Ecosystem Services Enhanced by Salmon Habitat Conservation in the Green/Duwamish and Central Puget Sound Watershed

Prepared for:

GREEN / DUWAMISH AND CENTRAL PUGET SOUND WATERSHED

and

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Abbreviations

GIS	Geographic Information System
NPV	Net Present Value
SAV	Submerged Aquatic Vegetation
PSRC	Puget Sound Regional Council
WRIA	Water Resource Inventory Area
WRIA 9 WCST	Water Resources Inventory Area 9 Watershed Coordination Services Team

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EXECUTIVE SUMMARY

The Water Resource Inventory Area 9 (WRIA 9) Habitat Plan is a long-term, comprehensive plan to protect and restore Chinook salmon[1] in the Green/Duwamish and Central Puget Sound Watershed. Restoring salmon has significant socio-economic implications. The greatest socio-economic implication of salmon recovery is in securing healthy ecosystems which provide vast public and private benefits. WRIA 9 ecosystems produce $1.7-6.3 billion dollars of value in goods and services each year, benefiting individuals, communities, businesses, and governments within WRIA 9. The value of salmon restoration and healthy ecosystems to future generations is far greater.

The Seattle based Asia-Pacific Environmental Exchange (APEX), with the University Vermont Gund Institute for Ecological Economics, worked with the WRIA 9 staff to estimate the value of ecosystem goods and services produced within the Green/Duwamish and Central Puget Sound Watershed. The ecosystem goods and services enhanced by actions to implement the Habitat Plan Conservation Hypotheses have been identified and two case studies for salmon restoration actions in the transition zone of the Green River and in the nearshore have also been examined.

The WRIA 9 Habitat Plan actions to restore viable salmonid populations will also preserve and restore 23 categories of valuable ecosystem goods and services identified in the Green/Duwamish and Central Puget Sound Watershed. Healthy ecosystems produce goods and services for free and in perpetuity. They are essential to maintaining a healthy economy and livable communities within WRIA 9. Ecosystem goods and services enhanced by Habitat Plan actions include: flood protection, natural storm water maintenance, drinking water production and filtration, reduction of pathogens and pollutants, waste absorption, storm protection, biodiversity preservation, nutrient regulation, increased production of fish, shellfish and other food and raw materials, erosion control, biodiversity, aesthetic value, recreational fishing, hunting, hiking, bird watching and educational and scientific benefits.

The full value of the benefits provided by ecosystems within WRIA 9 has never previously been estimated.

Until recently, the natural capital, goods and services produced by ecosystems within WRIA 9, including wild salmon, have been abundant. At one time, it was only a shortage of boats and nets that limited the amount of abundant wild salmon caught. Today boats, nets and fishing lures are abundant and a shortage of natural capital—wild salmon—is the limiting factor.

Wild salmon are more than an indicator species. Salmon are a valuable economic asset in and of themselves. Healthy ecosystems, healthy economies and healthy communities are all necessary to maintain and raise the high quality of life that citizens within WRIA 9

[1] Throughout this document "salmon" refers to Chinook salmon.

enjoy. As ecosystems are degraded our quality of life is degraded and citizens pay significant socio-economic costs. Either property owners suffer greater losses from increased flooding and other damage, or cities and counties must replace previously free ecosystem services with increasingly expensive engineering solutions. Increased expenses from lost ecosystem services include increased water filtration costs, storm water management, flood control, endangered species restoration, land slide damage, increased crime and other problems resulting from a degraded environment.

Ecosystems are the most economically efficient production systems for many critical goods and services. For example, healthy riparian areas filter drinking water, move a vast majority of storm water, channel flood waters, recharge aquifers and replenish surface waters. Replacing these services with engineering solutions requires costly capital projects like levees, storm water systems and water filtration facilities. Replacing ecosystem services with engineering systems requires capital costs and maintenance costs.

To understand the value of goods and services provided by ecosystems within WRIA 9, geographic information system (GIS) data for WRIA 9 was compiled for the acreages of forest, grass and shrublands, agriculture and pasturelands, wetlands, urban areas, lakes, ponds, rivers and streams, ice and rock. The team selected peer reviewed journal articles for each land use type and the value of associated ecological services. A benefit transfer methodology was applied to WRIA 9 to calculate a range of dollar value of ecosystem services provided annually within WRIA 9.

Ecosystems within WRIA 9 provide a dollar value greater than the range of $1.7-6.3 billion in ecosystem services annually. This is an underestimate of the true value because not all ecological services were valued. For example, because studies estimating many ecosystem services readily identified as valuable in the nearshore have not been conducted, the estimate for the value nearshore and coastal ecosystem services is far below the actual value.

Using the Army Corps of Engineers discount rate of 3.5 percent (over the next 100 years) this flow of annual benefits by ecosystems within WRIA 9 totals to $48.5-180.7 billion in net present value. Salmon are more than an indicator species for this tremendous amount of value. Secure native salmon populations ensure that much of the critical habitat producing these ecosystem services is also secured.

