The Puyallup River Watershed:

An Ecological Economic Characterization

EARTH ECONOMICS

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The authors are responsible for the content of this report.

Cover photo by Don Briggs

Abstract:

This document presents an ecological economic characterization of the Puyallup River Watershed, located in Washington State, USA. The primary goal of such a characterization is to understand nature and the human economy as a single system. Identifying and valuing nature's contribution to the economy enables better decisions that improve local and regional quality of life. The study introduces the watershed, geography and other relevant features. Ecological economics is a recent advancement in economics and provides an integrated approach to managing a watershed's economy and ecosystems. Using benefit transfer methodology and Geographic Information Systems (GIS) data, the ecosystem services of the Puyallup River Watershed are identified and valued. Not all ecosystem services identified can be valued; 19 ecosystem services were valued in this study. Results show that ecosystems in the Puyallup River Watershed provide $526 million to $5 billion in benefits to the regional economy every year. This includes flood risk reduction, salmon habitat, aesthetic value, biological control and nutrient cycling. Applications of ecological economics and ecosystem service valuation are discussed. Specific recommendations are offered for the Puyallup River Watershed economy.

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Executive Summary

The Puyallup River Watershed economy is a unique combination of natural, built, human, social and financial capital. It is the outcome of centuries of investment – from the first Coast Salish peoples to our generation. The Puyallup River Watershed economy faces unique challenges entering the 21st Century. Investments made today will determine its physical appearance and regional economic vitality tomorrow. Wise investments require an economic model equipped for these challenges to ensure prosperity and a high quality of life today and in the future.

In the 20th century, our economy was primarily limited by the production of built capital. To increase fish production, for example, required more boats and nets. Conversely, in the 21st century, our economy is limited by natural capital. Boats and nets are abundant while fish are increasingly scarce. Increasing fish production requires increased habitat: natural capital. Some of the most pressing challenges facing the Puyallup River Watershed economy stem from a loss or degradation of natural capital, including flood risk mitigation, food production, summer water availability, recovery of salmon populations and water quality. Scarcity and increasing costs to restore "green infrastructure" are addressed with the Whole Economy model introduced in this report.

This report illuminates reasons for decision-makers in the Puyallup River Watershed to choose to advance

Executive Summary

the economy for a sustainable future through wise investment decisions. These choices will provide the optimal balance between the production of built and green infrastructure (built and natural capital). Improvements in social, financial and human capital will also flow from these investments. Use of the Whole Economy model will lower costs, promote justice, improve efficiency, and advance the Puyallup River Watershed economy. It will also maintain crucial ecosystem services such as flood risk reduction, salmon habitat, climate regulation and freshwater supply.

Major Findings and their Implications

Ecosystem services in the Puyallup River Watershed can be identified. The value of some of these ecosystem services can be estimated in dollars based on eight valuation techniques including market value and cost avoidance. The results are compelling. By reducing the frequency and severity of floods, supplying water, buffering climate instability, supporting fisheries and food production, maintaining critical habitat, enhancing recreation and providing waste treatment, among other benefits, the **Puyallup River Watershed ecosystems provide between $526 million and $5 billion in benefits to the regional economy every year.**

Valuation of ecosystem services is new, and as in most economic analysis, uncertainty exists. The large range in values represents an "appraisal" of the Puyallup Watershed's natural capital, similar to a house or business appraisal. Though wide, it is a better estimate than zero, which has been the default value of ecosystems for too long. As further studies are added to the Earth Economics database, and as spatial mapping of the watershed's ecosystem services is completed, this range in values will narrow. A limited range of the known ecosystem services were valued in this study, so the low end of the range can be considered a baseline value.

Ecosystem services may also be treated like economic assets; they provide a stream of benefits over time, as do bridges or other built infrastructure. Valued as such, a discount rate may be applied to these services, allowing for calculation of the present value of these systems. If treated like an asset with a lifespan of 100 years, **the present value of the Puyallup River Watershed is between $13 billion and $120 billion (4.125% discount rate).** This is tremendous economic value, requiring some considerations:

- Recognizing this value presents an opportunity for advancement of the whole Puyallup River Watershed economy.
- Allowing ecosystems to be further degraded will create real and potentially significant negative economic tradeoffs within the Puyallup River Watershed.
- To ensure a healthy, resilient Puyallup River Watershed economy and a sustainable future, nature's economic value should be incorporated into decision-making.

In evaluating investments, these four guiding principles should be considered:

1. **Sustainability**. Ecosystems can be managed sustainably to produce economic benefit to current and future generations – or mismanaged at great cost.
2. **Justice**. Fair distribution of public and private gains from natural, built, human, social, and financial goods and services ensures maximum benefit for lowest public investment.
3. **Efficiency**. Careful decision-making regarding how and where resources are moved or invested is necessary to produce different suites of goods and services.
4. **Good Governance**. The creation and maintenance of institutions and groups, policy instruments, systems, markets and measures are necessary for prudent decision-making.

Next Steps

The quantification of tradeoffs among ecosystem services and their interactions with the economy and human well-being should now be a high priority in local decision-making. This report can be used to begin incorporating ecosystem services concepts into agency goals, metrics, indicators, assessment and general operations.

Ecosystem service values could also be considered when developing budgets, program plans, and grant applications; examining policies and accounting practices; reporting and aligning to Puget Sound health indicators; and developing review and permitting processes in rural areas. Puyallup River Watershed decision-makers have the opportunity to shift from addressing challenges at a single-issue scale to taking an integrated approach that develops a cost-efficient, sustainable and whole economy in which green infrastructure is an asset with recognized significant value.

While this report provides a valuation of ecosystem services in the Puyallup River Watershed and a whole view of the economy, it is only a first step. There is also a need to further develop goals, policies, and measures that support discussions about the tradeoffs in public and private investments that ultimately shape the regional economy for the generations to come. Recommended next steps include:

1. **Map and value potential flood risk reduction scenarios.** Analysis would consider floodplains along the Puyallup River and their value relative to land prices. Scenario studies could also include valuations of ecosystem services beyond flood risk reduction that would be enhanced by restoring the natural flows of the river.
2. **Ecosystem service mapping of service beneficiaries and provisioners.** Hydrological models and GIS data can depict locations of specific ecosystem services on the landscape, such as flood risk reduction or salmon habitat, and who benefits from those services. Mapping can also show impairments to ecosystem services, such as features on the landscape that impact salmon habitat.
3. **Funding mechanism review.** After modeling the flow of ecosystem service benefits and impairments across the landscape, funding mechanisms can be designed for green infrastructure investments. These investments typically reduce tax spending on solutions designed to address a single problem such as flood risk reduction, because they invest in a suite of ecosystem services for maximum economic returns.

Study Objectives

- Illuminate the connections between ecosystems and the economy of the Puyallup River Watershed.
- Introduce the discipline of ecological economics and describe its basic tools and applications, including ecosystem services.
- Provide a conceptual model for aligning multiple investment goals in the Puyallup River Watershed, including economic advancement, salmon recovery, and flood risk reduction.
- Identify and describe the goods and services sustained by ecosystems in the Puyallup River Watershed.
- Calculate the dollar-value of the natural goods and services provided in the Puyallup River Watershed.
- Discuss how this value could be included in local accounting and decision-making, both public and private, to improve prosperity for all.

Report Organization

- **Part I: The Puyallup River Watershed** introduces the geography, population, economy and ecology of the Puyallup River Watershed.
- **Part II: Key Ecological Economics Concepts** defines fundamental elements and definitions necessary to understanding the Puyallup River Watershed.
- **Part III: Ecosystem Services in the Puyallup River Watershed** describes ecosystem services valued in this report, with specific examples from within the Puyallup River Watershed.
- **Part IV: Valuation of the Puyallup River Watershed** determines a range of dollar values for some goods and services provided by ecosystems of the Puyallup River Watershed.
- **Part V: Applications of Study Findings** discusses investing in green infrastructure and whole systems economic analysis, with specific recommendations for decision-makers.

Part I The Puyallup River Watershed

__Section Summary:__ The Puyallup River Watershed is rich in geographic, cultural and biological diversity. It houses an advanced industrial economy, a national park, a large port, educational institutions and other assets nested within interconnected ecosystems from glaciers to marine waters. Tradeoffs between increased built areas and ecosystems are degrading and fragmenting ecological processes in the watershed, which in turn has caused greater flooding, loss of biodiversity and other impacts.

Geography

The Puyallup River Watershed is located in Washington State, largely within Pierce County and including a small area in King County.[1] It is often identified as Water Resource Inventory Area 10 (WRIA 10), as salmon recovery planning unit at the watershed scale.[2] The Puyallup Watershed shares major borders with the Nisqually River Watershed (WRIA 11) to the south, and the Green/ Duwamish Watershed (WRIA 9) to the north. The name "Puyallup" is derived from the Salish word *S'Puyalupubsh*, which translates as "generous and welcoming," referring to the Puyallup Tribe of Indians' reputation for generous dealing with friends and strangers (Puyallup Tribe of Indians, 2010).

The Puyallup Watershed has recent volcanic and sedimentary bedrock beneath the entire watershed. The most recent period of continental glaciation, the Vashon Glaciation, began in the Puget Sound lowlands approximately 15,000 years ago and ended 13,500 years ago. The Vashon Glaciation deposited a 200- to 400-foot layer of mixed glacial outwash and glacial till, contributing substantially to the Puyallup Watershed's present-day topography and drainage qualities. Approximately 5,600 years ago and 560 years ago, respectively, the Osceola and Electron Mudflows (lahars) originated on the flanks of Mount Rainier (Shared Strategy for Puget Sound, 2007; Ecology, 1980).[3]

The Osceola Mudflow is one of the largest known lahars in the world, covering approximately 124,800 acres (195 square miles) along the White River Valley at an average depth of 25 feet. The Electron Mudflow is a smaller lahar, confined to the Puyallup River floodplains and reaching several miles downstream of present-day Orting. Since the most recent glaciation, the Puyallup and White Rivers and their tributaries have cut through the various glacial deposits and mudflows. The rivers continue to transport and deposit large quantities of alluvial sediment within the riverbeds and floodplains – up to 500,000 tons per year in the Upper White River alone (Washington State Department of Ecology, 1980; GeoEngineers, 2003; Upper Puyallup Watershed Committee, 2002).

1 Henceforth referred to as "Puyallup Watershed".

2 Water Resource Inventory Areas (WRIAs) were formalized under Washington Administrative Code (WAC) 173-500-040 and authorized under the Water Resources Act of 1971, Revised Code of Washington (RCW) 90.54.

3 Cited in Upper Puyallup Watershed Committee, 2002

Figure 1 - Puyallup Watershed boundary

The Puyallup Watershed's boundary stretches from the crest of the Cascade Mountains and the summit of Mount Rainier, at 14,410 feet, to Commencement Bay and the City of Tacoma at sea level, drains an area of approximately 670,000 acres (1,053 square miles),[4] with over 728 miles of streams. The Puyallup River is the largest river in the watershed, beginning at the Puyallup and Tahoma glaciers and flowing about 46 miles northwestward to Commencement Bay. The two principal tributaries of the Puyallup River are the White and Carbon Rivers, both also originating on the slopes of Mount Rainier.

The White River was historically a tributary to the Green River until 1906, when a major flood diverted the flow into the Puyallup River. The diversion was later replaced with a permanent diversion wall, located at the Game Farm Park in Auburn. Other rivers in the Puyallup Watershed include the Mowich, Greenwater, Clearwater Rivers and South Prairie Creek. The Puyallup River and its tributaries together drain 60% of Mount Rainier. Annual precipitation in the watershed ranges from 40 inches in the lowlands to 120 inches in the upper elevations, with 75% falling between October and March (GeoEngineers, 2003; Ecology, 1980). Maps of the Puyallup Watershed are presented in Figures 1 and 2.

4 Calculated on ArcGIS software using Washington State Department of Ecology's WRIA GIS data. Shapefile is available at: http://www.ecy.wa.gov/services/gis/data/data.htm#w (retrieved November 2010). Other estimates for WRIA 10's drainage area have ranged from 622,000 acres (972 square miles) (Ecology, 1980) to 640,000 acres (1000 square miles) (Williams et al. 1975; Embrey 1991, both cited in Upper Puyallup Watershed Committee, 2002).

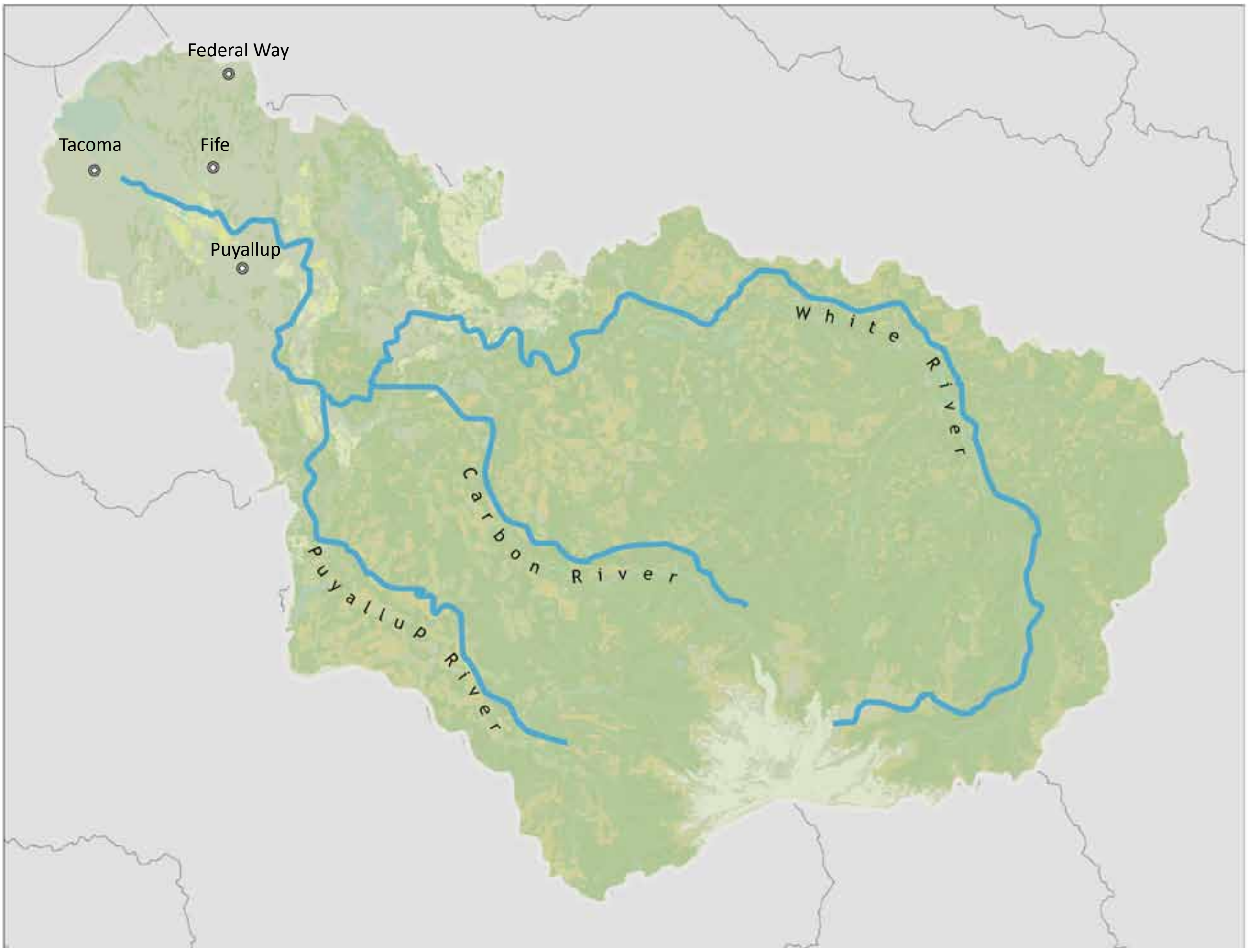


Figure 2 - Puyallup Watershed

The Watershed Economy

People

The Puyallup Watershed has sustained a human economy for thousands of years. The Muckleshoot Indian Tribe and the Puyallup Tribe of Indians, both descended from the Coast Salish peoples, have been the traditional stewards and inhabitants of the Puyallup Watershed and its surrounds, perhaps since the last glacial retreat (Washington Biodiversity Council, 2007).

The Muckleshoot Indian Tribe was signatory to both the Treaty of Point Elliot and the Treaty of Medicine Creek, and was named after Muckleshoot Prairie, where the Muckleshoot Reservation is located. Tribes and bands now part of the Muckleshoot Tribe include those of the Green, White, and Puyallup Rivers (Center for Columbia River History, 2010). Today, the tribe occupies a 3,600-acre reservation on the King County portion of the Puyallup Watershed.
The Puyallup Tribe of Indians is the present-day successor to the tribes and bands of the Puyallup River and its tributaries, as well as those of Vashon Island, who were all signatories to the Treaty of Medicine Creek (Center for Columbia River History, 2010). Today, the tribe occupies a reservation of approximately 18,000 acres. Both the Puyallup and Muckleshoot Tribes retain the right to fish in their usual and accustomed areas and catch up to 50% of harvestable fish, pursuant to their agreements with the United States government and confirmed by the landmark "Boldt Decision" in 1974.[5]

The Puyallup Watershed was one of the first areas to be settled by Europeans in the Puget Sound. Beginning in the 1850s, homesteads and settlements began to appear in the watershed as settlers were attracted to abundant natural resources such as forests, dense salmon runs and fertile agricultural soil (Shared Strategy for Puget Sound, 2007).
Today approximately 280,000 people live within the watershed, representing diverse cultures and backgrounds.[6] Most reside in one of 17 incorporated areas: Algona, Auburn, Bonney Lake, Buckley, Carbonado, Edgewood, Enumclaw, Federal Way, Fife, Milton, Orting, Pacific, Puyallup, South Prairie, Sumner, Tacoma, and Wilkeson. In addition to tribal lands and cities, other jurisdictions within the watershed include the Port of Tacoma, Pierce County, Washington State and the federal government.

Infrastructure

The natural capital, or green infrastructure, of the Puyallup River Watershed has historically provided the basis for its economy. It continues to play a critical role through the provisioning of at least 23 ecosystem services, including water supply, timber, aesthetic and recreational value, and flood risk reduction. The tribes and bands who originally settled the watershed established an economy based on these natural assets. They consumed salmon, wild game, shellfish, roots and berries. They built homes, clothing, utensils and canoes using the fibers of the western red-cedar trees and other vegetation (Puyallup Tribe of Indians, 2010).

Today, the natural capital of the Puyallup Watershed economy comprises evergreen and deciduous forests (>350,000 acres), mountains and sediments, wetlands, floodplains, biodiversity, rivers, lakes, aquifers and the Puyallup River estuary. The watershed's built capital includes residential homes and commercial buildings; roads; Interstate 5; railways and bridges; an extensive system of levees revetments and dikes;[7] and a major U.S. port that handles more than $25 billion in goods annually.

5 A court case in 1974 that reaffirmed the right of most of the tribes in Washington State to continue to harvest salmon. Case reference: United States v. Washington, 384 F.Supp. 312 (W.D. Wash. 1974).

6 Based on population numbers cited in Upper Puyallup Watershed Characterization and Action Plan (Upper Puyallup Watershed Committee, 2002) and Lower Puyallup Watershed Action Plan (Lower Puyallup Watershed Management Committee, 1995). Numbers were adjusted for population growth using Puget Sound Regional Council population data for Pierce County.

In addition, there is one hydroelectric dam in the Puyallup Watershed, the Electron Dam on the Upper Puyallup River, and one large flood control facility on the White River, Mud Mountain Dam.

Land Cover and Land Use

In the lower reaches of the watershed urbanization is more intensive. Land use in the Lower Puyallup Watershed is dominated by a combination of residential, industrial, commercial, agricultural, transportation, communication, and utility land covers (Lower Puyallup Watershed Management Committee, 1995).[8] The more expansive Upper Puyallup Watershed is predominantly commercial forestland with some conservation areas, including Mount Rainier National park (Upper Puyallup Watershed Committee, 2002).[9]

Historically, two important land covers in the watershed have been forest lands and agricultural lands. Both provide an important foundation for local quality of life. Forestland within the watershed is now managed for multiple uses, including timber and other forest products, recreation, wildlife habitat and water quality. Forests remain an important source of revenue and jobs within the watershed and contribute essential public and private goods and services to the local economy. Agricultural lands also serve the public by generating a suite of ecosystem services, ranging from food production to flood risk reduction for urban areas, aesthetic value, and habitat for wildlife. Some of the main features of forest lands and agricultural lands in the Puyallup Watershed are outlined below.

