0	12552	5439.2	0	0	0	0	0	0
Insects		0	0	0	0	25104	6276	6694.4	0	0	4602.4	29706.4	0	0
Birds		0	0	0	0	0	0	0	0	0	0	0	3096.16	0
Chipmunks		0	0	0	0	0	0	0	0	0	0	0	12928.56	0
Mice		0	0	0	0	0	0	0	0	0	0	0	4644.24	0
Deer		0	0	0	0	0	0	0	0	0	0	0	0	1882.8
Rabbits		0	0	0	0	0	0	0	0	0	0	0	0	418.4
Salamanders		0	0	0	0	0	0	0	0	0	0	0	460.24	0
Shrews		0	0	0	0	0	0	0	0	0	0	0	2970.64	0
Secondary Carnivores		0	0	0	0	0	0	0	0	0	0	0	0	0
Tertiary Carnivores		0	0	0	0	0	0	0	0	0	0	0	0	0
Photosynthesis	2.00E+09	1673600	17572800	0	0	0	0	0	0	0	0	0	0	0

Table A.5.7 Transformities Generated by Emergy Ecological Network Models, units are sej/j

	Forest Ecosystem	Suburban Ecosystem
Photosynthesis	2.00E+03	2.00E+03
Fruit and Seeds	2.16E+03	6.10E+03
Litter	3.00E+03	4.00E+03
Foliage/Woody	7.10E+03	6.10E+03
Detritus	7.15E+03	3.26E+03
Deer	7.10E+04	1.72E+05
Rabbits	7.10E+04	1.72E+05
Fungi and Bacteria	7.15E+04	1.63E+04
Chipmunks	2.22E+05	1.72E+05
Insects	3.89E+05	1.03E+05
Mice	5.95E+05	1.72E+05
Salamanders	1.95E+06	0.00E+00
Birds	3.16E+06	8.87E+05
Shrews	3.89E+06	1.03E+06
Secondary Carnivores	1.03E+07	4.04E+06
Tertiary Carnivores	1.81E+07	0.00E+00

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