Notably, there is also reason to consider the value of ecological services without discounting. Healthy ecosystems do not depreciate or require maintenance costs. Once restored, ecosystems are self-maintaining and appreciate in value. In contrast, human built capital, such as a car, requires maintenance and depreciates over time. After providing valuable service a car becomes garbage or recycling. Our grandchildren will likely get little use from the cars we now drive. However, they will unquestionably benefit from the drinking water, flood protection, Chinook salmon and recreation provided by healthy ecosystems. For these reasons it is important to be aware of the socio-economic value of ecosystem services without discounting future value.

Applying a zero discount rate to the flow of WRIA 9 ecosystem service benefits across the next 100 years yields a net present value of $171-637 billion over 100 years. Considering that these ecosystems have been productive for thousands of years, and if restored to health could produce these benefits into the indefinite future, this $171-637 billion represents only a small slice of the potential benefits healthy WRIA 9 ecosystems can produce for future generations. By enhancing salmon habitat, WRIA 9 ecosystems are enhanced and the public benefits directly and financially.

Another marker of value, the total value of taxed property within WRIA 9 was calculated at $71 billion. Of this, $44 billion is improvements on property, which clearly represents built human capital and has taken 150 years to accumulate. Over $23 billion of taxed property value is in land value, representing social, speculative, aesthetic and ecological values.

The standard of living in WRIA 9 is a product of the natural, social and human built capital. It is crucial to recognize the essential contribution of natural and social capital to our wellbeing. To understand the value of ecosystems to the public and economy, it is critical to understand how ecosystems function and how salmon restoration enhances their value to people.

The WRIA 9 conservation hypotheses identify the habitat conditions that are important or critical for salmon recovery based on best available science. Salmon restoration actions then not only restore salmon but provide a basket of other valuable ecological services. The APEX, Gund Institute team examined each of these conservation hypotheses and determined the ecosystem services that would be enhanced by salmon recovery actions.

Two salmon restoration actions were examined using ecological economics analysis for their value added contribution to ecosystem services, and are summarized below.

North Winds Weir Analysis

The North Winds Weir Project expands salmon habitat in the transition zone from fresh to salt water. Transition zone habitat is essential to salmon and may be so scarce that salmon extinction could result without increased transition habitat. This meets the criteria of "critical natural habitat." Though economic methods are based on marginal analyses and not well suited at a threshold for extinction, four different approaches to valuing the expansion of transition zone habitat justify high levels of expenditure actions to reclaim transition zone habitat.

Expenditures for salmon restoration within WRIA 9 to date exceed $59 million, and are expected to rise. Total expenditures over the next 10 years are likely to be $292-706 million or greater. This investment could be lost without securing sufficient transition zone habitat.

Scientific analysis shows that continued salmonid declines are likely without additional transition zone habitat. As a result, if increased transition zone habitat is not acquired

now, the Federal Government may require the acquisition of transitional zone habitat at a future date. If salmonid populations are further depressed, it may require a larger acquisition of transition zone habitat to restore populations.

Ecosystem services would also be enhanced with increased transition zone habitat for salmon. An underestimate, valuing a subset of ecosystem service values produced by the North Winds Weir provides a net present value for the project up to $1.4 million. Using a zero discount rate, (giving equal value to the service benefits of future generations) provides values of $1.35-23.72 million in net value for the North Wind's Weir depending on the time horizon considered. This partial analysis does not account for the value of securing viable salmonid species.

Finally, considering the full suite of expenditures for salmon recovery and the critical habitat functions provided by the transition zone, expenditures on the order of $19 million—far higher than the cost of the North Winds Weir—would be justified.

Ecosystem Services and Removal of Armoring in the Nearshore

The near shore is important habitat for salmonids, particularly young Chinook salmon. The restoration of near shore habitat also contributes to greater ecosystem service production. Though ecosystem service values in the nearshore of WRIA 9 are high, many nearshore ecosystem services have simply never been valued leaving many gaps in the literature. Peer-reviewed valuation studies representing 25 ecosystem services associated with particular land forms and habitats in the nearshore have been conducted. However, there are 161 other identified ecosystem service/habitat/landform associations for which no valuation studies exist. The value of ecosystem services produced in the nearshore is high, thus any benefit transfer valuation of nearshore ecosystem services is necessarily significantly below the true value. With this consideration, APEX identified ecosystem services most likely to be enhanced by removal of coastal armoring as were the ecosystem services associated with two conservation hypotheses associated with removal of armoring.

Another critical factor in this analysis is our lack of understanding of the dynamic oceanographic and biological processes that relate structure, function, process and value in the nearshore. WRIA 9 conservation hypotheses in the nearshore, as throughout WRIA 9 support the strengthening of healthy ecosystems and corresponding rises in the value of increased ecosystem goods and services. A partial estimate of the total value of ecosystem services provided by submerged aquatic vegetation (SAV) alone shows that armoring, docks and launches have contributed to the loss of over $45 million annually in Puget Sound. WRIA 9 is the most heavily armored and affected area along the Sound and accounts for a large portion of those losses. Removal of armoring also supports two salmon conservation hypotheses that would increase the quantity and value of ecological services provided. Depending on the site, oceanographic affects on siltation, SAV, and other dynamics, these salmon restoration actions in the nearshore would likely have a high value.