7 The Puyallup, White and Carbon Rivers are all contained within a revetment and levee system for their lower 26, 8 and 5 miles respectively (Kerwin, 1999).

8 *Lower Puyallup Watershed* refers to several sub-watersheds as defined in Pierce County's basin planning strategy, comprising the Hylebos, Commencement Bay, Clarks/Clear Creek, Lower White, and Middle Puyallup sub-watersheds. See the Pierce County website for more details: http://www.piercecountytv.org/pc/services/home/environ/water/ps/basinplans/bpmain.htm

9 *Upper Puyallup Watershed* refers to several sub-watersheds as defined in Pierce County's basin planning strategy, comprising the Upper Puyallup, Upper White, Upper Carbon, Lower Carbon, and South Praire Creek sub-watersheds. See the Pierce County website for more details: http://www.piercecountytv.org/pc/services/home/environ/water/ps/basinplans/bpmain.htm

Forest Lands

The ready supply of timber was a major reason for European settlement of the Puyallup Watershed. Tacoma, for instance, the largest city in the watershed and the third-largest city in Washington State, was founded as a timber town in 1869 when investors from San Francisco built the Hanson & Ackerman Mill (CityData.com, 2010). The vast majority of forestland today is located in the Upper Puyallup sub-watershed, where about half is in private ownership and much of the remaining half is owned and managed by the federal government (Upper Puyallup Watershed Committee, 2002).

Of the public forestland, about 130,000 acres is located within Mount Rainier National Park and 95,000 acres within the Mount Baker-Snoqualmie National Forest District (Upper Puyallup Watershed Committee, 2002). Forestlands in the lower portions of the Puyallup Watershed are less often managed for timber, but are nonetheless essential for many of the natural services they provide. Urban forests are often valued more highly than remote forests because they directly benefit more populous urban areas. Urban forests often experience greater development pressure as well.

Agricultural Lands/Floodplains

Agricultural lands in Puyallup Watershed make up nearly 30% of Pierce County's total agricultural lands. The Puyallup Valley (an area within the Puyallup Watershed) and the Bonney Lake-Buckley Plateau are two of the most concentrated areas of agricultural activity in the watershed. The Puyallup Valley includes the floodplain extending several miles on either side of the Puyallup River from near the City of Orting to Commencement Bay. Today the valley supports about 4,900 acres of productive farmland. The Bonney Lake-Buckley Plateau agricultural area lies roughly between Buckley, Bonney Lake, Carbonado and the Muckleshoot Reservation. About 3,700 acres of this area is used for agriculture, including cropland and pasture (Barney & Worth and Globalwise, 2006).

The Puyallup Valley has long been a regional center for agricultural activity, thanks to the presence of fine soils comprised of silt and sand that were deposited during the historic meandering and regular flooding of the Puyallup River. Today, the valley leads Washington State in the production of cabbage, lettuce, green onion, radishes and many other vegetables, berry fruits and nursery plants (Barney & Worth and Globalwise, 2006).

Like many other regions in the United States, agricultural land in the Puyallup Watershed today faces a number of challenges, notably a decline in the number and size of commercial farms and food processors, accompanied by a reduction farm employment. Flooding remains a major concern for Puyallup Valley farmers. In addition, according to a recent report, current prices of capital (land, buildings, equipment, operating expenses etc.) present a significant barrier to new farmers in Pierce County. In the Puyallup Valley, for example, the price of land can range from $50,000 to $1 million per acre, well above the economic value of most agricultural land. Fortunately, the location and nature of agricultural lands in the watershed also presents many opportunities for local agriculture. Conditions in the floodplains are excellent for growing produce, and many farmers have been able to capitalize on their proximity to the large, urban Puget Sound market (Barney & Worth and Globalwise, 2006).

Regional Biodiversity

In plain terms, biodiversity is the variety of life in a given area. Biodiversity is critical to the health and resilience of most ecosystems that humans rely on for survival (see Worm et al., 2006 for a marine example). Biodiversity is more technically defined as the diversity of multiple levels of biological organization at multiple scales of space and time (Marcot, 2006). In 2005, the Center for Biological Diversity (CBD) and Friends of the San Juans (FSJ) completed an extensive assessment of the Puget Sound Basin's biodiversity that identified the presence of at least 7,013 species, including 4,248 animals, 1,504 plants, 851 fungi and 392 algae. The Puget Sound was thus confirmed as a hotspot for biological diversity in the United States, containing more species than 31 other states combined (CBD and FSJ, 2005).

While not addressed specifically in the CBD report, the Puyallup Watershed is part of the Puget Sound and contains key habitats as identified by the CBD that sustain substantial biodiversity. The key habitats include old growth forest, rivers and streams, alpine meadows, freshwater wetlands, and coasts and estuaries. In 2004, the Pierce County Biodiversity Network identified 16 biologically rich areas in Pierce County (called "Biodiversity Management Areas"), 8 of which lie within the Puyallup Watershed. One important aspect of the Network's planning efforts is known as a "BioBlitz," a rapid biological inventory of the plant and animal diversity found in a designated area during a 24-hour time frame. The purpose of a BioBlitz is to monitor biodiversity levels in these areas and to build enthusiasm around biodiversity. During a 2006 BioBlitz held in the Lower White River Biodiversity Management Area, participants observed 81 species of birds, 27 species of mammals, 7 species of amphibians and 229 species of plants.[10]

10 The Lower White River Biodiversity Management Area is 1,560 acres in size. It consists of deciduous/conifer forest running along both sides of the river bisecting the cities of Buckley, Auburn, Pacific, Sumner, and Muckleshoot lands, immersed with wetlands, and low developed residential areas.

Today, despite their size, Puget Sound and the Puyallup Watershed are ecologically fragile, and their significant biodiversity is today threatened by a number of factors. To illustrate, as of 2010 more than 21 species in the Puget Sound have been listed as threatened or endangered under the Endangered Species Act (ESA) of 1973 (Puget Sound Partnership, 2009). The 2005 report by CBD and FSJ, offering perhaps a wider perspective on species threats, suggests that in the Puget Sound more than 957 species are imperiled, of which 285 are critically imperiled (CBD and FSJ, 2005).

It is generally agreed that the most significant threat to biodiversity is the loss or degradation of habitat due to urban and suburban development, logging, and shoreline armoring. For example, approximately 70% of the 357 known culverts in the Puyallup Watershed are partial or complete barriers to salmon, reducing access to upstream habitat (Shared Strategy for Puget Sound, 2010; CBD and FSJ, 2005; Puget Sound Partnership, 2009). Habitat is the biophysical space formed by (typically natural) processes in which species meet their needs. A healthy ecosystem provides physical structure, adequate food availability, appropriate chemical and temperature regimes, protection from predators and nursery functions.

Groups in the watershed, including tribes, Pierce County, cities, citizen groups and many others, have thus focused primarily on habitat restoration and protection as a means to improve watershed health, and by extension human well-being (Shared Strategy for Puget Sound, 2010; Puget Sound Partnership, 2009).

Part II Key Ecological Economics Concepts

Section Summary: *Human well-being and economic expansion have always been tied to a healthy supply of nature's goods and services. Early economic models were created in a time of abundant natural resources. In that context, only built, financial and human capital (labor) were identified as constraining factors in the production process. Today's context is very different. Our planet has become "full" of built capital, and natural capital is now scarce, a limiting factor in production. Ecological economics extends basic economic concepts and reflects today's economy more completely. The "ecosystem services" framework is an operational way of including natural capital in economic analysis and is important to understanding and embracing an integrated approach to managing a watershed economy.*

What's an Economy for, Anyway?

Economies preceded written language. Economic progress has been instrumental in raising global standards of living and comfort. In the late 18th century, Adam Smith, David Ricardo and others articulated many of the basic market concepts that guide economic policy today. When Smith and Ricardo lived, world population was less than one billion people, the Industrial Revolution was just beginning, the science of ecology did not exist, and natural goods and services were plentiful relative to manufactured and built capital (Norgaard et al., 2007). Thus, the economy focused on improving quality of life through built capital, allocating plentiful natural resources to build and distribute these built goods.

The Three Economic Questions

Economics is the study of the allocation of limited, or scarce, resources, among alternative, competing ends. This definition can be stated as three questions (Daly and Farley, 2004), in a prioritized order:

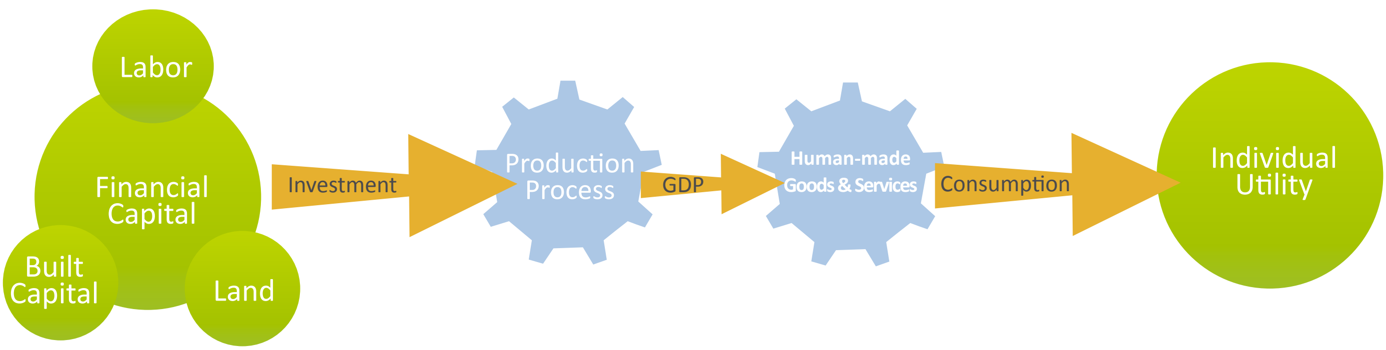
1. What ends do we desire?
2. What scarce resources do we need to attain these ends?
3. What ends receive priority, and to what extent do we allocate resources to them?

Traditionally, economists have answered "utility" or "human welfare" to the first question. Human welfare was thought to depend on what people wanted, revealed through market transactions, i.e. goods and services they bought and sold on a market. Early economics assumed that markets revealed most desired ends, and that most scarce resources were market goods. So it gave the most attention to one mechanism for allocating alternative resources to alternative ends: the market. Early economics focused secondarily on how the final goods and services were divided up (i.e., distribution), and not at all on the problem of an economy's size relative to the ecosystems in which it existed (i.e., scale).

Economic activity is tracked using measures such as the Gross Domestic Product (GDP). GDP adds together both final goods and services (salmon, theater visits, etc.) and "bads" (oil spill cleanup costs, policing costs, etc.) to arrive at an indication of the economy's total throughput.[11] Today, GDP is used to measure total output, assuming the market supplies most of our desired ends (or more specifically, preferences that people reveal for market goods and services). GDP is often inappropriately used as a human welfare measure, a purpose for which it was never intended.[12]

Because built capital was the primary goal of economic production, measures like the GDP focus on goods and services sold in markets. Natural, social (such as culture), and human capital (such as education), on the other hand, have infrequently been included in economic analysis.[13] The figure below provides a sketch of the "Partial Economy" model, which includes the traditional "factors of production" and the GDP measure.

Figure 3 - The Partial Economy Model



11 Throughput is rate at which material and energy resources are used by an economy.

12 The architects of the GDP, John Maynard Keynes and Simon Kuznets, cautioned against using the GDP as a measure of the welfare of a nation. In 1962, Kuznets lamented that, "…the welfare of a nation can scarcely be inferred from a measurement of national income as defined by the GDP…goals for 'more' growth should specify of what and for what." (Anielski, 1999)

13 An important caveat is that many of the environmental and social issues humans face today are due to insufficient attention to standard economics in everyday decision-making. Subsidized prices for natural resources, neglect of external costs and benefits, and political unwillingness to respect the basic notions of scarcity and opportunity cost are among the uneconomic policies that are often promoted in today's economy (Daly and Farley, 2004).

A Shift in Scarcity

Over the past 50 years, humans have altered ecosystems more rapidly and extensively than in any comparable period in human history (United Nations Environment Program, 2005). There is ample evidence that scarcity has shifted from built capital to natural capital. This is true for many resources within the Puget Sound. Our ability to lay asphalt outweighs our ability to provide flood risk reduction.

Similarly, once-extravagant timber harvests are now limited by land availability and tree growth, rather than available logging equipment. Consider that in 1900, the well-known timber magnate Frederick Weyerhaeuser purchased 900,000 acres of prime Washington forestland for just $137 million (in 2009 dollars), or approximately $150 per acre (Ficken and LeWarne, 1988).[14] Compare this value with a more recent assessment of forestland among 38 counties in western Washington and Oregon, which found average values of $1,483 per acre (Alig and Plantinga, 2004).[15]

On a global scale, many expert studies now show that humans are depleting Earth's flow of natural goods and services faster than the flow can be regenerated, and in many areas humans are depleting the natural capital that produces this flow. For example, it has been estimated that humans now directly or indirectly appropriate up to 40% of the Earth's Annual Net Primary Productivity (Vitousek et al., 1986; Haberl et al., 2007), dramatically reducing the amount available for other species, including those that support humans (such as fisheries). Net Primary Productivity is the total biomass that is produced by ecosystems through photosynthesis; it is the foundation for life on Earth. Other measures present a similar picture: The World Wildlife Fund recently calculated the "Ecological Footprint" of humanity, or the land and sea area that would be needed to sustainably regenerate the resources that humans consume and the waste they produce annually. It was found that the current rate of human resource consumption and waste disposal requires 1.3 planet Earths – and this "footprint" is growing (World Wildlife Fund, 2008).

An important reason for this shift in scarcity is that in the past century alone, the per-capita economic production of market goods and services has increased nine fold (Farley, 2009, citing Delong, 2002). The next two figures illustrate the human economy's move from the "Empty World" situation of the past to the "Full World" situation that humans live in today.

Figure 4 - Previous Empty World Situation

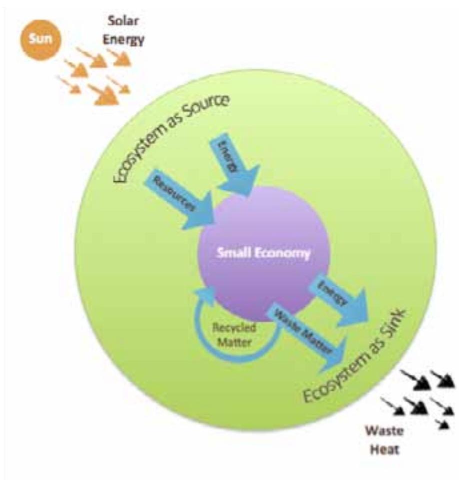
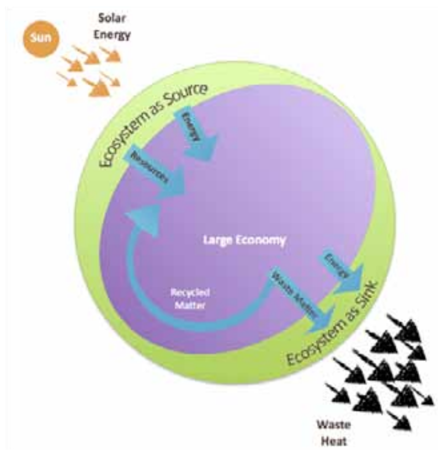


Figure 5 - Today's Full World Situation



14 Weyerhaeuser's purchase cost him $5.4 million in 1900; this value was converted to 2009 dollars using http://www.westegg.com/inflation/ (retrieved November 2010).

15 Original value in this 2004 study was $1,483. This value has also been converted to 2009 dollars using http://www.westegg.com/inflation/ (retrieved November 2010).

Why has the "Shift in Scarcity" been Overlooked?

The success of the industrial revolution has greatly reduced the scarcity of market goods for much of the world's population. The shift in scarcity, from built capital to natural capital, holds major implications for the way the economy is structured and understood. Yet it implies rebalancing natural and built capital. Why has this change been overlooked? Here are two reasons.

- Exponential Growth of Human Population. With a constant rate of population growth, the Earth would be expected to grow from 50% full to 100% full in one doubling period – the same period it required to grow from 1% full to 2% full. With improvements in technology and general living standards, the human population has, in reality, grown exponentially and doubling periods have shortened. For example, it took about 123 years (1804 – 1927) for the Earth's population to grow from one billion to two billion, and just 47 years (1927 – 1975) to grow from two billion to four billion (United Nations, 2000). Not only have human populations grown exponentially, but so has each individual's absolute use of resources. The shift from an "empty world" to a "full world" has occurred more quickly than economic models have been able to acknowledge.

- Complementary versus Substitutability. If two goods or services are thought of as substitutes in an economic model, then a shortage of one does not limit the productivity of another. Rather than substitutes, water and pipes are complements for delivering water to the tap. By default, the Partial Economy model has tended to view natural capital as expendable, with the assumption that built capital can be a perfect substitute. This would also avoid the problem of scarcity. The false assumption that built capital and natural capital are perfect substitutes can be largely attributed to the failure of the Partial Economy model to include natural capital explicitly as an essential factor of production (likely because the model was devised while the Earth was still "empty").

If natural capital is thought of as a complement to built capital (and human, social and financial capital) in the creation of goods and services, as it always must be to varying degrees, then its scarcity constrains the other capitals by definition. Some natural goods and services, such as oxygen production and carbon sequestration, can be thought of as complements to all types of built capital, because there is no practical built substitute (i.e. all built capital production would cease in the absence of oxygen). Natural capital is essential to built capital; indeed, all built capital is derived from natural capital.

The Whole Economy Model

Ecological economics grounds economic thinking in the physical reality of today's "full world," a necessary advancement of economic thought. Ecological economics is built upon supply and demand, and on the market economics of efficient allocation. It adds the constraints of shrinking oil supplies and other physical constraints, and the problem of scale (i.e. sustainability). Understanding the relationship between ecosystems, the economy, and human well-being is critical to economic progress in the 21st century (Daly and Farley, 2004).

The "Whole Economy" model, illustrated in Figure 6, demonstrates that production of goods and services is tied to five forms of capital (natural, built, human, social, and financial) and that ecosystem goods and services contribute to human well-being, both directly and by providing natural capital for the production process. The negative feedback loops from pollution and degradation are also included. In addition, there are four guiding principles for a healthy economy: good governance, sustainability, efficiency, and justice, which are displayed in blue.

Figure 6 - The Whole Economy Model

Desired Ends, Scarce Resources and Guiding Principles

Earlier in this section, three core questions of economics were posed. Answering the first guides the rest. What ends do we desire?

Desired Ends: Human Well-Being
Human well-being is not a rigidly defined state but a combination of physical and abstract human ends and needs that differ among individuals and places.[16] Many of these ends can be met on the market, but many cannot. For example, some basic shared needs may include a dependable supply of food and clean drinking water, and physical and financial security, family, health and social bonds such as friendship. Meeting the suite of human needs, now and into the future, largely depends on understanding the extent of society's scarce resources and how they are allocated to different ends.

16 Psychologist Abraham Maslow, for example, created an often-referenced framework for understanding the different types of human needs, referred to as "Maslow's hierarchy of needs" (Maslow, 1943). At the base of the hierarchy are "physiological" needs such as air, food, and water. Once the basic physiological needs are met, "safety" needs (physical safety, health, financial security etc.) can be attended. The final three categories of needs are "love and belonging", "esteem" and "self-actualization" (the highest human need).

Scarce Resources: The Five Capitals
Five Capitals represent the scarce resources that ultimately go towards human needs and human well-being, essential to economic progress. They are: natural, built, human, social and financial capital. Natural capital underlies all others, which in turn create the conditions for a healthy and sustainable economy:

- **Natural Capital.** The stock of minerals, energy, plants, animals and ecosystems found on earth that yields a flow of natural goods and services. When taken as one whole system, natural capital provides the total biophysical context for the human economy.

- **Human Capital.** The self-esteem and knowledge acquired through education, technical and interpersonal skills, such as communication, listening, cooperation, and individual motivation to be productive and socially responsible.

- **Social Capital.** The inventory of organizations, institutions, laws, informal social networks, and relationships of trust that make up or provide for the productive organization of the economy.