INTRODUCTION

This report addresses Tasks 9.3.1 and 9.3.2 of the Habitat Plan Work Plan and Schedule.

The Water Resource Inventory Area 9 (WRIA 9) Habitat Plan is a long-term, comprehensive plan to protect and restore salmon in the Green/Duwamish and Central Puget Sound Watershed. Restoring viable salmonid populations in WRIA 9 is not an easy task. Urbanization, suburban growth, pollution, filling, river diversions and a host of other current and historical actions confront restoration efforts. For this very reason, however, WRIA 9 demonstrates the importance of using socio-economic analysis that includes ecosystem services as inputs to restoration decisions.

Policies and actions that restore salmon habitat have significant socio-economic implications. Habitat improvements that contribute to healthy viable salmonid populations also restore a basket of ecosystem services associated with restored salmon habitat. These services include natural storm water regulation, drinking water production, recreational opportunities, waste treatment and a wide variety of other highly valuable ecological services. Thus, salmon restoration not only secures salmon for present and future generations, but contributes to economic security and development by restoring the natural capital upon which a healthy economy depends.

Understanding these implications is an important part of decision-making. In addition, the costs of restoration and benefits of habitat improvements are not necessarily born equally by everyone within the watershed. Equity issues in policy and action are increasingly important considerations in salmon restoration.

1. Background

1.1 Goals of the Study

The WRIA 9 socio-economic analysis examines social and economic impacts of salmon habitat restoration. The goals of this analysis are:

1) to provide information to the public and decision-makers regarding the socio-economic implications of the Habitat Plan;
2) to conduct an analysis of two proposed actions under the Habitat Plan;
3) to aid the successful implementation of the final Habitat Plan recommendations that watershed communities decide to adopt.

The socio-economic analysis in this report includes the following components:

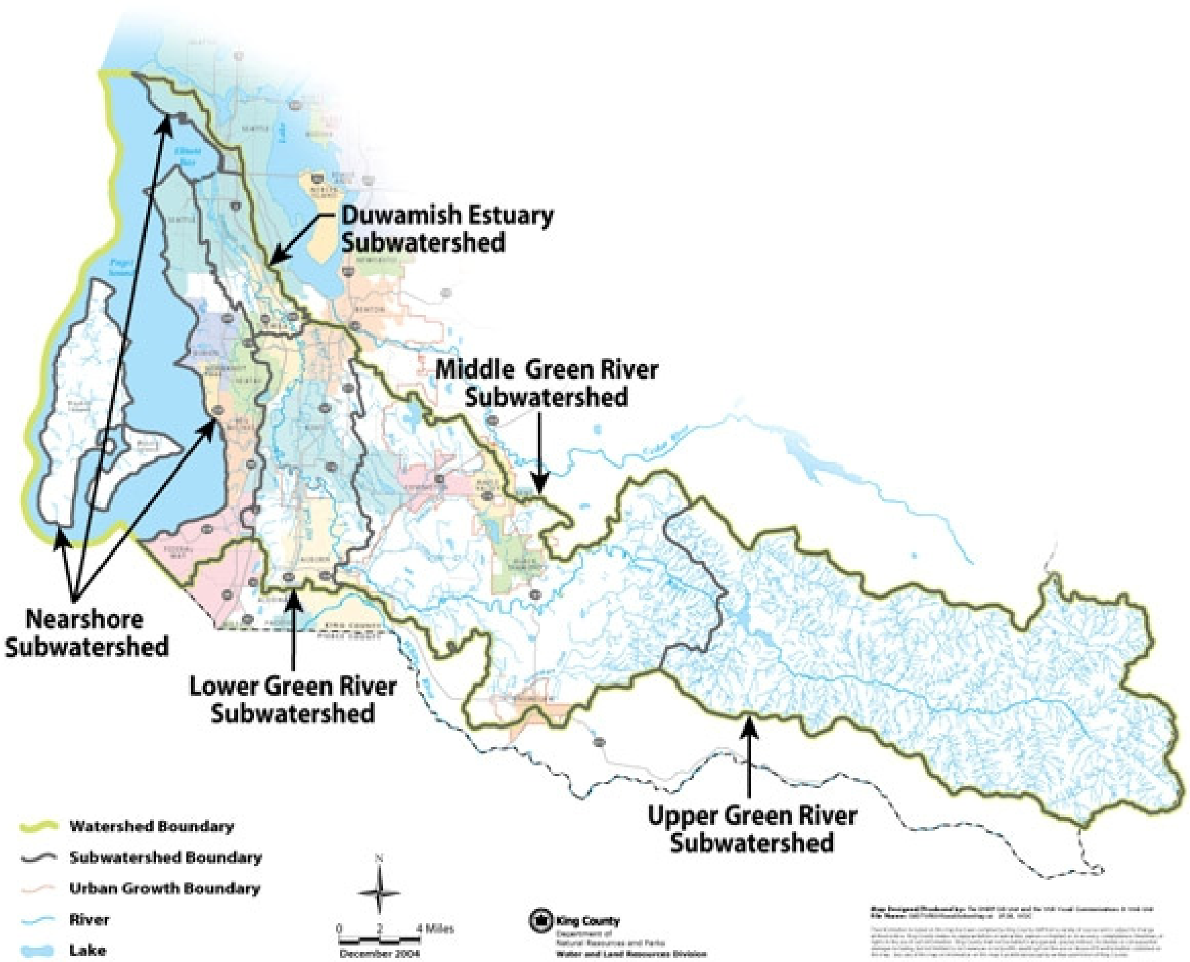
- An analysis of the sources of socio-economic value in the watershed presently and an overview of the watershed's natural capital, human-built capital, and social capital. The analysis then presents measures of the value generated by natural capital within the watershed.

- The analysis includes an examination of the socio-economic implications of salmon habitat conservation in the watershed.

1.2 Description of Green/Duwamish and Central Puget Sound Watershed (WRIA 9)

The Green/Duwamish and Central Puget Sound Watershed (WRIA 9) is part of the greater Puget Sound Basin. The watershed falls between Seattle and Mount Rainier, including and abutting major urban areas. The population within the watershed is 563,980 people, the second most populous WRIA in the state.

WRIA 9 is entirely within the boundaries of King County and includes all or part of fifteen cities: Algona, Auburn, Black Diamond, Burien, Covington, Des Moines, Enumclaw, Federal Way, Kent, Maple Valley, Normandy Park, Renton, SeaTac, Seattle, and Tukwila. The Muckleshoot Indian Tribe Reservation is partially within WRIA 9 and both the Muckleshoot Tribe and Suquamish Tribe (located outside WRIA 9) have usual and accustomed fishing and hunting rights within WRIA 9.



Source: WRIA 9

Figure 1. Map of WRIA 9 and Subwatersheds

WRIA 9 is commonly divided into five subwatersheds. The Upper Green River Subwatershed originates in the Cascade Range at an elevation of about 4,500 feet and is primarily managed forest. This area is used for timber production, municipal water supply, and recreation, and has no permanent population. The Middle Green River Subwatershed is a mix of forestland, farmland, urban and rural residential uses. This area has a population of over 100,000 and is about half residential, followed by commercial forestry and agriculture uses. The Lower Green River Subwatershed is largely urbanized with a population over 150,000. Half of the subwatershed is residential followed by industrial and commercial uses. The Duwamish Estuary Subwatershed is predominantly industrial and urban residential. The population of this area is about 60,000. The Nearshore Subwatershed has a population of over 250,000 and is mostly residential, with some industrial uses.[2]

The Upper Green, Middle Green, Lower Green, and Duwamish Estuary Subwatersheds make up the Green/Duwamish Watershed as watersheds are normally defined – a basin in which waters drain to a central point.[3] The Nearshore Subwatershed is technically not part of the Green/Duwamish watershed. It consists of the many small stream basins draining directly to Puget Sound, from the mainland and from Vashon-Maury Island. It also includes the Puget Sound "nearshore" and marine watersheds. These areas are managed together for salmon habitat planning purposes according to the Water Resource Inventory Area boundaries established by Washington State.

From a salmon habitat perspective, combining the Nearshore Subwatershed and the Green/Duwamish Subwatersheds makes sense, tracking of juvenile salmonids leaving the Green/Duwamish River shows that they rear and migrate through the Nearshore Subwatershed. For example, between two to four weeks after release, 86% of Chinook salmon tagged at the Soos Creek hatchery on the Green River were found south of Elliott Bay in Puget Sound (King County DNRP 2004). While these watersheds do not technically constitute one watershed, for ease of reference they are referred herein as the "Green/Duwamish and Central Puget Sound Watershed" or "WRIA 9."

1.3 Alteration of the Green/Duwamish and Central Puget Sound Watershed

Ecosystems provide valuable ecosystem services. The provision of ecological services and the associated costs or benefits to society are determined by the structure, health and quantity of the ecological systems present. Beyond land cover conversion, ecological systems within the watershed have been impacted by significant commercial forestry operations in the Upper Green River Subwatershed and extensive alterations of the natural hydrological, estuarine and nearshore systems throughout the WRIA 9.

The Green/Duwamish and Central Puget Sound Watershed is one of the most altered hydrological ecosystems in the Puget Sound basin. Historically, three rivers joined the

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[2] Vashon and Maury Islands are included for salmon habitat planning purposes as part of Water Resources Inventory Area 9 although they are part of WRIA 15.
[3] The Green River becomes the Duwamish at the historic confluence of the Green and Black in Tukwila.