- **Built Capital.** The infrastructure of technologies, machines, tools and transport that humans design, build and use for productive purposes. Coupled with learned skills and capabilities, the economy's built techno-infrastructure is what directly allows raw materials (i.e. natural capital) to be converted into a flow of economic goods and services, the products that are typically found in markets.

- **Financial Capital.** The shares, bonds, banknotes, and other paper and electronic financial assets that play an important role in the economy, enabling the other combinations of capital (e.g. healthcare, education) to be owned, traded and allocated. Financial capital is based on trust and represents a promise that it will eventually be honored with one of the other types of "real" capital.

Attaining Desired Ends: The Four Guiding Principles
The third question of economics is the least straightforward, namely: *What ends get priority, and to what extent do we allocate resources to them?* While the question cannot be answered directly, Four Guiding Principles help to address the long-term attainment of human well-being.

- **Sustainability.** Living within a physical scale that does not destroy the basic ecosystems that maintain the economy. Ecosystems are part of the economy's "commonwealth," which can be managed sustainably to produce economic benefit to current and future generations, or mismanaged at great cost.

- **Justice.** Fair distribution of public and private gains from natural, built, human, social, and financial goods and services to ensure maximum benefit for the lowest public investment. Intergenerational distribution is equally important; our children, grandchildren and future generations should be given fair access to the Earth's stock of mineral and ecological resources.

- **Efficiency.** Careful decision-making regarding how and where resources are moved or invested to produce different suites of goods and services. People must consider the most efficient balance of built, natural, human, social and financial capital for the types of goods and services they wish to enjoy, and whether or not a particular balance is detrimental to the goal of long-term sustainability.

- **Good Governance.** This principle consists of two elements:

    - Creation and maintenance of both private and public institutions and groups, policy instruments, systems, and markets that ensure sustainability, justice and efficiency are achieved.

    - Employing measurements that give an accurate indication of the Whole Economy's health, measuring what our scarce resources are and whether desired ends are being met.

Addressing Inherent Complexity

The economy is a complex system. Complex systems are characterized by strong (usually non-linear) interactions between the parts, and complicated feedback loops that make it difficult to distinguish cause from effect, with significant time and space lags, discontinuities, thresholds, and limits (Costanza et al., 1993, citing Rastetter et al., 1992 and von Bertalanffy, 1968).

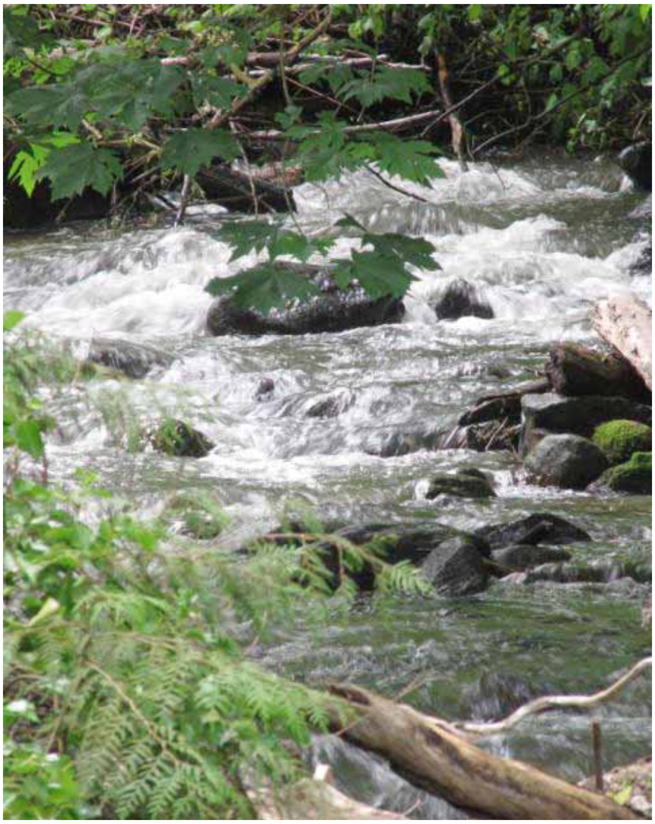
Resilience implies the potential of a system to return to a previous state after a disturbance. A system is assumed to be fragile when resilience is low. Fragile systems tend to be replaced when disturbed; for example, wetlands that are converted to open water produce reduced amounts of ecosystem services and provide less economic value (Gunderson and Holling, 2002). Without resilience, an entire economic system can also collapse and revert to a less productive one. Economic goals are more surely reached building in resilience, rather than building a more brittle system, as the recent financial crisis demonstrated.

Introduction to Ecosystem Goods and Services

Ecosystems provide economically valuable goods and services. Ecosystem services were recently given higher prominence in the Millennium Ecosystem Assessment, a project initiated in 2000 by then-United Nations Secretary-General Kofi Annan and completed in 2005. The Millennium Ecosystem Assessment examined the worldwide changes in ecosystems, their impacts on human well-being, and options for enhancing the conservation of ecosystems and their contribution to human well-being. The project, involving over 1,360 experts worldwide and a multi-stakeholder board representing governments, businesses, NGOs, indigenous peoples and international institutions, utilized the concept of "ecosystem services" to best understand the linkages between ecosystems and human well-being. Today, a number of federal agencies in the United States, including the Environmental Protection Agency, the United States Forest Service, the United States Geological Service, and the United States Department of Agriculture, house dedicated ecosystem services departments to advance understanding of how ecosystem services can be promoted to improve long-term economic prosperity for the nation.[17]

The natural environment provides many of the things humans need for survival, including breathable air, drinkable water, food for nourishment, and stable atmospheric conditions, to name a few. These "ecosystem goods and services," are derived from ecosystems and provide benefit to humans. Ecosystems perform many functions, but only functions that provide human benefits are considered ecosystem goods or services. Every ecosystem produces a suite of ecosystem services.

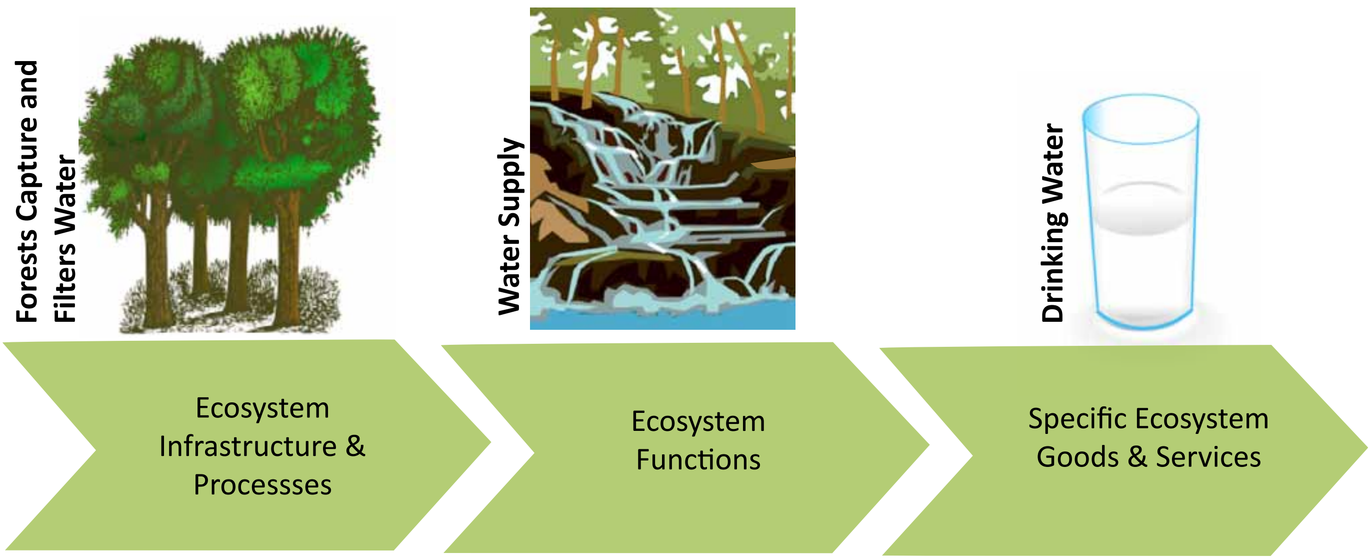
17 The agencies' websites contain more detailed information on these departments. For example: http://www.fs.fed.us/ecosystemservices/ (USFS); http://www.fs.fed.us/ecosystemservices/OEM/index.shtml (USDA).



Healthy, resilient, natural infrastructure, referred to as "natural capital," is critical to the production of ecosystem goods and services. The natural capital of an ecosystem consists of its individual structural components (trees, forests, soil, hill slopes, etc.) that produce dynamic processes (water flows, nutrient cycling, animal life cycles, etc.) which in turn create functions (water catchment, soil accumulation, habitat creation, etc.) that generate ecological goods and services (salmon, timber, flood risk reduction, recreation, etc.). It might be likened to the production of cars in a factory. Building a car (a "built" good) requires high quality built capital (e.g. the factory, machines and connection to a power plant), natural capital (e.g. the extracted metal, rubber, food for the workers), human capital (the workers), and financial capital (equity to buy the raw materials) and social capital (labor laws and agreements etc.). This relationship is summarized in figure 7.

The benefits of ecosystem goods and services are similar to the economic benefits provided by labor and capital that are typically valued in the economy, yet they are less often noticed or measured. For example, ecosystems (through ecological processes) provide the majority of flood risk reduction in

Figure 7 - The Link between Natural Infrastructure and Ecosystem Goods and Services



watersheds. If a levee is valued as an economic asset (as measured by the flood risk reduction provided and costs of the workers' time, fuel, and earthmoving equipment) but do not include the value of flood risk reduction provided by forests, wetlands, and lakes, then the economic analysis is deeply flawed. These natural assets provide as much, or often more, flood risk reduction than built structures and can frequently be implemented with little or no capital cost and low maintenance costs. Many built structures that people rely on for flood risk reduction, such as levees and dams, were installed decades ago, when understanding of land use practices was less refined. This has led to expensive cycles of loss and repair in many Washington watersheds, most often funded by taxpayers. Once lost, ecosystem goods and services are expensive to recover or may not be recoverable at all. If ecosystems are valued as assets however, the most valuable and cost-effective services will not be lost.

Ecosystem Goods

Ecosystem goods are typically tangible, quantifiable items or flows, such as drinking water, trees for forestry, fish, and food. Most goods are excludable, which means that if one individual owns or uses a particular good, that individual can exclude others from owning or using the same good. For example, if one person eats an apple, another person cannot eat that same apple. Excludable goods can be traded and valued in markets. The quantity of water produced per second or the amount of timber board feet produced in a 40-year rotation can be measured by the physical quantity an ecosystem produces over time. The current production of goods can be valued relatively easily, by multiplying the quantity produced by the current market price.

Ecosystem Services

Ecosystem services are defined as "the conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfill human life" (Daily 1997). Unlike ecosystem goods, ecosystem services are generally not tangible items that one can see or hold. Flood risk reduction, recreational value, aesthetic value, and storm-damage prevention are a few of the services that ecosystems may provide. Though often more difficult to value because market values rarely exist, ecosystems services have tremendous economic value and are critical both for our quality of life and economic production (Costanza, 1997; Daily, 1997).

Water filtration is an example of a critical ecosystem service. A standing forest may be cut down once every few decades to provide an ecosystem good (timber) with revenue generated from the harvest and sales of the wood. However, if left standing, the same forest might purify the drinking water for a nearby city for centuries, saving the cost of constructing a filtration plant and the additional costs of maintaining the plant each year as it begins to degrade. In addition, the forest may to provide flood risk reduction, soil erosion control, and many other services.

Public utilities for many North American cities, including Seattle, Everett, Tacoma, Portland, San Francisco, Vancouver (B.C.), New York and Boston have already decided that natural water purification is far more cost-effective than other alternatives. Each has purchased all or portions of forests near their water supply areas to purify their water. Seattle Public Utilities, for example, purchased a large portion of the Cedar River Watershed over 100 years ago. Through careful management of its forests the utility has avoided constructing a water filtration plant and upfront costs of $200 million (Batker et al., 2010; CH2MHILL, 2002). In addition, other ecosystem services such as carbon sequestration, wildlife habitat, soil erosion control, and many more will benefit from this management approach.

Ecosystem Service Valuation

Ecosystem service valuation assigns a dollar value to goods and services provided by a given ecosystem. This allows for proposed management policies to be considered in terms of their ability to improve ecological processes that produce valuable ecosystem goods and services. The full array of ecosystem goods and services produced in the Puyallup Watershed are valued in Part IV of this report.

Part III

Ecosystem Services in the Puyallup River Watershed

Section Summary: *Ecosystem services can be divided into four categories: Regulating, Habitat, Provisioning and Information services. In this section, a selection of ecosystem services is described in detail. Included are several examples of specific ecosystem services provided in the Puyallup Watershed.*

Categories of Ecosystem Services

Ecosystem services can be categorized in different ways. This study follows the approach developed by de Groot et al. (2002), dividing ecosystem services into functional categories. This approach is consistent with the Millennium Ecosystem Assessment completed in 2005, as well as much of the ecosystem service valuation literature. Economists have generally accepted these categories.

- **Regulating services** are benefits obtained from the natural control of ecosystem processes. Intact ecosystems provide regulation of climate, water, soil, flood and storms, and keep disease organisms in check.

- **Provisioning services** provide basic goods including food, water and materials. Forests grow trees that can be used for lumber and paper, wild and cultivated crops provide food, and other plants may be used for medicinal purposes. Rivers provide fresh water for drinking and fish for food. The coastal waters provide fish, shellfish and seaweed.

- **Information services** provide humans with meaningful interaction with nature. These services include spiritually significant species and natural areas, places for recreation, and educational opportunities through science.

- **Habitat services** provide refuge and reproduction habitat to wild plants and animals and thereby contribute to the (in situ) conservation of biological and genetic diversity and evolutionary processes.

Specific ecosystems services exist within each category, as identified in the following table.

Table 1 - List of 23 Ecosystem Services

	Good/Service	Economic Benefit to People
Provisioning	Water Supply	Water for human consumption, irrigation and industrial use.
	Food	Food for human consumption.
	Fiber and Fuel	Biological materials used for clothes, fuel, art and building. Geological materials used for energy, construction or other purposes.
	Medicinal Resources	Biological materials used for medicines.
	Ornamental Resources	Ornamental and companion uses (flowers, plants, pets, and other).
Regulating	Gas Regulation	Generation of atmospheric oxygen, regulation of sulfur dioxide, nitrogen carbon dioxide and other gaseous atmospheric components.
	Climate Regulation	Regulation of global and local temperature, climate, and weather, including evapotranspiration, cloud formation, and rainfall.
	Disturbance Prevention	Protection from floods, storms, and drought.
	Soil Retention	Erosion protection provided by plant roots and tree cover.
	Water Regulation	Water absorption during rains and release in dry times, temperature and flow regulation for people, plants and animals.
	Biological Control	Natural control of diseases and pest species.
	Water Quality and Waste Treatment	Absorption of organic waste, natural water filtration, pollution reduction.
	Soil Formation	Formation of sand and soil from decaying vegetation and erosion.
	Pollination	Fertilization of plants and crops through natural systems.
	Nutrient Regulation	Transfer of nutrients from one place to another; transformation of critical nutrients from unusable to usable forms.
Habitat	Habitat and Biodiversity	Providing habitat for plants and animals and their full diversity.
	Primary Productivity	Growth by plants provides basis for all terrestrial and most marine food chains.
Information	Aesthetic Information	The role which natural beauty plays in attracting people to live, work and recreate in an area.
	Recreation and Tourism	The contribution of ecosystems and environments in attracting people to engage in recreational activities.
	Scientific Knowledge	The value of natural systems for scientific research.
	Educational Value	The value of natural systems for education.
	Spiritual and Religious Experience	The use of nature for religious and spiritual purposes.
	Cultural and Artistic Information	The value of nature for cultural purposes.

Adapted from de Groot et al., 2002

Descriptions of Ecosystem Services

Disturbance Prevention

Healthy ecosystems often reduce the impact of natural disturbances on humans. Natural disturbances can include floods, storms, tsunamis, and fires. Flood and storm protection, in particular, are critical to maintaining economic security for communities, states and nations, as Hurricane Katrina demonstrated in New Orleans. Estuaries and bays, coastal wetlands, headlands, intertidal mudflats, sea-grass beds, rock reefs, and kelp forests provide storm protection along marine shorelines. These areas are able to absorb and store large amounts of rainwater or water runoff during a storm, in addition to providing a buffer for coastal waves (Batker et al., 2010; UNEP, 2005). Wetlands and floodplains are particularly important for absorbing waters during river flooding.

One of the most significant factors in an ecosystem's ability to attenuate flooding is the absorption capacity of the land. This is a factor of land cover type (forest vs. pavement, for example), soil structure and quality, and other hydrological and geological dynamics within the watershed. In the Puget Sound region, impermeable surface area, such as parking lots, roads and roofs, has increased by over 10% in the past 15 years. The U.S. Geological Survey estimates that in some rivers, urban development may lead to increases in flood-peak discharge flows of 100% to 600% for 2-year storm events, 20% to 300% for 10-year events, and 10% to 250% for 100-year events (Konrad, 2003).

Retention of forest cover and restoration of floodplains and wetlands provide tangible and valuable ecosystem services: reduced damage from floods to property, lost work time, injury, and loss of life. Today, changes in land use (such as urban development), combined with the potential for a higher return frequency for storm events due to climate change, make disturbance regulation highly important for the future of economic development in the Puyallup Watershed.

Local examples:
Flood risk reduction is an ecosystem service, arguably the most important kind of disturbance regulation in the Puyallup Watershed. Headwater forests to lowland wetlands and aquifers provide critical water regulation and storage that reduce floodwaters for downstream urban and rural residents. Floods have occurred for thousands of years along the rivers of the Puyallup Watershed. They are generated by the quantity, location, type and duration of precipitation, and by factors such as tides, terrain, vegetation, soil type, floodplain characteristics, channel shape and constrictions, temperature and hydrology. Flood damage occurs if people, houses, businesses, farms, and other assets are inundated. Substantial investments in pavement have caused more runoff in the Puyallup Watershed, spurring stormwater investments, contributing to greater flooding and requiring investments in higher levees downstream.

Minimizing risks from flooding is essential to the economy and quality of life in the Puyallup Watershed. Significant floods in November 1995 and February 1996, and several recent floods (November 2006, November 2008, and January 2009) have caused extensive flood damage in the Puyallup Watershed. A recent analysis (Entrix, 2010) focused on Pierce County's 100-year floodplain estimated that widespread flooding may cost up to $725 million in flood-related damage to personal property, economic output, recreation and transportation. Further, the vast majority of disruption is likely to occur within the Puyallup Watershed: Of the population and property value found within Pierce County's floodplains, approximately 99% is located in the Puyallup Watershed. In addition to economic impacts, flooding may have severe health and safety impacts. For example, three of Pierce County's wastewater treatment plants are located within the 100-year floodplain of the Puyallup River, in the cities of Puyallup, Sumner and Tacoma. Wastewater treatment plants can release untreated sewage if flooding damages the infrastructure (Entrix, 2010).

Greater investments in natural capital in the lower reaches of the Puyallup Watershed, where both urbanization and flood risk is greatest, could result in substantial returns on investment. The returns will be measured in ecosystem services, dollars, health, and social benefits. However, there is no single solution to flood risk reduction. A combination of built structures, ecosystems and social actions (such as warning systems and land use planning) are the most efficient and effective ways to provide flood risk reduction and build a healthy and prosperous economy. It is important to determine the right level of investment and balance between built structures and green infrastructure. In many cases it is possible to design built structures that function like green infrastructure. An example is a city stormwater system that retains water for longer (directing it to aquifers or wetlands) rather than hyper-efficiently pumping it back into the river (potentially increasing floodwaters downstream).

Recreation

Recreation is related to, but not totally encompassed by, aesthetic values. People travel to beautiful places for vacation, and engage in activities such as recreational fishing, scuba diving, surfing, kayaking, whale and bird watching, and enjoying local seafood and wines.

A substantial number of recreational activities, such as wildlife-watching and fishing, depend upon healthy ecosystems. Many other recreational activities would be less enjoyable and attract fewer participants without healthy ecosystems. Storm protection, shoreline stabilization, and waste treatment are also important ecological services associated with recreation and tourism because they help keep tourists safe as well as protect both private and public infrastructure needed for the tourist industry.

Local example:

The southeastern portion of the Puyallup Watershed is dominated by Mount Rainier. Mount Rainier is located within Mount Rainier National Park, which draws more than two million visitors each year, making it the most visited attraction in Washington State. The park offers a range of year-round and seasonal recreational opportunities, including skiing and snowboarding, hiking, mountain climbing, camping, bicycling, fishing and scenic drives. Recreation supported by the natural capital of Mount Rainier National Park is a significant driver for the local watershed economy and in general promotes sustainable jobs that require less intensive built capital inputs than other economic sectors. Mount Rainier also provides indirect recreational services to the lower reaches of the Puyallup Watershed by supplying large quantities of water to major streams, including the Puyallup, White and Carbon Rivers.

The 80 acres of Lake Tapps are popular for swimming, boat launching and park trails, while the Puyallup and White Rivers attract kayaking and fishing (Puget Sound Partnership, 2009; Pierce County Parks and Recreation, 2010). Tourism is a $13.8 billion industry in Washington State and close to 80% of this revenue is generated within the Puget Sound region (Puget Sound Partnership Resource Center, 2010).

Science and Education

The number of educational and research institutions devoted to studying marine and terrestrial environments shows the scientific and educational importance of ecosystems. Government, academic, and private resources are devoted to formal study of ecosystems in the Puget Sound Basin. Study of the natural environment produces human, social and economic benefits. Scientific and educational institutions devoted to both marine and terrestrial environments also provide local employment.

Local example:
The Center for Urban Waters, located in Tacoma, houses the City of Tacoma's Environmental Services division, the University of Washington Tacoma's environmental sciences research program, and the Puget Sound Partnership's offices. The Center "…brings together organizations with complementary missions and individuals with diverse skills to develop innovative approaches to environmental restoration, as well as protection and to sustainable urban development." (University of Washington, 2010). The building is located on the Thea Foss Waterway, a body of water in Commencement Bay widely seen as a model for restoration that achieves both environmental and economic benefits. The center houses teams of scientists doing theoretical and applied research and modern laboratories where scientists and technical staff can monitor levels of pollutants in water, soils, sediment, biota and air throughout the Puget Sound region. The common location allows analysts and other technical staff from three major agencies to collaborate in real time, creating natural synergies. The center is being used to develop scientific assessments on which policymakers can base important decisions. Also, undergraduate and graduate students at the University of Washington Tacoma have the opportunity to work alongside staff at the Center, exposing the students to a world-class research facility and disciplinary experts.

Water Supply

As water moves through a watershed, it can be extracted as surface water or ground water for the use of large metropolitan areas, industry and agriculture. The hydrologic cycle is affected by structural elements of a watershed, such as forests, wetlands and geology, as well as by processes such as evapotranspiration and climate. More than 60% of the world's population gets its drinking water from forested watersheds (UNEP, 2005). Increasing loss of forest cover around the world has decreased water supply, due to lower ground water recharge and lower flow reliability (Syvitski, 2005).

Local examples:
In the Puget Sound region, snowpack performs a critical water storage and supply service. Snowmelt in the Puget Sound provides around 70% of drinking water annually (Chang et al., 1987). Current reservoir systems in the region largely depend on snowpack to supplement water storage: almost all of the major municipal water systems west of the Cascades have storage-to-instream flow ratios of less than 10% (Hamlet et al., 2001). Snowpack in the region may in this way be viewed as essentially a large, inexpensive system of reservoirs. The economic value of snowpack to the Puget Sound population can be assessed by exploring the replacement cost for an alternative storage system, such as a surface water reservoir. If the environmental costs of implementing man-made reservoir systems were included – such as disruption of salmon runs and loss of vegetation – the replacement cost of snowpack might be substantially higher.

The delivery and quality of ground water through watershed processes is vital to many residents of the Puyallup Watershed. Most domestic water needs are met by wells reaching several hundred feet deep into glacial deposits that underlie the area. Tacoma Public Utilities' existing groundwater sources include 24 wells located within the city's service area and the Green River, located in the Green-Duwamish Watershed (Water Supply Forum, 2010). These water sources help supply water to more than 310,000 people, including residents of the City of Tacoma (Tacoma Water, 2008). The City of Puyallup draws 62% of its water from the Salmon and Maplewood Springs, both of which are supplied by the melting snowpack of Mount Rainier and local precipitation (City of Puyallup, 2008), with much of the remainder sourced from one of five local wells. Rapid growth of population in the Tacoma-Puyallup area has placed increasing demands on groundwater resources, and some concerns have been raised that land development may impede infiltration of precipitation downward into the ground, thus increasing surface water runoff (contributing to flooding) and reducing available groundwater (Jones et al., 1999). In addition, some land uses can impact the quality and safety of ground water. For example, shallow aquifers underlying areas of high urban and agricultural concentration are at the highest risk of nitrate contamination (Tesoriero and Voss, 1997, cited in Jones et al., 1999), and traces of industrial pollutants have previously been found in two wells in South Tacoma (Historylink, 2010).

Nutrient Regulation

The transfer of nutrients from one place to another and transformation of critical nutrients from unusable to usable forms is an essential ecosystem service. All living things depend on the nutrient cycles of carbon, oxygen, nitrogen, phosphorous, and sulfur in relatively large quantities. These are also the nutrient cycles that humans have most affected through the burning of fossil fuels, deforestation, heavy use of agricultural fertilizers, and other activities. Silicon and iron are important elements in oceanic nutrient cycles because they affect phytoplankton community composition and productivity. Natural processes facilitate the movement of nutrients and turn them from biologically unavailable forms, such as rocks or gases in the atmosphere, into forms that can be used by other living things. Nutrient cycling is a fundamental precursor to ecosystem and economic productivity; without functioning nutrient cycles, life on the planet would cease to exist.

Living organisms mediate nutrient regulation. On land, plants depend on biologically mediated breakdown of organic matter to make the nutrients they need for growth available. As plants and plant parts decompose, they contribute to the pool of organic matter that feeds the microbial, fungal and micro-invertebrate communities in soils. Underground fungal structures can also provide support to living plants. For example, young trees may not receive enough light (and therefore nutrients) because mature trees block sunlight, but they can draw nutrients from fungal structures hundreds of yards away (Stamets, 2005). Such communities facilitate the transformation of nutrients from one form to another. Larger animals play a crucial role in nutrient cycles by moving nutrients from one place to another in the form of excrement, and through the decomposition of their bodies after they die. Animals also play a role in transporting nutrients between terrestrial and aquatic environments. Salmon and marine birds bring marine nutrients into terrestrial and freshwater ecosystems, enhancing the productivity of these systems throughout several layers of the food web (Polis et al., 1997).

Local example:
Salmon enhance local ecosystems in the Puyallup Watershed by moving nutrients into creeks and rivers such as South Prairie Creek. Salmon spend most of their lives in the nutrient-rich northern Pacific Ocean, where they accumulate carbon, nitrogen, phosphorous and other micronutrients in their body tissue. When they return to spawn and die, these marine-derived nutrients are released into the freshwater river system, providing an important "energy subsidy" to nutrient-poor rivers and streams (Merz and Moyle 2006; Willson and Halupka 1995). This process is vital to the biological productivity and health of inland streams and riparian vegetation (Wipfli et al., 1999; Bilby et al., 2003; Kline et al., 1990). It has also been found to elevate the growth rates of young salmon and resident fish, such as trout, resulting in improved survival rates, and greater abundance of fish in following years (Wipfli et al., 2003). Salmon therefore play an important role in cycling nutrients back into the watershed, promoting the health of their habitat and, in turn, the health of their own populations.

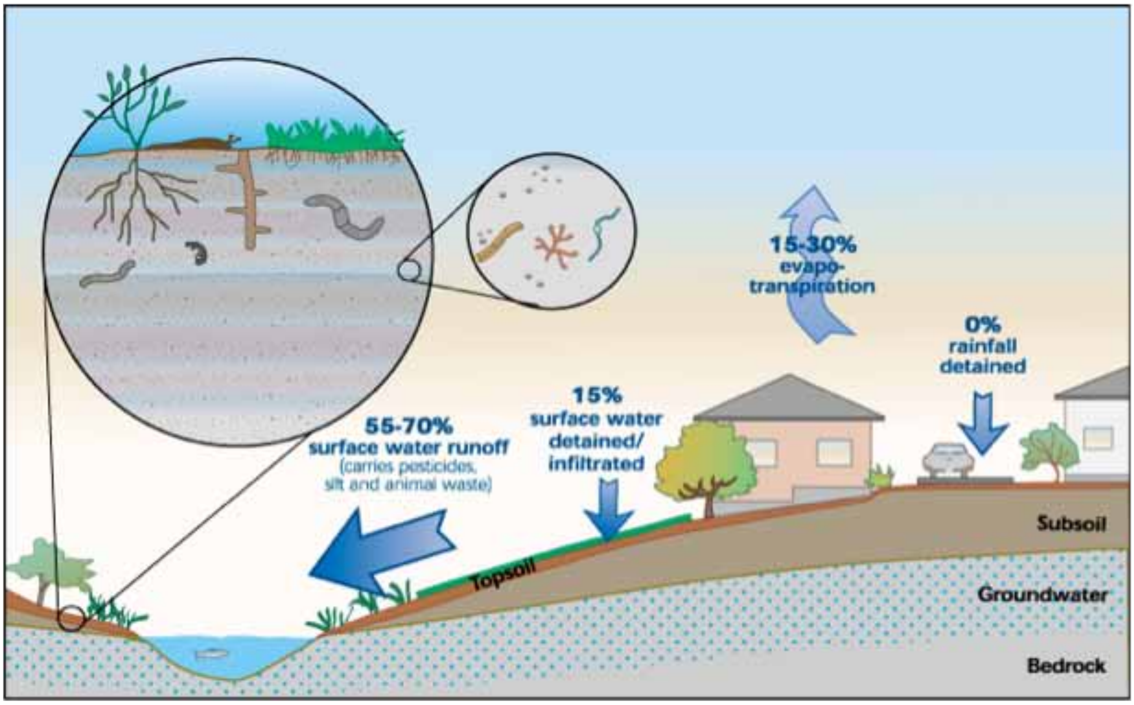
Water Regulation

The amount and timing of water flow in the Puyallup Watershed is important for many reasons: The supply of adequate amounts of cool water at critical times is important for salmon migration, and the filtration of water allows for clean drinking water. Also important in Washington State, the operation of reservoirs and dams for the production of hydroelectricity is tuned to the seasonal timing and volume of stream flow. Recent analysis suggests that a lengthened summer low-flow period may increase competition over water use for hydroelectric generation, irrigation, and in-stream flow protection for salmon (Casola et al., 2005). Water regulation includes regulation of water flows through the ground and along terrestrial surfaces, and regulation of temperature, dissolved minerals and oxygen. Many ecosystems absorb water during rains and release it in dry times, and also regulate water temperature and flow for plant and animal species. Forest cover, riparian vegetation, and wetlands all contribute to modulating the flow of water from upper portions of the watershed to streams and rivers in the lower watershed. In undeveloped areas of a watershed, typically less than 15% of precipitation reaches streams or rivers as surface runoff, compared with 55 to 70% in a developed watershed. See Figures 8 and 9 for a graphic illustration.

When forested basins are heavily harvested the ground's capacity to absorb water is reduced, and surface water runoff is increased and conveyed into streams and rivers, contributing to higher peak flows, more frequent flood events, erosion and landslide issues. Another result may be lower low flows in summer months, because the water is not retained in soils and aquifers (Moore and Wondzell, 2005).

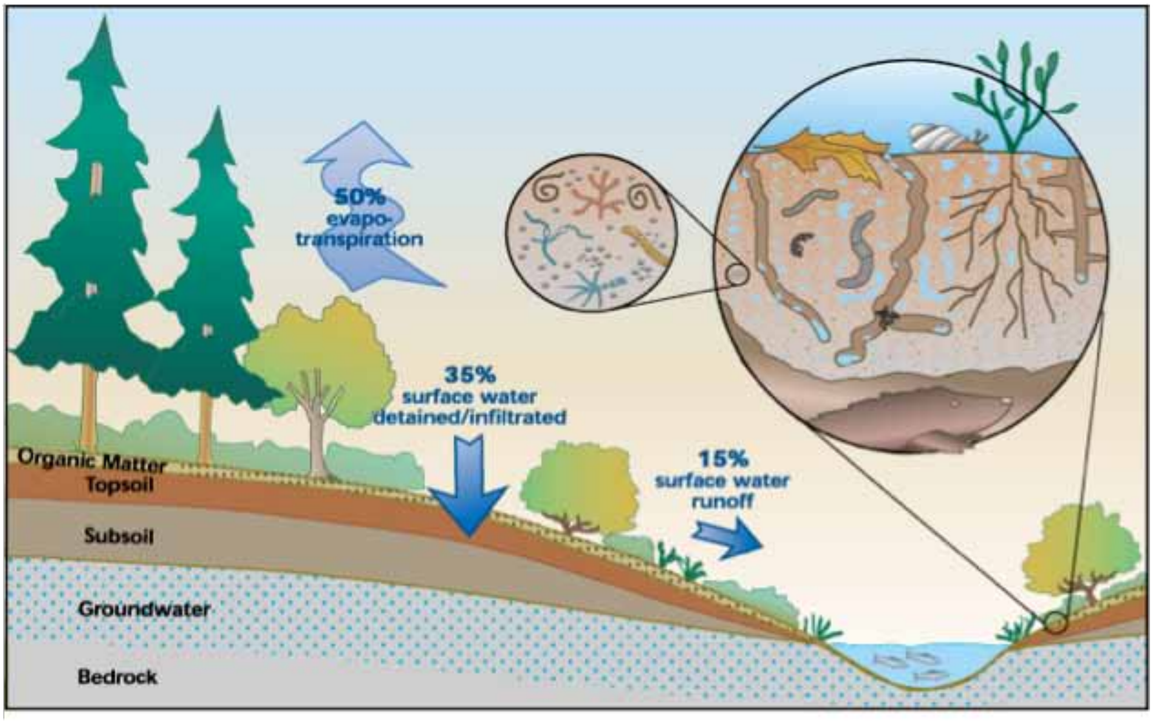
Local example:
The Climate Impacts Group, a research group based at the University of Washington, recently published a report on the likely effects of climate change in the Pacific Northwest region (Mantua, Tohver and Hamlet, 2009). Their simulations suggest that climate change will have an effect on the timing and magnitude of annual river and stream flows. This means that in the Puget Sound region, salmon with an ocean-type life history (with a relatively brief freshwater rearing period) are likely to experience a reduction in freshwater survival and productivity because a greater frequency and magnitude of winter flooding will affect egg-to-fry survival rates. A management approach that acknowledges changes in future water flow regimes and builds resilience into ecosystems is therefore essential to regional salmon recovery efforts.

Figure 8 - The Movement of Water in a Developed Watershed



Source: King County

Figure 9 - The Movement of Water in a Forested Watershed



Source: King County

Spiritual and Religious Experience

Many natural areas have special importance to tribes from a spiritual perspective, as evidenced by indigenous traditions, including stories and art depicting salmon, other marine organisms and watershed residents. Non-tribal people also tend to feel an emotional or spiritual connection to the landscape in which they live. Spiritual and religious values are difficult to assess monetarily, as there is no real way to measure their quantity or importance across individuals. One way to gain insight is to ask people how much they would be willing to pay to protect a given species or area.

Soil Formation

Soil serves a vital function in nature, providing a medium for plant growth as well as nutrients for plants, and habitat for millions of micro- and macro-organisms. Healthy soils are able to store water and nutrients, regulate water flow, and neutralize pollutants more efficiently than degraded soils (Marx et al., 1999). Soil retention contributes to a number of other ecosystem services, including disturbance prevention, salmon habitat, and provisioning of raw materials such as timber. Soil quality and abundance is critical for human survival. However, many human actions can negatively affect natural formation of high-quality soils. Soil is formed over thousands of years through a process that involves parent material, climate, topography, organisms, and time (United States Department of Agriculture Soil Conservation Service, 1983).

Soil Retention

The interplay between soil retention and natural rates of soil erosion is important to Pacific Northwest ecosystems, for example allowing fertile soils to be deposited on floodplains and providing the gravel required for salmon spawning. Coastal erosion is a natural process along Puget Sound's shorelines, building, maintaining and moving shorelines naturally with interactions of wave energy and sediment deposition. Erosion also creates raw materials for human use: Historic gravel deposits are mined in the Puyallup Watershed (Lower Puyallup Watershed Management Committee, 1995).

The soil retention properties of ecosystems determine the soil's rate of erosion. The susceptibility of a given slope to erosion is determined by factors such as grain size, soil cohesion, slope gradient, rainfall frequency and intensity, surface composition and permeability, and type of land cover. Soil retention is closely linked with prevention of disturbances, such as landslides, which are often caused by excessive erosion and can frequently be attributed to human land use. A healthy forest's organic layers act as a natural sponge, absorbing water during periods of heavy precipitation and preventing erosion. In areas where active forestry occurs, the upper layers of soil are often removed or degraded.

Water Quality and Waste Treatment

Microorganisms in sediments and mudflats of estuaries, bays, and nearshore submerged lands break down human and other animal wastes (Weslawski et al., 2004). They can also detoxify petroleum products. The physical destruction of habitat, alteration of food webs, or overload of nutrients or waste products disrupts disease regulation and waste processing services. Alteration of ecosystems can also create breeding sites for disease vectors where they were once nonexistent. People can be exposed to disease in coastal areas through direct contact with bacterial or viral agents while swimming or washing in fresh or saltwater, and by ingesting contaminated fish, seafood, or water.

Water quality is extremely important to healthy native fish and wildlife populations. Because most aquatic biological processes are limited by nitrogen and phosphorous, changes in these nutrient levels may have significant effects on ecosystems. For example, increases in nutrient loading in Hood Canal due to failing septic systems has caused low dissolved oxygen, or "dead zones," where fish are unable to live. Land-use patterns also play an important role. Researchers have found that more agriculturally active and heavily urbanized watersheds contribute three times the nitrogen and phosphorous loads to Puget Sound waters than the forested watersheds in the Olympic Mountains (Embrey and Inkpen, 1998). Wetlands, estuarine macroalgae and nearshore sedimentary organisms play a crucial role in removing nitrogen and phosphorous from water (Garber et al., 1992; Weslawski et al., 2004).

Biological Control

Healthy ecosystems limit the population of invasive plant species, pests and diseases, protecting human health, crops and livestock. A number of natural predators exist for pest species, which can contribute to control of damages. Natural predators can also play a role in protecting forests from pests. For example, birds consume insects that may prey on trees.

Many exotic species have in modern times been introduced to areas beyond their natural range, and some have caused significant crop damage; estimates for this damage in the United States range from $1.1 billion to $137 billion annually (Chapin et al., 2000). Another study estimated that the loss of major crops (wheat, maize and cotton) due to weeds, pests and disease was at least 28% for the years 2001-2003. The study also found that the proportions of crop losses have not decreased significantly over the last 40 years, despite a clear increase in the use of pesticides (Oerke, 2006).

The evolving field of integrated pest management has shown that pests are best managed naturally and treated with pesticides only as a last resort. There are also ways to manage crops so as to enhance biological control services. These techniques include crop diversification and genetic diversity, crop rotation, and promoting an abundance of smaller patches of fields (Lichtfouse et al., 2009; Risch et al., 1983).

Habitat and Biodiversity

Biological diversity is defined as the number and types of species as well as the ecosystems they comprise. It is measured at gene, population, species, ecosystem, and regional levels (Magurran, 1988). Biodiversity must exist for the flow of ecosystem services, and can also be considered an ecosystem service in itself (UNEP, 2005). Ecosystems with a diverse complement of native species tend to be more productive and more resilient to change despite environmental conditions or external shocks.

Habitat is the biophysical space formed by (typically natural) processes in which species meet their needs. A healthy ecosystem provides physical structure, adequate food availability, appropriate chemical and temperature regimes and protection from predators. In addition to the physical structure provided to species, food web relationships are important components of habitats.

One recent meta-analysis of marine data and studies examining the effects of biodiversity on ecosystem services found strong evidence that loss of biodiversity leads to fisheries collapse, lower potential for species population and system recovery, loss of system stability, and decreased water quality. The relationship is one of an exponential loss of ecosystem services with declining diversity (Worm et al., 2006). The study also found that restoration of biodiversity, through such mechanisms as the establishment of marine reserves protected from fishing pressures, may lead to a fourfold increase in system productivity and a 21% decrease in variability (i.e., an increase in resilience). This study provides the best evidence to date of the direct relationship between biological diversity and ecosystem services in the marine environment.