Duwamish-Green River: the Cedar, the Black and the White. All three rivers were diverted and separated from the Green River during engineered water projects in the early 1900s. Over the same time period, the Army Corps of Engineers straightened the meandering Duwamish River, removing a total of four miles of river. Seventy percent of the watershed's historical water flow has been diverted out of the basin (Kerwin et al. 2000). In the Middle Green River subwatershed, the 100 year flood plain is 52% of its historic size (Reinelt 2004). In the Lower Green River subwatershed, the 100 year flood plain is 25% of its historic size (Reinelt 2004). The reduction of fresh water flow and straightening of the river has shifted the salt gradient up stream including the transition zone for salmon.

There are two dams on the upper stretch of the Green River. The Howard Hanson Dam, constructed in 1962 primarily for flood control, also augments summer low flows in the Green River for drinking water supply. The Howard Hanson Dam and its reservoir interrupt the natural flow of sediments, including gravel and large woody debris, to lower mainstream Green River reaches. The dam chronically floods upstream habitat when the reservoir is full. Three and one-half miles downstream from Howard Hanson Dam, Tacoma maintains a diversion dam, where the city withdraws a maximum of 113 cubic feet/second of water from the river for municipal uses. The natural landscape and ecosystem services capturing, filtering, regulating and producing this significant fresh water supply are of critical regional value. The withdrawal of this water also has ecosystem service costs. Since 1911, salmon access to the upper watershed has been blocked. Much of the lower river from Auburn downstream is constrained by levees to protect the land from flooding. It is estimated that 80 percent of the Green River from river mile 17 to river mile 33 has been levied or revetted on at least one bank for flood protection (Perkins 1993). Most of the floodplain has been drained, filled and developed.

The estuary and shoreline have also been dramatically altered. Losses of the river edge have occurred via the straightening and armoring of the channel, and from the construction of roads. The main channel of the Green River has been shortened by 17 percent through straightening and narrowed by 29 percent. The shoreline has been straightened and reduced in length by 27 percent. In the Duwamish estuarine tideflats, habitat has been reduced from between 2,100 and 2,500 acres to only 25 acres, a result of filling and dredging. The Nearshore Subwatershed has one of the highest degrees of shoreline modification in the state, with only 19,000 feet of vegetated riparian shoreline remaining (USACE 2004).

A century ago, ecological services were in great abundance within WRIA 9. No one foresaw that some salmonid species would one day be threatened with extinction. Today, with a dramatically altered watershed, the benefits of healthy ecosystems have become scarce and increasingly valuable with scarcity. A century ago, a shortage of salmon was due to a shortage of nets, not of salmon. Today, salmon are threatened for many reasons, and primary among these reasons are habitat reduction and degradation. Restoring viable salmonid species to the watershed is not only legally required and socially important, but economically beneficial as well.

2. Approach

Ecosystems provide goods and services, including salmon, are valuable and essential to the quality of life, economic prosperity and natural beauty of our region. When these ecosystem services are lost, it is at great expense that we replace only one or two of these services with human built capital. For example, water filtration can be provided by a healthy watershed providing high quality drinking water without cost, or by the construction and operation of a $500 million drinking water filtration plant.

Ecosystem services are largely non-market services and have not, until recently, been recognized for their local and global significance (Costanza et al. 1997 and Daily 1997). Work on the identification, classification and valuation of ecological services is ongoing (De Groot et al. 2002). The sophistication and applicability of ecosystem service valuation has also rapidly expanded (Farber et al. 2002).

Valuing every service separately within a watershed would be extremely costly and difficult. However, databases, such as that maintained by the University of Vermont Gund Institute for Ecological Economics and methods for benefit transfer (Desvouseges et al. 1998) have made valuation of ecological services in watersheds viable. Important new advancements developed by Dr. Roelof Boumans of the Gund Institute of Ecological Economics have also added the ability to account for dynamic changes in ecological conditions and ecosystem service values (De Groot et. al. 2002). These ecosystem analyses can be combined with socio-economic analyses to give a better picture of both the ecological and market-based costs and benefits of management options (De Groot et al. 2000). This information can now be integrated into the knowledge base about watersheds or ecosystems, and has been successfully used in management for watersheds and coastal ecosystems (Boumans et al. 2004). Fundamentally, the purpose of all this effort to expand traditional socio-economic analysis is to improve the information available to decision makers and secure better policy, better restoration and better economic decisions (Bingham et al. 1995).

Restoring salmon habitat not only recovers threatened salmon species, but produces a full basket of ecosystem services and goods associated with restored healthy ecosystems. These benefits are large and have often been overlooked, resulting in an underestimation of the benefits of salmon restoration. Some activities clearly damage salmon habitat, inhibit restoration, and reduce the full basket of ecosystem services associated with healthy salmon habitat.