Primary Productivity

Primary productivity is another supporting service upon which all other ecosystem services depend. It refers to the conversion of energy from sunlight into forms that living organisms use. Aquatic and upland plants perform this function in a variety of habitats. Human life depends on primary productivity through consumption of food such as crops, wild plants, seaweed, seafood, and livestock, and use of photosynthesis-dependent materials such as wood, cotton, medicines and petroleum.

Humans appropriate over 40% of the planet's terrestrial primary productivity, and this share is increasing – with tremendous ecological implications for the rest of the planet's organisms and energy budget (Vitousek et al., 1986; Pimm, 2001). One likely outcome of greater consumption of primary productivity is the loss of biological diversity, which, as discussed above, would have severe consequences on the delivery of many other ecosystem services. Loss of forests to development also decreases primary productivity.

Marine primary productivity comes from wetland plants, macro-algae, and sea grasses in the coastal and nearshore environment, as well as from phytoplankton in the continental shelf and deep-sea waters. Most marine primary productivity occurs in the coastal zone out to the farthest extent of the continental shelf. About 8% of total primary productivity of ocean ecosystems supports fisheries. However, when the calculation is confined to parts of the ocean where most primary productivity and fish catches occur, the number approaches the productivity of terrestrial systems, or 25 to 30% (Pauly and Christensen 1995, Pimm, 2001).

When humans consume most ocean primary productivity, less productivity will be left to fuel the remainder of the food web and all the ecological processes that it drives (Pimm, 2001). Whereas fish harvests in the past were focused primarily on the top-level food-web species such as cod, as demand has grown and many fisheries have collapsed, fishing pressure has been increased on smaller species like mackerel, herring and anchovies. This shift in target species, often called "fishing down the food chain," place additional pressure on top predator fish by removing their food supply. In addition, climate change has large implications for ocean productivity due to changes in currents, upwelling, and changes in water chemistry (Orr et al., 2005).

Gas and Climate Regulation

Gas regulation and climate regulation refer to the roles that ecosystems play in regulating the gaseous phase of organic and inorganic compounds that affect atmospheric composition, air quality and climate. Atmospheric oxygen is a product of photosynthesis from marine plankton and terrestrial plants. Removal of pollutants is another important aspect of gas and climate regulation. American Forests (1998) calculated that urban forests remove 78 million pounds of pollutants per year in the Puget Sound area. Low air quality can cause health care costs to spike as respiratory diseases develop. The regulation of climate is dependent on the composition of the atmosphere. "Greenhouse gases" such as $CO2$ are transparent to light, but trap heat, warming the planet like a greenhouse. Carbon dioxide is removed through carbon sequestration as plants absorb $CO2$ to grow.

Pollination

Pollination is essential to agricultural crops, trees and flowers. Insects, birds, mammals and the wind transport pollen grains to fertilize plants. People depend on pollination directly for food and fiber (such as wood, paper and cloth), and indirectly as part of ecosystem productivity. Many plant species would go extinct without animal- and insect-mediated pollination. Pollination services by wild animals are also crucial for crop productivity for many types of cultivated foods, enhancing the basic productivity and economic value of agriculture (Nabhan and Buchmann, 1997). Notably, some plants have only a single species pollinator. The importance of wild pollinators to food crops means that wild habitats near croplands are necessary in order to provide sufficient habitat to keep populations of pollinators intact.

Food

Providing food is one of the most important functions of ecosystems. Agricultural lands are the primary source of food for humans. Farms are considered modified ecosystems, and food is considered an ecosystem good with labor and built capital inputs. In traditional economic analyses, agricultural value is measured by the total market value of crops produced. While this measure is useful, market value is only a small portion of the total value agricultural lands provide through pollination, carbon sequestration, aesthetic value, and other services. Marine ecosystems are the largest sources of food from wild ecosystems. Globally, fish and seafood are the primary source of protein for one billion people, with fishing and fish industries providing direct employment to some 38 million people (UNEP, 2005).

Aesthetic Information

Aesthetic value, as an ecosystem service, refers to the appreciation of and attraction to beautiful natural landscapes and seascapes. The existence of national seashores, state and national parks, scenic areas, and officially designated scenic roads and pullouts attest to the social importance of this service. There is also substantial evidence demonstrating the economic value of environmental aesthetics through analysis of data on housing markets, wages, and relocation decisions (Palmquist, 2002 and see studies included in valuation results). Degraded landscapes are frequently associated with economic decline and stagnation (Power, 1996).

Part IV Valuation of the Puyallup River Watershed

Section Summary: *The economic value of ecosystem services generated in the Puyallup Watershed was estimated using benefit transfer methodology. The results show that ecosystem goods and services within the Puyallup Watershed generate at least* ***$526 million to $5 billion*** *in economic value annually. If treated like a traditional economic asset, these ecosystem services would have a value of between* ***$13 billion and $120 billion, calculated with a 4.125% discount rate over 100 years.***

Overview

The valuation of ecosystem services in the Puyallup Watershed can be divided into the following steps:

- Quantification of Land Cover Classes: Geographic Information Systems (GIS) data is used to assess the acreage of each land cover class within the watershed. Examples of land cover classes include pasture, estuary, urban green space and riparian forest. Land cover classes were chosen based on the ability to derive ecosystem valuation data for that type of class.

- Identification of Ecosystem Services and Valuation of Land Cover Classes: The ecosystem services provided within the watershed are identified. Using a database of peer reviewed ecosystem service valuation studies, a range of studies for each specific land cover class is selected depending on the geographic and land-cover match to the site. These are like comparables used in a house or business appraisal. Each land cover class is assigned a total high and low annual per-acre value for its ecosystem services.

- Valuation of the Puyallup Watershed: The total high and low annual value of ecosystem services for each land cover class is multiplied by the acreage of that land cover class within the watershed to arrive at total high and low annual value estimates. Land cover class values are summed to arrive at a total annual value for the Puyallup Watershed. Net present values are calculated for the watershed over 100 years at two discount rates: zero (no discount) and 4.125% (the U.S. Army Corps of Engineers 2011 discount rate).

Quantification of Land Cover Classes

Geographic Information Systems (GIS) data is used to assess and categorize the land cover in the Puyallup Watershed. The GIS data is gathered through aerial and/or satellite photography and can be classified according to several classification systems or "layers." Earth Economics maintains a database of peer-reviewed valuation studies organized by land cover

Table 2 - NLCD Land Cover Classes used in this Study

NLCD Code	NLCD Description
11	Open Water
12	Perennial Ice/Snow
21	Developed, Open Space
22	Developed, Low Intensity
23	Developed, Medium Intensity
24	Developed, High Intensity
31	Barren Land
41	Deciduous Forest
42	Evergreen Forest
43	Mixed Forest
52	Shrub/Scrub
71	Herbaceous
81	Hay/Pasture
82	Cultivated Crops
90	Woody Wetlands
95	Emergent Herbaceous Wetlands

class, which typically requires GIS data from several different sources. For this valuation, the Puyallup Watershed was divided into 13 land cover classes.

The United States Geological Survey 2001 National Land Cover Database (NLCD) was used as the foundational GIS layer. NLCD land cover types found in the Puyallup Watershed are listed in Table 2, and referenced by Table 3. One other layer, consisting of the Pierce and King County Urban Growth Area boundaries, was then combined with the NLCD layer using specific rules to yield 13 final land cover classes. Table 3 presents the final land cover classes and acreages that comprise the Puyallup Watershed, as categorized for this report, a description of the layer(s), and the rationale employed to obtain the acreage values. Figure 10 graphically depicts the distribution of land cover within the Puyallup Watershed.

Figure 10 - Land Cover Classes within the Puyallup Watershed

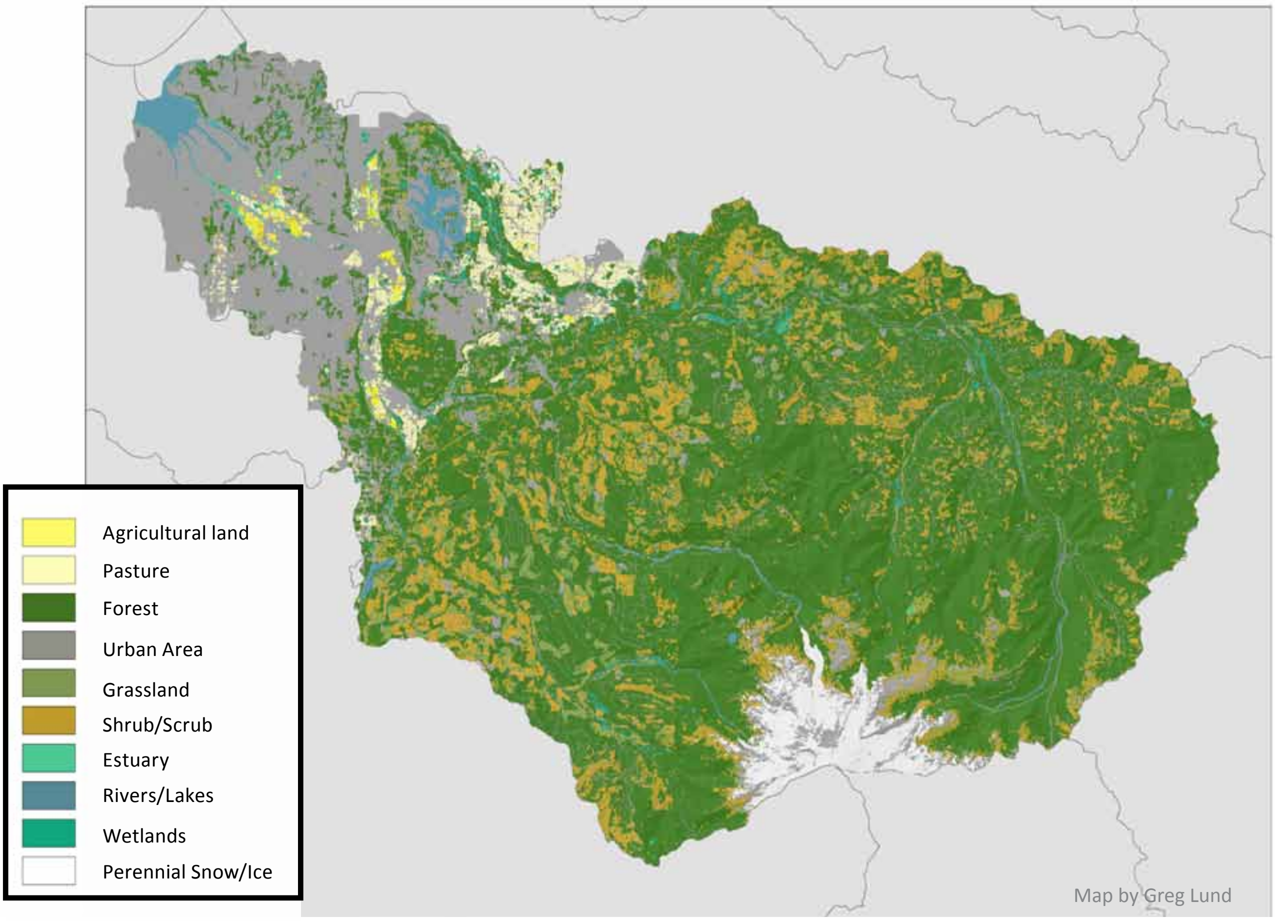


Table 3 - Total Acreages by Land Cover Class in the Puyallup River Watershed

Land Cover Class	Acreage	Data Source(s)/Layers Used and Rationale
Agricultural Lands	2,470	NLCD 82.
Pasture	16,646	NCLD 81.
Forest	359,586	NLCD 41, 42, 43
Urban Green Space	18,594	NLCD 41, 42, 43 within Urban Growth Areas minus Riparian Forest and Riparian Shrub.
Grasslands	30,037	NLCD 71.
Shrub/Scrub	77,723	NLCD 52.
Riparian Forest	1,326	NLCD 41, 42, 43 within 50 ft. buffer of NLCD 11 except Commencement Bay Estuary area.
Estuary	4,028	NLCD 11 within Commencement Bay area.
Rivers and Lakes	6,776	NLCD 11 minus Estuary.
Emergent Herbaceous Wetlands	1,606	NLCD 95.
Woody Wetlands	9,144	NLCD 90.
Perennial Ice/Snow	18,232	NLCD 12.
Barren/Developed	126,964	NLCD 21, 22, 23, 24, 31.
Total	**673,916**	

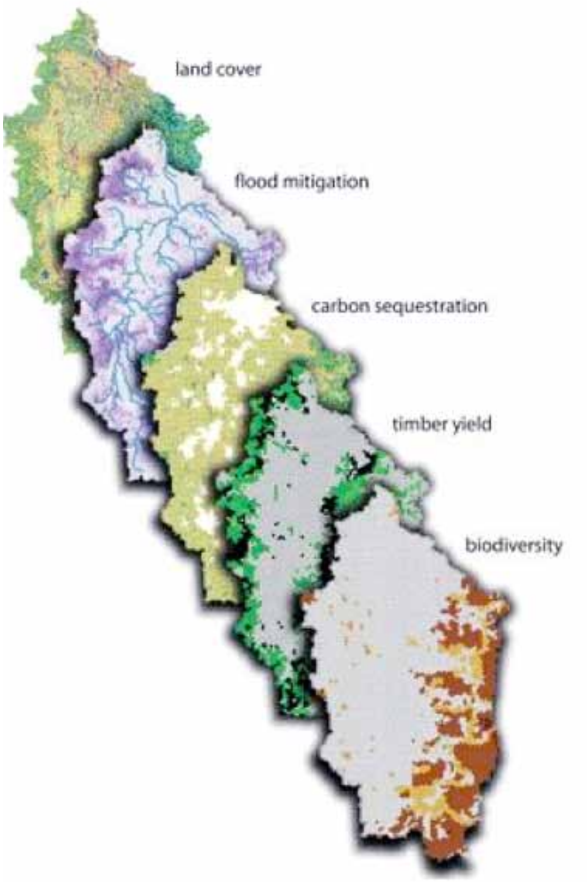
Identification of Ecosystem Services and Valuation of Land Cover

Identification of Ecosystem Services

The spatial distribution of goods and services produced in a region's economy can be mapped across the landscape. Mapping goods and services provided by factories, restaurants, schools and businesses provides a view of the economy of that region. For example, retail, residential and industrial areas occur in different parts of the landscape. The economic value of these goods, services, housing and industry can also be estimated from market or appraisal values.

The distribution of ecosystem services throughout the Puyallup Watershed is similar. Each land cover class, from wetland to mature forest to agricultural field, provides economically valuable goods and services. For example, a wetland provides ecosystem services such as flood risk reduction, biodiversity, climate regulation and soil formation. Eelgrass provides shoreline stabilization and climate regulation, but not soil formation. Figure 11 illustrates how ecosystem services are "stacked" upon the landscape, in the Willamette Basin in Oregon. The first layer, "land cover," depicts the land cover classes providing ecosystem services. Some land cover classes produce both flood risk reduction and carbon sequestration, while others produce only flood risk reduction. Note that biodiversity is concentrated in one half of the basin, so these areas are critical to a biodiversity strategy.

Figure 11 - Example of different Suites of Ecosystem Services Provided by Various Land Covers



Source: Erik Nelson and Heather Tallis, Stanford University, Palo Alto, California

Land Cover Class Values

Natural capital in the Puyallup Watershed generates a flow of value, analogous to an annual stream of income. As long as this natural infrastructure of the watershed is not degraded or depleted, this flow of value will likely continue into the distant future. This flow of value is expressed in $/acre/year, which represents the dollar value generated by a single ecosystem service on a particular land cover class. For example, based on a specific peer-reviewed scientific report, urban wetlands in Western Washington were shown to provide up to $51,000/acre/year in flood risk reduction benefits (Leschine et al., 1997).

The full suite of ecosystem services produced by a particular land cover class yield a total flow of value for that land cover class. In the case of wetlands, this means summing all of its known ecosystem service values (i.e. water regulation, habitat, recreation, etc.), for which valuation studies have been completed. This number can then be multiplied by the number of acres of wetlands in the Puyallup Watershed for a value in $/year.

By “transferring” values from a database of peer-reviewed academic studies and journal articles, the appraisal of ecosystem service values is accomplished. This approach is known as “benefit transfer.” This is an appraisal, rather than a precise measure, because often the location of the wetland or other land cover is critical to the valuation. For example a wetland right upstream from a town provides greater flood risk reduction value than a wetland downstream. The next step of spatial valuation on the landscape depending on proximity has been the subject of a National Science Foundation grant to Earth Economics and academic partners. See Appendix B for the list of primary studies applied to the Puyallup Watershed valuation. These primary studies utilized one of the eight valuation methods shown in Table 4.

Table 4 - Valuation Methods Used to Value Ecosystem Services in Primary Studies

Avoided Cost (AC): services allow society to avoid costs that would have been incurred in the absence of those services; for example storm protection provided by barrier islands avoids property damages along the coast.

Replacement Cost (RC): services can be replaced with man-made systems; for example waste treatment provided by wetlands can be replaced with costly built treatment systems.

Factor Income (FI): services provide for the enhancement of incomes; for example water quality improvements increase commercial fisheries catch and therefore fishing incomes.

Travel Cost (TC): service demand may require travel, which have costs that can reflect the implied value of the service; recreation areas can be valued at least by what visitors are willing to pay to travel to it, including the imputed value of their time.

Hedonic Pricing (HP): service demand may be reflected in the prices people will pay for associated goods, for example housing prices along the coastline tend to exceed the prices of inland homes.

Marginal Product Estimation (MP): service demand is generated in a dynamic modeling environment using a production function (Cobb-Douglas) to estimate the change in the value of outputs in response to a change in material inputs.

Contingent Valuation (CV): service demand may be elicited by posing hypothetical scenarios that involve some valuation of alternatives; for instance, people generally state that they are willing to pay for increased preservation of beaches and shoreline.

Group Valuation (GV): this approach is based on principles of deliberative democracy and the assumption that public decision making should result, not from the aggregation of separately measured individual preferences, but from open public debate.

Due to limitations in the range of primary valuation studies conducted on ecosystem services, not all ecosystem services that were identified on each land cover class could be assigned a known value from the database. For example, the land cover class “Urban Green Space” has only been valued for four ecosystem services – climate regulation, aesthetic value, water regulation, and science and education – though such areas also clearly provide biological control, disturbance prevention, nutrient cycling, and a number of other important benefits. A matrix that summarizes the suite of ecosystem services identified by each land cover type in the Puyallup River Basin, compared with those that were actually valued in this study, is provided in Table 5.

Table 5 - Ecosystem Services Valued and/or Identified in the Puyallup River Watershed

	Agriculture	Beach	Eel grass beds	Estuary	Forest - Mid	Forest - Late	Grasslands/Rangelands	Lakes/Rivers	Marine	Pasture	Riparian buffer	Shrub	Urban green space	Wetland	Barren/Developed	Perennial Ice/Snow
Provisioning Services																
Food	x															
Raw Materials																
Genetic Resources																
Medicinal Resources																
Ornamental Resources																
Regulating Services																
Gas Regulation						x	x				x	x	x	x		
Climate Regulation																
Disturbance Prevention											x			x		
Soil Retention							x									
Water Regulation						x	x				x		x	x		
Water Supply				x	x			x	x		x			x		
Biological Control					x		x									
Water Qty./Waste Trtmt.							x							x		
Soil Formation										x						
Nutrient Regulation																
Pollination																
Habitat Services																
Habitat and Biodiversity				x	x	x		x			x	x		x		
Nursery																
Provisioning Services																
Aesthetic Information	x			x	x						x			x		
Recreation	x			x	x	x		x		x	x	x	x	x		
Cultural & Artistic Info.																
Science and Education																
Spiritual & Historic Info.											x			x		

Key:

(blue)	Ecosystem service produced by land cover class but not valued in this report
x	Ecosystem service produced by land cover class and valued in this report
	Ecosystem service not produced by land cover class

Table 5 indicates that a large number of ecosystem services (for each land cover class) have yet to be valued in a primary study. This suggests that the dollar estimation is a significant underestimate of the true value, because many ecosystem services identified as valuable do not have an associated valuation study. As further primary studies are added to the database, the combined known value of ecosystem services in the Puyallup Watershed will rise. Tables 6 – 10 summarize the final ecosystem service values for individual land cover classes in the Puyallup Watershed.

Table 6. High and Low Dollar per Acre Estimates for Estuary, Forest All Ages, and Rivers and Lakes

	Estuary		Forest All Ages		Rivers and Lakes	
Ecosystem Service General	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**
Aesthetic & Recreational	$1.44	$1,298.23	$0.18	$2,158.01	$1.79	$20,880.94
Biological Control	$31.57	$31.57	$1.62	$9.53		
Cultural & Spiritual	$15.04	$20.82	$0.26	$2.41		
Disturbance Regulation	$229.44	$229.44	$14.83	$14.83		
Erosion Retention			$55.37	$110.34		
Gas & Climate Regulation			$10.57	$1,049.40		
Genetic Resources			$9.23	$9.23		
Habitat Refugium & Nursery	$12.24	$1,468.64	$1.05	$2,972.74	$17.13	$1,568.63
Nutrient Cycling	$5,909.39	$16,556.93	$208.23	$534.31		
Pollination			$59.00	$420.45		
Raw Materials	$15.57	$15.57	$10.00	$348.47		
Soil Formation			$4.05	$5.77		
Storm Protection			$1.15	$1.15		
Waste Treatment			$35.21	$166.29	$74.43	$967.62
Water Regulation			$0.06	$534.31	$908.86	$3,510.07
Water Supply	$5.53	$135.51	$9.00	$843.44	$32.34	$5,925.34
Food Production	$15.97	$708.84	$28.12	$28.84	$16.59	$16.59
Science and Education			$39.08	$67.27		
TOTAL	**$6,236.19**	**$20,465.55**	**$487.01**	**$9,276.79**	**$1,051.14**	**$32,869.19**

Table 7. High Low Dollar per Acre Estimates for Pasture and Urban Green Space

	Pasture		Urban Green Space	
Ecosystem Service General	**Min**	**Max**	**Min**	**Max**
Aesthetic & Recreational	$0.03	$25.77	$1,336.99	$3,919.27
Biological Control	$13.56	$13.56		
Cultural & Spiritual				
Disturbance Regulation				
Erosion Retention				
Gas & Climate Regulation			$28.42	$927.28
Genetic Resources				
Habitat Refugium & Nursery				
Nutrient Cycling				
Pollination	$2.25	$11.34		
Raw Materials				
Soil Formation	$0.57	$6.59		
Storm Protection				
Waste Treatment				
Water Regulation			$6.06	$166.29
Water Supply				
Food Production	$34.91	$34.91		
Science and Education			$39.08	$67.27
TOTAL	**$51.32**	**$92.17**	**$1,410.55**	**$5,080.10**

Table 8. High and Low Dollar per Acre Estimates for Grasslands and Shrub

	Grasslands		Shrub	
Ecosystem Service General	**Min**	**Max**	**Min**	**Max**
Aesthetic & Recreational			$0.19	$2,139.70
Biological Control	$9.15	$13.42		
Cultural & Spiritual				
Disturbance Regulation				
Erosion Retention	$16.93	$17.89		
Gas & Climate Regulation	$0.06	$166.08	$6.57	$73.30
Genetic Resources	$0.01	$0.01		
Habitat Refugium & Nursery			$1.30	$530.25
Nutrient Cycling				
Pollination	$10.12	$420.45		
Raw Materials				
Soil Formation	$0.49	$0.58		
Storm Protection				
Waste Treatment	$50.78	$50.78		
Water Regulation	$1.75	$2.03		
Water Supply				
Food Production	$23.08	$23.08		
Science and Education			$39.08	$67.27
TOTAL	**$112.37**	**$694.32**	**$47.15**	**$2,810.52**

Table 9. High and Low Dollar per Acre Estimates for Riparian Forest and Agricultural Lands

	Riparian Forest		Agricultural Lands	
Ecosystem Service General	**Min**	**Max**	**Min**	**Max**
Aesthetic & Recreational	$0.18	$11,261.59	$25.77	$29.15
Biological Control	$9.11	$9.53	$2.06	$515.82
Cultural & Spiritual	$4.95	$4.95		
Disturbance Regulation	$8.01	$249.87	$4.94	$120.10
Erosion Retention			$14.83	$1,416.76
Gas & Climate Regulation	$10.57	$1,049.40	$9.11	$515.82
Genetic Resources				
Habitat Refugium & Nursery	$0.26	$2,972.74		
Nutrient Cycling			$2.06	$166.08
Pollination	$66.75	$420.45	$2.25	$420.45
Raw Materials				
Soil Formation			$0.57	$256.55
Storm Protection				
Waste Treatment	$166.29	$166.29		
Water Regulation	$10.19	$534.31		
Water Supply	$5.16	$13,795.98		
Food Production			$34.91	$34.91
Science and Education	$39.08	$67.27		
TOTAL	**$320.55**	**$30,532.39**	**$96.50**	**$3,475.64**

Table 10. High and Low Dollar per Acre Estimates for Emergent Herbaceous Wetlands and Woody Wetlands

	Emergent Herbaceous Wetlands		Woody Wetlands	
Ecosystem Service General	**Min**	**Max**	**Min**	**Max**
Aesthetic & Recreational	$1.12	$9,908.17	$1.12	$9,908.17
Biological Control				
Cultural & Spiritual				
Disturbance Regulation	$14,528.95	$14,528.95	$14,528.95	$14,528.95
Erosion Retention				
Gas & Climate Regulation	$4.94	$515.82	$4.94	$774.40
Genetic Resources				
Habitat Refugium & Nursery	$5.92	$13,289.37	$5.92	$13,289.37
Nutrient Cycling	$7,318.04	$7,318.04	$7,318.04	$7,318.04
Pollination				
Raw Materials	$4.26	$2,760.11	$2,760.11	$2,760.11
Soil Formation				
Storm Protection	$1,394.58	$1,394.58	$1,394.58	$1,394.58
Waste Treatment	$166.29	$1,058.45	$166.29	$1,058.45
Water Regulation	$557.66	$6,739.17	$557.66	$6,739.17
Water Supply	$0.44	$33,288.83	$0.44	$33,288.83
Food Production	$53.37	$1,233.49	$53.37	$1,233.49
Science and Education				
TOTAL	**$24,035.58**	**$92,034.99**	**$26,791.43**	**$92,293.57**

Valuation of the Puyallup Watershed

Annual Flow of Value

Values for all land cover classes were combined. Table 11 summarizes the valuation of ecosystem services across all land cover types in the Puyallup River Watershed. The table includes each land cover class with its acreage and value, and the total annual value for all lands within the Puyallup Watershed.

Table 11– Final Annual Value of all Ecosystem Services Provided by the Puyallup River Watershed

Land Cover (EE)	Total Acreage	Per Acre Low	Per Acre High	Total Low	Total High
Agricultural Lands	2,470	$97	$3,476	$238,398	$8,586,362
Pasture	16,646	$51	$92	$854,278	$1,534,270
Forest	359,586	$487	$9,277	$175,122,069	$3,335,803,898
Urban Green Space	18,594	$1,411	$5,080	$26,227,704	$94,459,125
Grassland	30,037	$112	$694	$3,375,271	$20,855,257
Shrub/Scrub	77,954	$47	$2,811	$3,675,268	$219,091,750
Riparian Forest	1,326	$321	$30,532	$425,121	$40,492,968
Estuary	4,028	$6,236	$20,466	$25,121,762	$82,443,016
Rivers and Lakes	6,776	$1,051	$32,869	$7,122,436	$222,718,569
Emergent Herbaceous Wetlands	1,606	$24,036	$92,035	$38,611,750	$147,848,842
Woody Wetlands	9,144	$26,791	$92,294	$244,971,412	$843,899,977
Perennial Snow/Ice	18,232	Not Available	Not Available	$0	$0
Barren/Developed	126,964	Not Available	Not Available	$0	$0
TOTALS	**673,363**			**$525,745,469**	**$5,017,734,035**

Net Present Value

An ecosystem produces a flow of valuable services across time. In this sense it can be thought of as a capital asset. This analogy can be extended by calculating the net present value of the future flows of ecosystem services, just as the asset value of a traditional capital asset (or large project) can be approximately calculated as the net present value of its future benefits. This calculation is an exercise however, because ecosystems are not bought and sold in this manner.

Calculating the net present value of an asset in traditional economics requires the use of a discount rate. The Army Corps of Engineers use a 4.125% discount rate for large projects, which lowers the value of the benefits by 4.125% every year into the future. Seattle Public Utilities and some other institutions use a 5% discount rate for capital construction projects. The net present value of the Puyallup Watershed was valued using two discount rates: zero and 4.125%.

A discount rate is designed to control for the following:

1. **Pure time preference of money.** This is the rate at which people value what they can have now, compared with putting off consumption or income until later.

2. **Opportunity cost of investment.** A dollar in one year's time has a present value of less than a dollar today, because a dollar today can be invested for a return in one year.

3. **Depreciation.** Built assets such as cars and levees tend to deteriorate and lose value due to wear and tear, while natural assets tend to appreciate in value. Discounting can be adjusted for different types of assets.

Discounting has limitations. Using a discount rate assumes that the benefits humans reap in the present are more valuable than the benefits provided to future generations. Renewable resources should be treated with lower discount rates than built capital assets because they provide a rate of return over a far longer period of time. Most of the benefits that a natural asset such as the Puyallup Watershed provides reside in the distant future, whereas most of the benefits of built capital reside in the near-term, with few or no benefits provided into the distant future. Both types of assets are important to maintain a high quality of life, but each also operates on a different time scale. It would be unwise to treat human time preference for a forest like it was a building, or a building like it was a disposable coffee cup.

Results

Overall, 18 categories of ecosystem services were valued across 13 land cover classes. **Results show that nature in the Puyallup Watershed generates at least $526 million to $5 billion in goods and services to humans every year.**

From this annual flow of value, a net present value analogous to an "asset value" can be calculated. This is like the difference between the sum of monthly mortgage payments across the year (an annual flow of value for living in the house for one year) and the full sale value of a house (the asset value, or net present value of the house). To determine the asset value of the Puyallup Watershed's ecosystems to society, we apply a discount rate of 4.125% over 100 years from the present day. Because natural assets tend to appreciate, rather than depreciate, the true discount rate is likely to be lower.

The asset value of the Puyallup Watershed is between $13 billion and $120 billion, calculated at a 4.125% discount rate over the next 100 years. The Puyallup Watershed's asset value was also calculated at a zero discount rate, treating the value these ecosystems will provide to future generations as equal to that of present generations. **At a zero discount rate, the watershed's asset value is estimated at between $53 billion and $502 billion.** More detailed information on the primary studies used in this benefit transfer is listed in Appendix C, and study limitations are outlined in Appendix D.

Part V Applications of Study Findings

*Section Summary: Economies depend upon ecosystem goods and services, and become weakened when regional ecosystems are degraded. The long-term health of the Puyallup Watershed and the Puget Sound region depends upon our ability to make wise choices and investments that increase the productive capacity of the watershed's natural capital. Recommendations on how to understand and positively apply the results of this study are designated in **bold** text below.*

Investing in the Future

The term "investment" describes the choices people make today to place resources for returns in the future. An economy is the product of previous decades of investment. Future generations will benefit or suffer from the choices made today. When Tacoma Public Utilities invested in a 43-mile pipeline from the Green River Watershed and a subsequent watershed protection program, its leaders were considering not only the short-term costs and benefits of natural water filtration but also the long-term investment. In hindsight, this investment has vastly increased in both production and monetary value over time.

The substantial economic value currently being generated in the Puyallup Watershed demonstrates that nature is an investment worth maintaining. While the watershed's economy is already closely intertwined with its natural foundations, much can be done to further account for the natural goods and services that are produced for greater overall well-being in this Whole Economy.

As ecosystems in the Puyallup Watershed become fragmented and more scarce, it is imperative to consider both the retention (conservation) and the restoration of these systems as a key investment in the future economy as supported by green infrastructure.

Flood Risk Reduction

One of the most critical ecosystem services is flood risk reduction. The Puyallup River is the most armored river in the Puget Sound Basin, and one of the most prone to flooding. The loss of natural floodwater conveyance has accompanied the loss of floodplain. The loss of infiltration capacity from investment in impermeable surfaces and stormwater systems, which shunt surface waters quickly into the Puyallup River, and tightly constraining levees have combined to become expensive investments in built capital, which have exacerbated flooding. The loss of wetlands, forests and other ecosystem structures that reduce peak flows and promote infiltration and conveyance have also increased flood risk. Currently, no flood planning in the U.S. fully accounts for the flood risk reduction provided by both natural and built infrastructure.

Solving flooding in the Puyallup River Watershed will require both built and natural capital. Understanding the ecosystem service function of water regulation and flood risk reduction is crucial to making good investments both in natural and built capital. Flood risk reduction cannot be considered a single infrastructure investment (levees and dams). It must include stormwater systems, natural capital, social systems such as warning systems, increased conservation and widening of the floodway to provide more resilient flood hazard reduction.

Decision Support

The large dollar values of ecosystem goods and services in the Puyallup Watershed demonstrate the importance of ecosystems to the local economy. The appraisal values identified in this study are defensible and applicable to informing decisions at every jurisdictional level.

This study provides decision-makers an opportunity to shift from addressing issues and challenges at a single jurisdiction and single issue scale to taking an integrated approach of developing a sustainable green economy in which natural capital is an integral part of safe investments that maintain or rise in value over time.

Watershed Characterization

Watershed characterizations, salmon habitat plans and other watershed-based analysis should be informed by ecosystem service analysis. These characterizations have been advancing dramatically in recent years. Including the human economy and ecosystem services is crucial in advancing the understanding, value and depth of watershed characterization. It is also important that state and federal agencies, particularly the Washington State Department of Natural Resources, Washington State Department of Ecology, and the Army Corps of Engineers (all of which have supported ecosystem service analysis and valuations in the past for specific projects) adopt this analysis as a normal part of operations. Training for private firms – including consulting companies, government agencies and non-profits – in ecosystem service analysis should proceed at a rapid pace.

Economic benefits provided by ecosystems are important and need to be valued to properly inform public and private investment. These improvements in economic analysis, which promote better investment, are informed by ecosystem services. The mapping of ecosystem services on the landscape, their provisioning, beneficiaries and impediments all inform how institutions should be set up and how incentives and funding mechanisms should be created.

Watershed characterization should include ecosystem services, which are crucial to solving many biological and economic sustainability issues in the Puyallup.

Cost-Benefit Analysis

All federal and state agencies, cities, counties and many private firms utilize (a variety of) cost/benefit analyses to make investment decisions in areas such as health care, levee construction, education, road building, economic development, tax breaks and others. If a cost/benefit analysis is flawed, investments will be flawed. For example, a fish-processing plant counts as an asset in cost/benefit analysis, yet federal rules dictate that the system that actually produces the fish does not count as an asset and cannot be valued in the analysis.

In the U.S., significant changes in the federal cost/benefit analysis rules for water and land resources ("Principles and Guidelines") are currently under consideration. Proposed changes include the valuation of ecosystem services. It is uncertain how long this consideration will take, but it is Earth Economics' experience that when local and regional jurisdictions factor natural capital into cost/benefit analysis, better-informed decisions result.

When working with federal agencies on shared projects, jurisdictions have an opportunity to take a leadership role. The Army Corps of Engineers, for example, will grant exemptions to include the values of ecosystems in a cost/benefit analysis to ensure they are considered along with built infrastructure for a more complete and accurate flood risk management plan and strategy. Local jurisdictions should encourage this during project planning. [20]

Project Prioritization

Criteria for selection and prioritization of capital infrastructure projects need to reflect the goals of the communities and the policies of local jurisdictions. Though not a comprehensive list of criteria, some questions driven by ecosystem services-related policies include:

1. **Does the project enhance natural processes?**

2. **Do the project impacts enhance or degrade associated ecosystem services (such as habitat or water quality) at the site-specific or regional scales?**

3. **Are the costs and benefits (safety, health, economic and ecological) of this project distributed equitably over time and space?**

20 The first exemption granted by the Army Corps of Engineers occurred in 2009, partly as a result of an Earth Economics study which highlighted scientific work done by the University of Louisiana and informed jurisdictional leaders and Army Corp staff about the hurricane and flood risk reduction value of wetlands on the Louisiana Coast.

Environmental Impact Statements

In Washington State, environmental impact statements often have an effect on project design, and thus investment, by identifying actions that reduce the negative environmental impacts or enhance restoration. One of the fundamental challenges of environmental impact statements is the lack of an economic interface. In other words, environmental damages can be quantified in scientific terms, but this has no common language with project financing, which is denominated in dollars. Ecosystem service identification and valuation often strengthen what is the weakest area of environmental planning and analysis: the economic implications and value provided by restoration projects.

In 2010, Earth Economics provided the first economic section in an environmental impact analysis for Snohomish County's Smith Island restoration project. Three scenarios were examined for ecosystem service enhancement and valuation. Providing this information allows for a stronger understanding of the economic benefits the project provides. Identifying the dollar value of ecosystem services enhanced by the project and provided to the public also strengthens the capacity for funding proposals.

Private and public institutions should include an ecosystem service analysis to strengthen environmental impact assessments. Policy makers in Washington State should lead the nation in requiring ecosystem service analysis in all applicable environmental impact statements.

Land Use Policy and Management

One of the biggest environmental threats to the South Puget Sound region is the loss of forest.[21] The region has been losing forest at a rate of 10 acres per day since 1990 (University of Washington School of Forest Resources, 2009), and currently there are more than 275,000 acres of forest in the region "at risk" of being lost, or 28% of total forest area. Currently, approximately 5.7 million acres of private forestland in the Puget Sound are owned by small private landowners, comprising approximately half of the total forestland in private ownership.[22] The tax burden of forest ownership is a great burden on small landowners, because taxes are based on the "highest and best use" of the land. The cost of land taxes makes forestry less viable and puts pressure on small landowners to convert forestlands into real estate development and other uses.

Certain land cover types have higher ecosystem service values than others, and where the choice exists in land use planning, the higher-value land cover types should be maintained or increased. The role of private landowners should not be underestimated: The rate of (especially lowland) forest conversion must be slowed, and incentives and education should continue to be provided for small forest landowners to keep their property forested and healthy.

Internal Policy and Procedure Revamp

Shifting private and public investment toward green infrastructure, buildings, and investment requires that natural capital be recognized as a capital asset that is measurable within standard accounting systems. The creation of Tacoma Public Utilities (TPU) in 1893 was a visionary and successful institutional development. Although considered a radical and expensive idea at the time, the construction of the 43-mile Green River pipeline to supply water to the city was approved by Tacoma's citizens in 1909. Had the utility required a threshold rate of return on investment, it would likely never have justified this daring project. The goal of the investment was not to maximize "net present value" but to provide safe and reliable drinking water for the people of Tacoma and Pierce County into the distant future. By 1968, Tacoma had acquired 10,000 acres of land surrounding the Green River Watershed and declared its source water protection program a success (Historylink, 2010). Although the project was controversial at the time and presented a number of legal, physical and political challenges, it is now

21 South Puget Sound comprises Kitsap, Mason, Pierce, and Thurston Counties in the report cited.

22 Owning less than 5,000 acres.

recognized a magnificent investment. Tacoma has since acquired an additional 5,000 acres in critical areas of the Green River Watershed (Tacoma Water, 2008).

Decision-makers for local jurisdictions and tribes should consider an "Accounting Review" of existing capabilities to implement natural capital accounting within the Puyallup Watershed. The review can be used to make recommendations for incorporating ecological economics and ecological accounting methods, procedures and auditing.

Development of Funding Sources

The values included in this report provide reference values for some of the ecosystem services that are produced by comparable ecosystems to those in the Puyallup Watershed. A riparian restoration group, for example, might like to apply for grant funding that would restore 100 acres of shrub/scrub to riparian forest. Using the values found in this appendix as a reference, they can perform a simple calculation to show the increase in public economic value generated by a proposed restoration. This calculation will show the economic return on investment to the region, in addition to the ecological return on investment.

Ecosystem service valuation can provide conservation and restoration organizations, cities and private owners with the tools to show a rate of return on investment for natural resource investments. This is a new tool and enables restoration projects to show monetary as well as ecological benefits of projects implemented.