In addition to an ecosystem services analysis, a traditional socio-economic analysis is significantly important, and would include benefits and costs born by affected private individuals and corporations, as well as public institutions. Issues of equity are often overlooked in traditional studies. Changes in land use regulations necessary for salmon recovery may restrict activities such as development or bulk heads on some properties. This provides incentives to shift development and investment to other properties. Rather than an overall economic loss, this results in a transfer of opportunity and development. Critical areas ordinances, for example, may restrict activity in critical ecological areas.

One equity issue is leaving healthy ecosystems and the substantial economic benefits they produce for future generations. Another issue is the differential effects on land owners. Understanding the socio-economic implications of salmon restoration and their distribution within the watershed and among stakeholders in the present and future is crucial.

Three very general forms of capital are identified within WRIA 9:

1. Human built capital, such as houses and roads;
2. Natural capital, which produces ecosystem services and goods;
3. Human and social capital, or community.

It is important to consider the long-term, intergenerational impacts of ecological restoration or degradation on all three types of capital. In addition, it is important to consider the distribution of benefits and costs across different communities (equity issues) and the changes in ecological functions that are of value, but may not be easily described in dollar values.

The APEX team worked with WRIA 9 staff to estimate the value of ecological services within WRIA 9. Geographic information system (GIS) data and related land cover classifications were used with a database of known, generalized ecosystem service values. Utilizing a benefit transfer method provided a cursory range of ecosystem service values within the entire watershed.

This identification and valuation of ecosystem services provided by the watershed's natural capital provides decision-makers within the WRIA 9 watershed with critical economic information. It allows the first opportunity to take stock of the economic value of natural assets within WRIA 9. Without considering the full socio-economic value of these ecological assets and the goods and services they produce, economic policy would be incomplete and inefficient.

However, this generalized analysis has two significant flaws—it is neither dynamic, nor specific enough spatially and temporally to provide sufficient information for specific suites of restoration actions or alternatives. Further work on two proposed restoration actions provided information for examining specific restoration actions and alternatives.

Economic analysis was conducted on two actions from the Habitat Plan: the North Winds Weir Project in the transition zone and the removal of armoring in the nearshore. The North Winds Weir, located in the critical transition zone habitat area was examined with four methods. The transition zone is critical natural capital and is in severe shortage. As this critical threshold of scarcity is approached or surpassed, marginal analysis is of reduced value. The ecological services most likely to be enhanced were identified and four tools were used for examining the socio-economic importance and value of this project. The second case study concerns the removal of coastline armory. Ecosystem services associated with removal were identified and general values examined. Finally,

the relationship between armory and the reduction of submerged aquatic vegetation was examined and valued.

2.1 Natural Capital Concepts and the Methodology of Ecosystem Service Valuation

2.1.1 Natural Capital and WRIA 9

Human activity within WRIA 9, including economic activity, depends upon the intricate natural processes that keep our watershed and region livable.

Natural capital is capital provided by nature which contributes to our economy and quality of life. It is defined as the ecosystems from the alpine areas to Puget Sound. It includes the services provided by native plants and animals, the topography, geology, nutrient and water flows and natural processes (stocks or funds) provided by nature that yield a valuable, regular return of benefits. Natural, or ecological, services are "the conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfill human life" (Daily 1997). These benefits are either natural resources (timber, fish, minerals, berries) or natural services (storm and flood regulation, recreation, aesthetic value) and are provided in perpetuity and for free by healthy ecosystems (Daly et al. 2004).

Ecosystem Goods and Services

Ecosystems provide a variety of goods and services that individuals and communities use and rely upon not only for their quality of life, but also for economic production (Daily 1997; Costanza et al. 1997). Ecosystem goods such as salmon or timber are familiar, but ecosystem services have been often overlooked until they are lost. As Table 1 indicates, these services include everything from air purification to pollination.

Table 1. Examples of Natural Services

Purification of the air and water
Mitigation of floods and droughts
Recreation
Detoxification and decomposition of wastes
Generation and renewal of soil and soil fertility
Pollination of crops and natural vegetation
Control of the vast majority of potential agricultural pests
Dispersal of seeds and translocation of nutrients
Maintenance of biodiversity
Protection from the sun's harmful ultraviolet rays
Partial stabilization of climate
Moderation of temperature extremes and the force of wind and waves
Support of diverse human cultures
Providing of aesthetic beauty

Source: Daily 1997

Ecosystems have components (trees, soil, hill slope, water flows etc.), or infrastructure, that interact in complex processes, create functions and generate environmental goods and services (see Figure 2). The ecosystem infrastructure is defined as the physical components present within the boundaries of the ecosystem. The infrastructure includes biotic and abiotic components, including plant and animal species, the hydrological cycle geomorphological structure and topography. The infrastructure itself is dynamic, as biotic structures migrate and abiotic components flow through the watershed, often via air or water. Some ecosystems are constrained by clear spatial boundaries, others are not.