Green Jobs Analysis

Ecosystem services and jobs are closely connected. An examination of jobs created by capital and restoration projects that improve ecosystems generally looks at how many construction jobs are created by moving earth or planting native vegetation. Yet most restoration projects also provide quantifiable ecosystem goods and services that have economic importance and provide an increase in sustainable, well-paid jobs. Establishing an increase in permanent employment is far more important than providing temporary jobs, and federal agencies recognize and measure this accordingly. Earth Economics has helped organizations secure project funding by linking projects to green jobs development.

Jobs analysis (i.e. number of jobs created) is increasingly important in securing funding, and is a part of many federal applications. Restoration projects can and should be effectively linked to economic advancement and sustainability.

Watershed Investment Districts

As the Puget Sound region has become more crowded, so have its tax districts. Inevitably, there can be conflicts. In the Green River Valley, over a dozen stormwater districts previously invested millions of dollars to build stormwater systems that generally get water out of cities and into the main stem of the river as fast as possible. Prior to 2008, six flood districts positioned at the lower reaches of the rivers received higher peak flows every year as forests disappeared and impermeable surfaces and stormwater systems expanded, causing greater flooding. Because the flood districts were restricted to the areas of flooding, they could not invest in the upper and middle watershed areas. The districts were constrained to investing primarily in higher levees in the lower reaches, which were increasingly damaged by higher peak water flows. This self-perpetuating type of infrastructure conflict is part of a cycle that is unhealthy for humans, salmon, the economy and the environment.

The work accomplished by Water Resource Inventory Area 9 (WRIA 9) with Earth Economics in the Green River Valley demonstrates an impressive, innovative approach for adding a new level of rationality to the existing tax district structure. WRIA 9 is charged with salmon restoration and encompasses the cities of the Green River Valley from Seattle to Black Diamond. Along with Vashon Island, Seattle Public Utilities, the King Conservation District, King County, the Boeing Corp. and other stakeholders, WRIA 9 is leading the charge in the state by boldly proposing a path to better coordinate and rationalize watershed-based tax districts (called "Watershed Investment Districts") as part of its effort to restore salmon populations.

Puyallup Watershed leaders should facilitate discussions about institutions and improvements that help coordinate and rationalize current tax districts, thereby saving money and providing greater services as well. Ecosystem services can be a guide for improvement by setting a context wherein alternative goals, such as salmon restoration, flood control, storm water conveyance and water quality can be simultaneously improved, avoiding "infrastructure conflict."

Towards a Sustainable and Desirable Future

This region's infrastructure can be further integrated to satisfy multiple goals (e.g. sustainability, salmon recovery and flood risk reduction) to provide a better return on investment. In the case of salmon recovery, green infrastructure (floodplains and deltas) is utilized along with built capital (levees and reducing fish blockages), increasing the provision of a range of other ecosystem services. A successful salmon plan improves confidence in the system and social bonds; improves natural capital and builds sustainable communities – all contributing to human well-being. Understanding where and how to invest in a watershed is essential to improvement in the five capitals and the goal of human well-being.

Puyallup Watershed leaders can use the concepts, values and recommendations presented in this study to begin incorporating ecosystem services into agency goals, metrics, indicators, assessment and general operations. Examples include: developing budgets and program planning; writing grant applications to secure federal and outside funding; examining policies and accounting practices; reporting and aligning to Puget Sound ecosystem health indicators; and development review and permitting processes in rural areas.

Conclusion

There are many ways in which the economy of the Puyallup Watershed – and the quality of life for its citizens – depends upon functioning ecosystems. When ecosystems are healthy, they provide vast amounts of economic value at a relatively low cost; once degraded, ecosystems require investments such as the installation of built infrastructure that depreciates over time. When functioning ecosystems are compromised, a new tax district is often created – with typically a narrow focus on the partial flow of a single ecosystem good or service such as flood risk reduction.

This report provides an appraisal valuation of ecosystem services in the Puyallup Watershed, quantifying the economic value supplied by nature in the watershed every year. The results are compelling: By protecting against flooding, assuring water supply, buffering climate instability, supporting fisheries and food production, maintaining critical habitat, providing waste treatment and other benefits, **Puyallup Watershed ecosystems provide between $526 million and $5 billion in economic value every year.**

Ecosystem services may also be treated like an economic asset, providing a stream of benefits over time the way a bridge or other capital infrastructure does. Valued as such, a discount rate may be applied to these services, allowing for calculation of the present value of these systems. **If treated like an asset with a life span of 100 years, the present value of the Puyallup Watershed would be between $13 billion and $120 billion, using a 4.125% discount rate.**

Though a snapshot in time, these appraisal values are defendable and applicable to decision-making at every jurisdictional level. Ecosystem service valuations can aid effective and efficient natural resource management. This study also introduces a Whole

Conclusion

Economy model to explicitly link the regional economy to the watershed. It can also be used to help guide advancements towards a sustainable green economy by shifting investments towards achievement of the ideal balance of five capitals: natural, built, human, social and financial.

Quantification of tradeoffs among ecosystem services and their interactions with human well-being are now among the most pressing areas of concern in the Puyallup Watershed. Decision-makers in the watershed – government, tribal, business and others – can use the concepts and values presented in this study to begin incorporating ecosystem services into agency goals, metrics, indicators, assessments and general operations. For example, ecosystem service values should be considered when developing budgets and program planning; grant applications to secure federal and outside funding; examining policies and accounting practices; reporting and aligning to Puget Sound health indicators, and development review and permitting processes in rural areas.

While this report provides a valuation of ecosystem services in the Puyallup River Watershed and a whole view of the economy, it is only a first step in the process of developing policies, measures and indicators that support discussions about the tradeoffs in investments of public and private money that ultimately shape the regional economy for the generations to come.

Next steps recommended in this study include:

1. **Map and value potential flood risk reduction scenarios.** Analysis would consider floodplains along the Puyallup River and their value relative to land prices. Scenario studies could also include valuations of ecosystem services beyond flood risk reduction that would be enhanced by restoring the natural flows of the river.

2. **Ecosystem service mapping of service beneficiaries and provisioners.** Using hydrological models and GIS data, sophisticated maps can show geospatially where specific ecosystem services, such as flood risk reduction or salmon habitat, are provisioned on the landscape and who is benefiting from those services. Mapping can also show impairments to ecosystem services, such as features on the landscape that impact salmon habitat.

3. **Funding mechanism review.** After modeling the flow of ecosystem service benefits and impairments across the landscape, funding mechanisms can be designed for green infrastructure investments. These investments typically reduce tax spending on solutions designed to address a single problem, such as flood risk reduction, and instead invest in a suite of ecosystem services for maximum economic returns.

Residents and decision-makers in the Puyallup Watershed have an excellent opportunity to begin developing policies, measures and indicators that can provide the data and information needed to support discussions about the tradeoffs among many potential investments of public and private money – investments that ultimately affect human well-being. Seizing the opportunity and rising to the challenge will ensure a sustainable and desirable future for all Puyallup Watershed residents.

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Appendix C. Value Transfer Studies Used by Land Cover Class

Land Cover Class	Ecosystem Service	Study Author(s)	Minimum Value ($)	Maximum Value ($)
Emergent Herbaceous Wetlands	Aesthetic & Recreational	Doss, C. R. and Taff, S. J.	4,439.16	4,904.33
		Gund Database	68.09	217.79
		Mahan, B. L., Polasky, S. and Adams, R. M.	36.84	36.84
		Roel/Ken	187.43	586.87
		Thibodeau, F. R. and Ostro, B. D.	33.36	695.71
		Whitehead, J. C.	1,107.34	2,226.41
		Wilson, Sara J.	127.02	127.02
		Allen, J. 1992	1.12	9,908.17
		Hayes, K. M., Tyrrell, T. J. and Anderson, G. 1992	1,285.61	2,457.18
		Dodds, W.K., et al. 2008	1,655.89	1,655.89
	Disturbance Regulation	Dodds, W.K., et al. 2008	14,528.95	14,528.95
	Gas & Climate Regulation	Costanza et al. 1997	152.73	152.73
		Roel calculation for LA	29.43	267.43
		Roel/Ken	48.02	348.48
		Wilson, Sara J.	4.94	515.82
		Dodds, W.K., et al. 2008	121.32	121.32
	Habitat Refugium & Nursery	Kazmierczak 2001b	222.27	530.31
		Knowler, D. J. et. al.	62.42	286.10
		Streiner and Loomis 1996	1,568.63	1,568.63
		Vankooten, G. C. and Schmitz, A.	5.92	5.92
		Wilson, Sara J.	2,045.64	2,045.64
		Allen, J. et. al. 1992	5,456.03	13,289.37
		Dodds, W.K., et al. 2008	175.80	175.80
	Nutrient Cycling	Dodds, W.K., et al. 2008	7,318.04	7,318.04
	Raw Materials	Roel/Ken	4.26	4.34
		Dodds, W.K., et al. 2008	2,760.11	2,760.11
	Storm Protection	Roel/Ken	1,394.58	1,394.58
	Waste Treatment	Wilson, Sara J.	166.29	1,058.45
	Water Regulation	Thibodeau, F. R. and Ostro, B. D.	6,739.17	6,739.17
		Wilson, Sara J.	1,416.76	1,416.76
		Woodward and Wui, 2001 (low value); New Jersey from A-C studies (for high value)	557.66	5,957.20
	Water Supply	Creel, M. and Loomis, J.	575.21	575.21
		Lant, C. L. and Roberts, R. S.	0.44	0.55
		Lant, C. L. and Tobin, G.	211.06	2,324.23
		Lant - IL water qual study 1989	182.23	182.23
		Pate, J. and Loomis, J.	3,814.18	3,814.18
		Roel/Ken	42.52	113.39
		Hayes, K. M., Tyrrell, T. J. and Anderson, G. 1992	1,365.10	2,121.96
		Allen, J. et. al. 1992	11,117.28	33,288.83
		Dodds, W.K., et al. 2008	1,352.36	1,352.36
	Food Production	Roel/Ken (for low value); Woodward and Wui, 2001 (for high value)	53.37	1,233.49

Estuary	Aesthetic & Recreational	de Groot (1992) (Calculated 1990)	119.27	347.01
		Johnston, R. J. et. al.	147.50	376.47
		Kahn, J. R. and Buerger, R. B.	3.93	3.93
		Whitehead, J. C., Hoban, T. L. and Clifford, W. B.	1.44	9.77
		New Jersey Type A-C studies 2006	10.82	1,298.23
	Biological Control	Pimentel et al 1996 (Calculated 1994)	31.57	31.57
	Cultural & Spiritual	de Groot (1992) (Calculated 1982)	15.04	20.82
	Disturbance Regulation	Thibodeau & Ostro 1981 (Calculated 1990)	229.44	229.44
	Habitat Refugium & Nursery	Armstrong, 2003	23.51	131.65
		de Groot 1992 (Calculated 1991)	79.92	79.92
		Farber, S. and Costanza, R.	16.97	16.97
		Farber, S. and Costanza, R.	12.24	12.24
		Johnston, R. J. et. al.	92.39	1,468.64
		Woodward and Wui, 2001 (low value); New Jersey from A-C studies (for high value)	87.16	332.79
	Nutrient Cycling	Costanza 1997 (Calculated 1994)	5,909.39	16,556.93
	Raw Materials	de Groot (1992) (Calculated 1993)	15.57	15.57
	Water Supply	Bocksteal, N. E., McConnell, K. E. and Strand, I. E.	76.35	135.51
		Leggett, C. G. and Bockstael, N. E.	45.75	45.75
		Whitehead, J. C., Hoban, T. L. and Clifford, W. B.	6.25	23.92
		New Jersey Type A-C studies 2006	5.53	119.79
	Food Production	Costanza 1997 (Calculated 1994)	15.97	708.84
Forest All Ages	Aesthetic & Recreational	Bennett, R., et. al.	179.28	179.28
		Bishop, K.	1,909.08	2,139.70
		Boxall, P. C., McFarlane, B. L. and Gartrell, M.	0.18	0.18
		Haener, M. K. and Adamowicz, W. L.	0.20	0.20
		Maxwell, S.	12.49	12.49
		Prince, R. and Ahmed, E.	1.49	1.90
		Shafer, E. L., et. al.	571.33	571.33
		Shafer, E.L. et. al.	97.24	97.24
		Willis, K. G.	0.42	202.10
		Willis, K. G. and Garrod, G. D.	3.50	3.50
		Wilson, Sara J.	126.92	126.92
		Dodds, W.K., et al. 2008	857.93	857.93
		Walsh et al. 1978	5.99	23.19
		New Jersey Type A Studies 2006	0.36	2,158.01
	Biological Control	Costanza et al. 1997	2.30	2.30
		Wilson, Sara J.	9.11	9.11
		Pimentel et al. 1997	1.62	1.62
		Krieger, D.J.,	9.53	9.53
	Cultural & Spiritual	Adger et al. 1995	0.26	2.41

	Disturbance Regulation	Dodds, W.K., et al. 2008	14.83	14.83
	Erosion Control	Costanza et al. 1997	55.37	55.37
	Gas & Climate Regulation	In-house Calculation	51.30	1,049.40
		Wilson, Sara J.	14.83	348.47
		Pimentel, D. 1998	13.33	13.33
		Dodds, W.K., et al. 2008	132.31	132.31
		Adger et al. 1995	39.08	59.82
		Mates. W., Reyes, J. 2004	10.57	10.57
		New Jersey Type A Studies 2006	10.57	13.33
	Genetic Resources	Costanza et al. 1997	9.23	9.23
	Habitat Refugium & Nursery	Amigues, J. P., et. al.	64.04	2,532.79
		Amigues, J. P., et. al. 2002	75.16	2,972.74
		Garber et al. 1992	286.04	479.72
		Haener, M. K. and Adamowicz, W. L.	1.52	10.42
		Kenyon, W. and Nevin, C.	530.25	530.25
		Shafer, E. L. et. al.	2.98	2.98
		Dodds, W.K., et al. 2008	1,416.76	1,416.76
		New Jersey Type A Studies 2006	1.05	543.42
	Nutrient Cycling	Costanza et al. 1997	208.23	208.23
		Dodds, W.K., et al. 2008	534.31	534.31
	Pollination	Hougner, C. 2006	66.75	299.79
		Wilson, Sara J.	188.40	420.45
		New Jersey Type A-C studies 2006	59.00	265.00
	Raw Materials	Costanza et al. 1997	14.42	14.42
		Dodds, W.K., et al. 2008	348.47	348.47
		Sharma 1992	10.00	10.00
	Soil Erosion Control	Dodds, W.K., et al. 2008	110.34	110.34
	Soil Formation	Costanza et al. 1997	5.77	5.77
		Pimentel et al. 1997	4.05	4.05
	Storm Protection	Costanza et al. 1997	1.15	1.15
	Waste Treatment	Wilson, Sara J.	166.29	166.29
		Pimentel et al. 1997	35.21	35.21
	Water Regulation	Loomis, J.B. 1988	10.19	10.19
		Wilson, Sara J.	534.31	534.31
		Adger et al. 1995	0.06	0.06
		Otewiler, N.	31.02	31.02
	Water Supply	Ribaudo, M. and Epp, D. J.	665.16	843.44
		Dodds, W.K., et al. 2008	36.17	36.17
		New Jersey Type A-C studies 2006	9.00	385.00
	Food Production	Costanza et al. 1997	28.84	28.84
		Lampietti and Dixon (1995)	28.12	28.12

	Science and Education	Bishop, K.	39.08	67.27
Grasslands	Biological Control	Pimentel et al. 1995	9.15	9.15
		Pimentel et al. 1997	13.42	13.42
	Erosion Control	Barrow (1991) (Calculated 1992)	17.89	17.89
	Gas & Climate Regulation	Copeland et al. (in press) (Calculated 1994)	0.06	0.06
		Costanza et al. 1997	3.85	3.85
		Fankhauser and Pearce (1994)	3.81	3.81
		Wilson, Sara J.	10.79	166.08
	Genetic Resources	Perrings (1995) (Calculated 1992)	0.01	0.01
	Pollination	Pimentel et al. 1995	10.12	10.12
		Wilson, Sara J.	420.45	420.45
		Pimentel et al. 1997	14.60	14.60
	Soil Erosion Control	Costanza et al. 1997	16.93	16.93
	Soil Formation	Costanza et al. 1997	0.58	0.58
		Sala and Paruelo (1997) (Calculated 1994)	0.49	0.49
	Waste Treatment	Pimentel et al. 1997	50.78	50.78
	Water Regulation	Costanza et al. 1997	1.75	1.75
		Jones et al. (1985) (Calculated 1992)	2.03	2.03
	Food Production	US Dept of Comm (1995) (Calculated 1992)	23.08	23.08
Shrub	Aesthetic & Recreational	Bennett, R., et. al.	179.28	179.28
		Bishop, K.	1,909.08	2,139.70
		Boxall, P. C., McFarlane, B. L. and Gartrell, M.	0.19	0.19
		Haener, M. K. and Adamowicz, W. L.	0.21	0.21
		Maxwell, S.	12.49	12.49
		Prince, R. and Ahmed, E.	1.58	2.01
		Shafer, E. L., et. al.	571.33	571.33
		Willis, K. G.	0.45	202.10
		Willis, K. G. and Garrod, G. D.	4.36	4.36
	Gas & Climate Regulation	In-house calculation	6.57	73.30
	Habitat Refugium & Nursery	Kenyon, W. and Nevin, C.	530.25	530.25
		Shafer, E. L. et. al.	3.16	3.16
		Haener, M. K. and Adamowicz, W. L. 2000	1.30	8.97
	Science and Education	Bishop, K.	39.08	67.27
Woody Wetlands	Aesthetic & Recreational	Doss, C. R. and Taff, S. J.	4,439.16	4,904.33
		Mahan, B. L., Polasky, S. and Adams, R. M.	36.84	36.84
		Roel/Ken	187.43	586.87
		Thibodeau, F. R. and Ostro, B. D.	33.36	695.71
		Whitehead, J. C.	1,107.34	2,226.41

		Wilson, Sara J.	127.02	127.02
		Allen, J. 1992	1.12	9,908.17
		Hayes, K. M., Tyrrell, T. J. and Anderson, G. 1992	1,285.61	2,457.18
		Dodds, W.K., et al. 2008	1,655.89	1,655.89
	Disturbance Regulation	Dodds, W.K., et al. 2008	14,528.95	14,528.95
	Gas & Climate Regulation	Costanza et al. 1997	152.73	152.73
		Roel calculation for LA	29.43	267.43
		Roel/Ken	106.70	774.40
		Wilson, Sara J.	4.94	515.82
		Dodds, W.K., et al. 2008	121.32	121.32
	Habitat Refugium & Nursery	Kazmierczak 2001b	222.27	530.31
		Knowler, D. J. et. al.	62.42	286.10
		Streiner and Loomis 1996	1,568.63	1,568.63
		Vankooten, G. C. and Schmitz, A.	5.92	5.92
		Wilson, Sara J.	2,045.64	2,045.64
		Allen, J. et. al. 1992	5,456.03	13,289.37
		Dodds, W.K., et al. 2008	175.80	175.80
	Nutrient Cycling	Dodds, W.K., et al. 2008	7,318.04	7,318.04
	Raw Materials	Dodds, W.K., et al. 2008	2,760.11	2,760.11
	Storm Protection	Roel/Ken	1,394.58	1,394.58
	Waste Treatment	Wilson, Sara J.	166.29	1,058.45
	Water Regulation	Thibodeau, F. R. and Ostro, B. D.	6,739.17	6,739.17
		Wilson, Sara J.	1,416.76	1,416.76
		Woodward and Wui, 2001 (low value); New Jersey from A-C studies (for high value)	557.66	5,957.20
	Water Supply	Creel, M. and Loomis, J.	575.21	575.21
		Lant, C. L. and Roberts, R. S.	0.44	0.55
		Lant, C. L. and Tobin, G.	211.06	2,324.23
		Lant? - IL water qual study 1989	182.23	182.23
		Pate, J. and Loomis, J.	3,814.18	3,814.18
		Roel/Ken	42.52	113.39
		Hayes, K. M., Tyrrell, T. J. and Anderson, G. 1992	1,365.10	2,121.96
		Allen, J. et. al. 1992	11,117.28	33,288.83
		Dodds, W.K., et al. 2008	1,352.36	1,352.36
	Food Production	Roel/Ken (for low value); Woodward and Wui, 2001 (for high value)	53.37	1,233.49
Riparian Forest	Aesthetic & Recreational	Bennett, R., et. al.	179.28	179.28
		Bishop, K.	1,909.08	2,139.70
		Boxall, P. C., McFarlane, B. L. and Gartrell, M.	0.18	0.18
		Duffield, J. W., Neher, C. J. and Brown, T. C.	1,106.08	1,562.65
		Greenley, D., Walsh, R. G. and Young, R. A.	8.57	8.57
		Haener, M. K. and Adamowicz, W. L.	0.20	0.20
		Kulshreshtha, S. N. and Gillies, J. A.	50.96	50.96
		Maxwell, S.	12.49	12.49