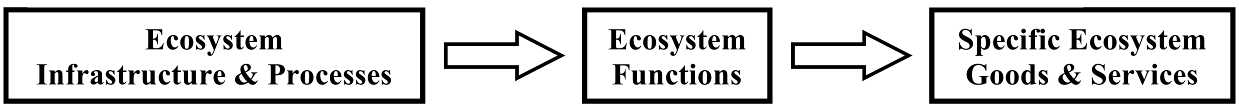

Figure 2. Relationship of ecosystems to ecosystem services

In a natural system, interactions between the components often make the whole greater than the sum of its individual parts -- each of the physical and biological components of watersheds, if they existed separately, would not be capable of generating the same goods and services provided by the processes and functions of an intact watershed system (EPA 2004). Similarly, a heart or lungs cannot function outside a human body. Good human health requires the organs to work together. Ecosystem services are provided by systems of enormous complexity. Individual services influence and interact with each other, often in nonlinear ways (Limburg et al. 2002).

Resilience implies the potential of a system to return to a previous state after disturbance. A system is assumed to be fragile when resilience is low. Fragile systems tend to be replaced with alternative systems after disturbance. These alternative systems often produce reduced amounts of ecosystem services and are consequently of lesser value.

Ecosystems may be resilient or fragile systems. While signs might be present when an ecosystem is on the verge of collapse, there is little science available to show the minimum threshold of ecosystem infrastructure necessary to halt a breakdown of services. Likewise, ecosystems have been shown to be quite resilient; in some cases ecosystem health improves when restoration projects are initiated.

When ecosystems are healthy, they can provide valuable ecological services for free and in perpetuity. For example, healthy forests slow water runoff and, combined with sufficient flood plains, they protect against flooding. When forest cover is lost and flood plains are filled, flooding downstream is increased. If natural flood prevention functions (provided for free) are destroyed, then flood damage will exact costs on individuals and communities. Private individuals, firms and governments will either suffer the costs of flood damage or pay for engineering structures and storm water infrastructure to compensate for the loss of ecosystem flood prevention, previously provided for free by specific geomorphological conditions and healthy ecosystems. Without healthy ecosystems, taxpayers, businesses and governments incur damage or costs to repair or replace these ecosystem services. Salmon restoration not only provides viable salmon

populations, but also restores healthy ecosystems that provide other economic benefits such as flood protection.

Figure 3 shows the connection between management systems and the WRIA 9 conservation hypotheses. Improving ecosystem functions raises the value of ecosystem goods and services which directly contribute to economic, social and ecological well-being. The measurement and recognition of these benefits should adaptively improve management systems.

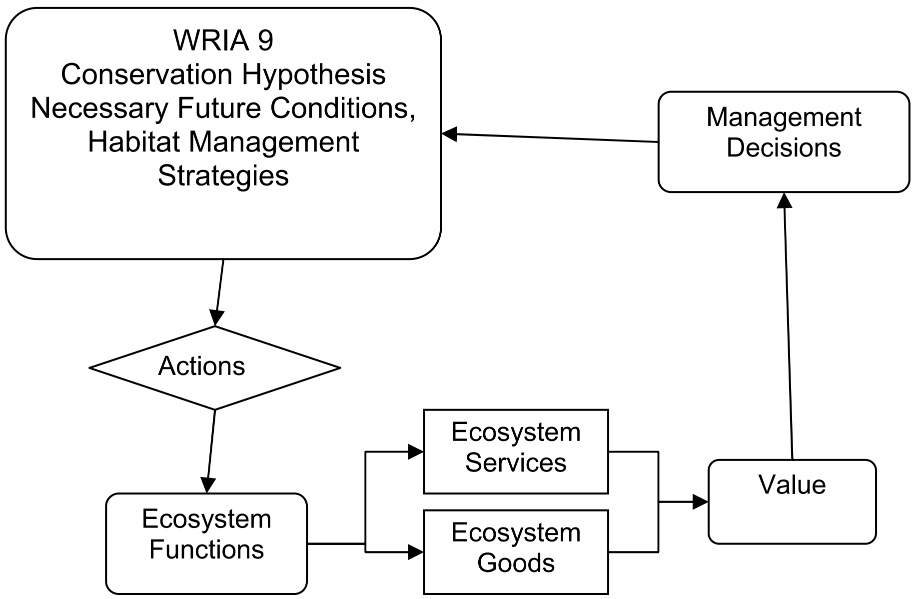

Figure 3: Relationship between ecosystem services and WRIA 9.

2.1.2 Categorizing Ecological Services

De Groot et al. (2002) provides a list of twenty-three ecosystem processes and functions from which all ecosystem services are derived (see Table 2). These are grouped into four function categories: 1) regulation; 2) habitat; 3) production; and 4) information functions. Regulation and habitat functions are considered essential functions necessary before production and information functions can be active.

An assessment by the Gund Institute of Ecological Economics indicates that all 23 ecological services are produced within the WRIA 9 watershed. These services are grouped into four categories of ecosystem functions: regulation, habitat, production and information.