		Mullen, J. K. and Menz, F. C.	384.43	384.43
		Prince, R. and Ahmed, E.	1.49	1.90
		Sanders, L. D., Walsh, R. G. and Loomis, J. B.	2,435.23	2,435.23
		Shafer, E. L., et. al.	571.33	571.33
		Shafer, E.L. et. al.	97.24	97.24
		Willis, K. G.	0.42	202.10
		Willis, K. G. and Garrod, G. D.	3.50	3.50
		Wilson, Sara J.	126.92	126.92
		Bowker, J. M., English, D.B. and Donovan, J.A. 1996	4,685.77	11,261.59
		Rein, F. A. 1999	30.22	132.48
	Biological Control	Wilson, Sara J.	9.11	9.11
		Krieger, D.J.	9.53	9.53
	Cultural & Spiritual	Greenley, D., Walsh, R. G. and Young, R. A.	4.95	4.95
	Disturbance Regulation	Rein, F. A. 1999	8.01	249.87
	Gas & Climate Regulation	local estimate	51.30	1,049.40
		Wilson, Sara J.	14.83	348.47
		Pimentel, D. 1998	13.33	13.33
		Mates. W., Reyes, J. 2004	10.57	10.57
	Habitat Refugium & Nursery	Amigues, J. P., et. al.	64.04	2,532.79
		Amigues, J. P., et. al. 2002	75.16	2,972.74
		Garber et al. 1992	286.04	479.72
		Haener, M. K. and Adamowicz, W. L.	1.52	10.42
		Kahn, J. R. and Buerger, R. B.	0.26	15.29
		Kenyon, W. and Nevin, C.	530.25	530.25
		Knowler, D. J. et. al.	62.42	286.10
		Shafer, E. L. et. al.	2.98	2.98
	Pollination	Hougner, C. 2006	66.75	299.79
		Wilson, Sara J.	188.40	420.45
	Waste Treatment	Wilson, Sara J.	166.29	166.29
	Water Regulation	Faux et al. 1999	39.27	193.84
		Loomis, J.B. 1988	10.19	10.19
		Wilson, Sara J.	534.31	534.31
		Olewiler, N.	31.02	31.02
	Water Supply	Berrens, R. P., Ganderton, P. and Silva, C. L.	2,231.42	2,231.42
		Danielson, L., et. al.	5,094.63	5,094.63
		Gramlich, F. W.	221.01	221.01
		Lant - IL water qual study 1989	182.23	182.23
		Mathews, L. G., Homans, F. R. and Easter, K. W.	13,795.98	13,795.98
		Oster, S.	15.16	15.16
		Ribaudo, M. and Epp, D. J.	665.16	843.44
		Rich, P. R. and Moffitt, L. J.	5.16	5.16
		Rein, F. A. 1999	41.81	185.36
	Science and Education	Bishop, K.	39.08	67.27

Agricultural lands	Aesthetic & Recreational	Bergstrom, J., Dillman, B. L. and Stoll, J. R. 1985	29.15	29.15
		New Jersey Type A Studies 2006	25.77	25.77
	Biological Control	Costanza et al. 1997	13.56	13.56
		Wilson, Sara J.	2.06	515.82
	Disturbance Regulation	Wilson, Sara J.	4.94	120.10
	Erosion Control	Canadian Urban Institute.	14.83	1,416.76
	Gas & Climate Regulation	Smith, W.N. et al.	9.11	515.82
		Wilson, Sara J.	10.84	420.45
	Nutrient Cycling	Canadian Urban Institute.	132.31	132.31
		Wilson, Sara J.	2.06	166.08
	Pollination	Wilson, Sara J.	204.61	420.45
		Robinson, W. S., Nowogrodzki, R. and Morse, R. A. 1989	12.83	12.83
		Southwick, E. E. and Southwick, L. 1992	2.54	2.54
		New Jersey Type A Studies 2006	2.25	11.34
	Soil Formation	Canadian Urban Institute.	256.55	256.55
		Costanza et al. 1997	0.57	0.57
		Sandhu, H.S., Wratten, S.D., Cullen, R., and Case, B.	188.40	188.40
		Wilson, Sara J.	2.23	184.32
	Food Production	Costanza et al. 1997	34.91	34.91
Pasture	Aesthetic & Recreational	Boxall, P. C.	0.03	0.03
		New Jersey Type A Studies 2006	25.77	25.77
	Biological Control	Costanza et al. 1997	13.56	13.56
	Pollination	New Jersey Type A Studies 2006	2.25	11.34
	Soil Formation	Costanza et al. 1997	0.57	0.57
		Pimentel, D. 1998	6.59	6.59
	Food Production	Costanza et al. 1997	34.91	34.91
Urban Green Space	Aesthetic & Recreational	Tyrvainen, L.	1,336.99	3,919.27
	Gas & Climate Regulation	McPherson, E. G. 1992	185.89	927.28
		McPherson, E. G., Scott, K. I. and Simpson, J. R. 1998	28.42	28.42
		Birdsey, R.A.	534.31	534.31
	Water Regulation	McPherson, E. G. 1992	6.06	6.06
		Birdsey, R.A.	166.29	166.29
	Science and Education	Bishop, K.	39.08	67.27
Rivers and Lakes	Aesthetic & Recreational	Burt, O. R. and Brewer, D.	489.53	489.53
		Cordell, H. K. and Bergstrom, J. C.	143.49	1,504.83
		Kealy, M. J. and Bishop, R. C.	13.71	13.71
		Kreutzwiser, R.	192.13	192.13
		Patrick, R.,et. al.	1.79	27.09
		Piper, S.	254.61	254.61
		Shafer, E. L. et. al.	584.84	1,167.50
		Ward, F. A., Roach, B. A. and Henderson, J. E.	21.71	2,033.73
		Young, C. E. and Shortle, J. S.	86.76	86.76

		Loomis J.B. 2002	11,798.86	20,880.94
		Postel & Carpenter 1997	93.08	93.08
	Habitat Refugium & Nursery	Loomis 1996	17.13	17.13
		Streiner and Loomis 1996	1,568.63	1,568.63
	Waste Treatment	Gibbons (1986) (Calculated 1980)	74.43	967.62
	Water Regulation	Gibbons (1986) (Calculated 1980)	908.86	3,510.07
	Water Supply	Bouwes, N. W. and Scheider, R.	654.51	654.51
		Croke, K., Fabian, R. and Brenniman, G.	599.86	599.86
		Gibbons (1986) (Calculated 1980)	66.24	509.04
		Henry, R., Ley, R. and Welle, P.	455.06	455.06
		Howe & Easter (1971) (Calculated 1971)	146.26	5,925.34
		Knowler, D. J. et. al.	62.42	286.10
		Piper, S.	32.34	32.34
		Ribaudo, M. and Epp, D. J.	894.05	894.05
	Food Production	Postel & Carpenter 1997	16.59	16.59

Appendix D. Study Limitations

The results of this first attempt to assign monetary value to the ecosystem services rendered by the Puyallup Watershed have important and significant implications on the restoration and management of natural capital. Valuation exercises have limitations that must be noted, although these limitations should not detract from the core finding that ecosystems produce a significant economic value to society. Benefit transfer analysis estimates the economic value of a given ecosystem (e.g., wetlands) from prior studies of that ecosystem type. Like any economic analysis, this methodology has strengths and weaknesses. Some arguments against benefit transfer include:

1. Every ecosystem is unique; per-acre values derived from another location may be irrelevant to the ecosystems being studied.

2. Even within a single ecosystem, the value per acre depends on the size of the ecosystem; in most cases, as the size decreases, the per-acre value is expected to increase and vice versa. (In technical terms, the marginal cost per acre is generally expected to increase as the quantity supplied decreases; a single average value is not the same as a range of marginal values).

3. Gathering all the information needed to estimate the specific value for every ecosystem within the study area is not feasible. Therefore, the "true" value of all of the wetlands, forests, pastureland, etc. in a large geographic area cannot be ascertained. In technical terms, we have far too few data points to construct a realistic demand curve or estimate a demand function.

4. To value all, or a large proportion, of the ecosystems in a large geographic area is questionable in terms of the standard definition of exchange value; we cannot conceive of a transaction in which all or most of a large area's ecosystems would be bought and sold. This emphasizes the point that the value estimates for large areas (as opposed to the unit values per acre) are more comparable to national income accounts aggregates and not exchange values (Howarth & Farber, 2002). These aggregates (i.e. GDP) routinely impute values to public goods for which no conceivable market transaction is possible. The value of ecosystem services of large geographic areas is comparable to these kinds of aggregates (see below).

Proponents of the above arguments recommend an alternative valuation methodology that amounts to limiting valuation to a single ecosystem in a single location and only using data developed expressly for the unique ecosystem being studied, with no attempt to extrapolate from other ecosystems in other locations. An area with the size and landscape complexity of the Puyallup Watershed will make this approach to valuation extremely difficult and costly. Responses to the above critiques can be summarized as follows (See Costanza et al., 1998; and Howarth and Farber, 2002 for more detailed discussion):

1. While every wetland, forest or other ecosystem is unique in some way, ecosystems of a given type, by their definition, have many things in common. The use of average values in ecosystem valuation is no more and no less justified than their use in other macroeconomic contexts; for instance, the development of economic statistics such as Gross Domestic or Gross State Product.

This study's estimate of the aggregate value of the Puyallup Watershed's ecosystem services is a valid and useful (albeit imperfect, as are all aggregated economic measures) basis for assessing and comparing these services with conventional economic goods and services.

2. The results of the spatial modeling analysis that were described in other studies do not support an across-the-board claim that the per-acre value of forest or agricultural land depends on the size of the parcel. While the claim does appear to hold for nutrient cycling and other services, the opposite position holds up fairly well for what ecologists call "net primary productivity" or NPP, which is a major indicator of ecosystem health. It has the same position, by implication, of services tied to NPP – where each acre makes about the same contribution to the whole regardless of whether it is part of a large plot of land or a small one. This area of inquiry needs further research, but for the most part the assumption (that average value is a reasonable proxy for marginal value) is appropriate for a first approximation. Also, a range of different parcel sizes exist within the study site, and marginal value will average out.

3. As employed here, the prior studies we analyzed encompass a wide variety of time periods, geographic areas, investigators and analytic methods. Many of them provide a range of estimated values rather than single-point estimates. The present study preserves this variance; no studies were removed from the database because their estimated values were deemed to be "too high" or "too low." Limited sensitivity analyses were also performed. The approach is similar to determining an asking price for a piece of land based on the prices for comparable parcels; even though the property being sold is unique, realtors and lenders feel justified in following this procedure to the extent of publicizing a single asking price rather than a price range.

4. The objection to the absence of even an imaginary exchange transaction was made in response to the study by Costanza et al. (1997) of the value of all of the world's ecosystems. Leaving that debate aside, one can conceive of an exchange transaction in which, for example, all or a large portion of a watershed was sold for development so that the basic technical requirement of an economic value reflecting the exchange value, could be satisfied. Even this is not necessary if one recognizes the different purpose of valuation at this scale – a purpose that is more analogous to national income accounting than to estimating exchange values (Howarth and Farber 2002).

In this report we have displayed our study results in a way that allows one to appreciate the range of values and their distribution. It is clear from inspection of the tables that the final estimates are not extremely precise. However, they are much better estimates than the alternative of assuming that ecosystem services have zero value, or, alternatively, of assuming they have infinite value. Pragmatically, in estimating the value of ecosystem services, it seems better to be approximately right than precisely wrong.

The estimated value of the world's ecosystems presented in Costanza et al. (1997), for example, has been criticized as both (1) a serious underestimate of infinity and (2) impossibly exceeding the entire Gross World Product. These objections seem to be difficult to reconcile, but that may not be so. Just as a human life is "priceless" so are ecosystems, yet people are paid for the work they do.

That the value ecosystems provide to people exceeds the gross world product should, with some reflection, not be so surprising. Costanza's estimate of the work that ecosystems do is an underestimate of the "infinity" value of priceless systems, but that is not what he sought to estimate. Consider the value of one ecosystem service, such as photosynthesis, and the ecosystem good it produces: atmospheric oxygen. Neither is valued in Costanza's study. Given the choice between breathable air and possessions, informal surveys have shown the choice of oxygen over material goods is unanimous. This indicates that the value of photosynthesis and atmospheric oxygen to people exceeds the value of the gross world product – and oxygen production is only a single ecosystem service and good.

General Limitations

- **Static Analysis.** This analysis is a static, partial equilibrium framework that ignores interdependencies and dynamics, though new dynamic models are being developed. The effect of this omission on valuations is difficult to assess.

- **Increases in Scarcity.** The valuations probably underestimate shifts in the relevant demand curves as the sources of ecosystem services become more limited. The values of many ecological services rapidly increase as they become increasingly scarce (Boumans et al. 2002). If the Puyallup Watershed's ecosystem services are scarcer than assumed here, their value has been underestimated in this study. Such reductions in "supply" appear likely as land conversion and development proceed; climate change may also adversely affect the ecosystems, although the precise impacts are more difficult to predict.

- **Existence Value.** The approach does not fully include the infrastructure or existence value of ecosystems. It is well known that people value the existence of certain ecosystems, even if they never plan to use or benefit from them in any direct way. Estimates of existence value are rare; including this service will obviously increase the total values.

- **Other Non-Economic Values.** Economic and existence values are not the sole decision-making criteria. Techniques called multi-criteria decision analysis are available to formally incorporate economic values with other social and policy concerns (see Janssen and Munda, 2002 and de Montis et al., 2005 for reviews). Having economic information on ecosystem services usually helps this process because traditionally, only opportunity costs of forgoing development or exploitation are counted against non-quantified environmental concerns.

GIS Limitations

- **GIS Data.** Since this valuation approach involves using benefits transfer methods to assign values to land cover types based, in some cases, on their contextual surroundings, one of the most important issues with GIS quality assurance is reliability of the land cover maps used in the benefits transfer, both in terms of categorical precision and accuracy.

- *Accuracy*: The source GIS layers are assumed to be accurate but may contain some minor inaccuracies due to land use change since the data was sourced, inaccurate satellite readings and other factors.

- *Categorical Precision*: The absence of certain GIS layers that matched the land cover classes used in the Earth Economics database created the need for multiple datasets to be combined. For example, a "riparian buffer" layer was not obtainable for the Puyallup Watershed, so the "riparian buffer" cover class was applied to all forest and layers (i.e. forest cover) within 50 feet of the Rivers and Lakes layer (NLCD Code 11 minus Estuary). This process is likely to produce some inaccuracies in final acreage values for each land cover class and thus affect the final dollar valuation of the Puyallup Watershed.

- **Ecosystem Health.** There is the potential that ecosystems identified in the GIS analysis are fully functioning to the point where they are delivering higher values than those assumed in the original primary studies, which would result in an underestimate of current value. On the other hand, if ecosystems are less healthy than those in primary studies, this valuation will overestimate current value.

- **Spatial Effects.** This ecosystem service valuation assumes spatial homogeneity of services within ecosystems, i.e. that every acre of forest produces the same ecosystem services. This is clearly not the case. Whether this would increase or decrease valuations depends on the spatial patterns and services involved. Solving this difficulty requires spatial dynamic analysis. More elaborate systems dynamics studies of ecosystem services have shown that including interdependencies and dynamics leads to significantly higher values (Boumans et al., 2002), as changes in ecosystem service levels ripple throughout the economy.

Benefit Transfer/Database Limitations

- **Incomplete coverage.** That not all ecosystems have been valued or studied well is perhaps the most serious issue, because it results in a significant underestimate of the value of ecosystem services. More complete coverage would almost certainly increase the values shown in this report, since no known valuation studies have reported estimated values of zero or less. Table 5 illustrates which ecosystem services were identified in the Puyallup Watershed for each land cover type, and which of those were valued.

- **Selection Bias.** Bias can be introduced in choosing the valuation studies, as in any appraisal methodology. The use of a range partially mitigates this problem.

- **Consumer Surplus.** Because the benefit transfer method is based on average rather than marginal cost, it cannot provide estimates of consumer surplus. However, this means that valuations based on averages are more likely to underestimate total value.

Primary Study Limitations

- **Willingness-to-pay Limitations.** Most estimates are based on current willingness-to-pay or proxies, which are limited by people's perceptions and knowledge base. Improving people's knowledge base about the contributions of ecosystem services to their welfare would almost certainly increase the values based on willingness-to-pay, as people would realize that ecosystems provided more services than they had previously known.

- **Price Distortions.** Distortions in the current prices used to estimate ecosystem service values are carried through the analysis. These prices do not reflect environmental externalities and are therefore again likely to be underestimates of true values.

- **Non-linear/Threshold Effects.** The valuations assume smooth responses to changes in ecosystem quantity with no thresholds or discontinuities. Assuming (as seems likely) that such gaps or jumps in the demand curve would move demand to higher levels than a smooth curve, the presence of thresholds or discontinuities would likely produce higher values for affected services (Limburg et al., 2002). Further, if a critical threshold is passed, valuation may leave the normal sphere of marginal change and larger-scale social and ethical considerations dominate, such as an endangered species listing.

- **Sustainable Use Levels.** The value estimates are not necessarily based on sustainable use levels. Limiting use to sustainable levels would imply higher values for ecosystem services as the effective supply of such services is reduced.

If the above problems and limitations were addressed, the result would most likely be a narrower range of values and significantly higher values overall. At this point, however, it is impossible to determine more precisely how much the low and high values would change.

About Earth Economics

Since 1998, Earth Economics has been providing science-based economic analysis for sound action in project and planning efforts. We apply ecosystem service and whole systems analysis to complex, multi-jurisdictional problems and use our findings to create accounting and funding mechanisms for shifting investments towards building sustainable economies. By using systems modeling, GIS mapping and new science-based economic tools, combined with financial and accounting analysis, we are able to help decision makers, business leaders and the public recognize that intact ecosystems provide immense value to regional and local economies. We have a track record of developing case studies, piloting tools and delivering solutions that can be adapted and applied nationally and internationally. We are a 501c3 non-profit proudly based in Tacoma, Washington.

Mission Statement:

Earth Economics applies new economic tools and principles to meet challenges of the 21st century: achieving the need for just and equitable communities, healthy ecosystems, and sustainable economies.

Program Work:

- Ecosystem Service Valuations: Working with public, private and NGO agencies, Earth Economics' Ecosystem Service Valuation (ESV) studies quantify the value of the goods and services provided by regional ecosystems. This valuation justifies the shift of investment toward environmental preservation and/or restoration.

- Economic Environmental Impact Statements: Working with planners, policy makers and private consulting firms, Earth Economics provides justification for specific projects and scenarios based on environmental economic analysis.

- Jobs Analysis: Working with local and regional economists, agencies, businesses and jurisdictions, Earth Economics analyzes the jobs that will be created, maintained, or lost by doing or not doing a project.

- Accounting and Management Strategies: Working with public utilities, businesses, large land owners and managers, Earth Economics identifies, and helps clients adopt, new management approaches that value ecosystem services in addition to built infrastructure and raw materials.

- Scenario Mapping and Modeling: Working with leading systems modelers, ecologists and hydrologists, Earth Economics analyzes ecosystem services such as freshwater provisioning, carbon sequestration, flood protection, biodiversity and hurricane protection. This information is used to provide current and future maps showing ecosystem services provisioning, beneficiaries and damage under different planning scenarios.

- Funding Mechanisms for Conservation and Restoration: Working with local and state jurisdictions, Earth Economics applies innovative approaches to fund critical natural infrastructure and conservation work.

- Educational Outreach: Working with philanthropic organizations, environmental and policy NGOs, schools and public agencies, Earth Economics conducts workshops, lectures and media events to increase awareness about ecological economics.

- Conversion to Sustainability: Working with the electronic recycling industry, paper mills and other industries, Earth Economics helps catalyze the shift from unsustainable to sustainable technology and industrial processes.

- Further Valuation Studies: Working with academics from around the world, Earth Economics is continually upgrading and refining our Benefit Value Transfer tool and ESV Study Database to ensure the most up-to-date appraisals possible.

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