Regulation functions are critical to all other functions and to the provision of ecosystem goods such as breathable air, water, timber and fish. These regulation functions are essential for the maintenance of life and life support systems. They regulate how water, atmospheric gases, climate, soils, nutrients, and wastes are moved through ecosystems, this controls the production of goods. The regulation functions of landscapes and

ecosystems also buffer against disturbances such as storms, floods, landslides, earthquakes, volcanic eruptions, outbreaks of pests or diseases, and they provide pollination services.

Habitat functions provide the livable space for native plants and animals; refugia for migrating birds, animals or salmon; nursery functions for juvenile salmon and other species; the maintenance of species diversity and biodiversity; and the conditions to reproduce for native and commercial species, such as timber.

Production functions facilitate the growth and production of natural resources including water for industrial, agricultural and household use, breathable air, soil, provision of wildlife for hunting and fishing, timber, fruit and other native plant harvests, agricultural production, genetic, medicinal and ornamental resources.

Information functions include opportunities for aesthetic enjoyment and appreciation, recreation, education, scientific advancement, cultural and spiritual value and quality of life.

The complete categories of ecosystem services are listed in Table 2 below.

Table 2. Ecosystem Services Produced in WRIA 9

Functions		Ecosystem Infrastructure and Processes	Goods and Services (examples)
Regulation Functions		*Maintenance of essential ecological processes and life support systems*	
1	Gas regulation	Role of ecosystems in bio-geochemical cycles	Provides clean, breathable air, disease prevention, and a habitable planet
2	Climate regulation	Influence of land cover and biological mediated processes on climate	Maintenance of a favorable climate promotes human health, crop productivity, recreation, and other services
3	Disturbance prevention	Influence of ecosystem structure on dampening environmental disturbances	Prevents and mitigates natural hazards and natural events, generally associated with storms and other severe weather
4	Water regulation	Role of land cover in regulating runoff and river discharge	Provides natural irrigation, drainage, channel flow regulation, and navigable transportation
5	Water supply	Filtering, retention and storage of fresh water (e.g. in aquifers and snow pack)	Provision of water for consumptive use, includes both quality & quantity
6	Soil retention	Role of vegetation root matrix and soil biota in soil retention	Maintains arable land and prevents damage from erosion, and promotes agricultural productivity
7	Soil formation	Weathering of rock, accumulation of organic matter	Promotes agricultural productivity, and the integrity of natural

			ecosystems
8	Nutrient regulation	Role of biota in storage and re-cycling of nutrients	Promotes health and productive soils, and gas, climate, and water regulations
9	Waste treatment	Role of vegetation & biota in removal or breakdown of xenic nutrients and compounds	Pollution control/ detoxification; Filtering of dust particles through canopy services
10	Pollination	Role of biota in movement of floral gametes	Pollination of wild plant species and harvested crops
11	Biological control	Population control through trophic-dynamic relations	Provides pest and disease control, reduces crop damage
Habitat Functions *Providing habitat (suitable living space) for wild plant and animal species*			
12	Refugium function	Suitable living space for wild plants and animals	Maintenance of biological and genetic diversity (and thus the basis for most other functions)
13	Nursery function	Suitable reproduction habitat	Maintenance of commercially harvested species
Production Functions *Provision of Natural Resources*			
14	Food	Conversion of solar energy into edible plants and animals	Hunting, gathering of fish, game, fruits, etc.; small scale subsistence farming & aquaculture
15	Raw materials	Conversion of solar energy into biomass for human construction and other uses	Building and manufacturing; fuel and energy; fodder and fertilizer
16	Genetic resources	Genetic material and evolution in wild plants and animals	Improve crop resistance to pathogens & pests
17	Medicinal resources	Variety in (bio)chemical substances in, and other medicinal uses of, natural biota	Drugs, pharmaceuticals, chemical models, tools, test and essay organisms
18	Ornamental resources	Variety of biota in natural ecosystems with (potential) ornamental use	Resources for fashion, handicraft, jewelry, pets, worship, decoration & souvenirs
Information Functions *Providing opportunities for cognitive development*			
19	Aesthetic information	Attractive landscape features	Enjoyment of scenery
20	Recreation	Variety in landscapes with (potential) recreational uses	Travel to natural ecosystems for eco-tourism, outdoor sports, etc.
21	Cultural and artistic information	Variety in natural features with cultural and artistic value	Use of nature as motive in books, film, painting, folklore, national symbols, architecture, advertising, etc.
22	Spiritual and historic information	Variety in natural features with spiritual and historic value	Use of nature for religious or historic purposes (i.e., heritage value of natural ecosystems and features)
23	Science and education	Variety in nature with scientific and educational value	Use of natural systems for school excursions, etc. Use of nature for scientific research

In reviewing the ecological services present in WRIA 9, it is important to consider two key factors that impact the ability of the watershed to produce ecological services. The first is the amount of undeveloped land cover in the watershed, and the second is the quality, condition, or health of the ecosystems with that land cover. Developed and partially developed lands can also produce significant amounts of ecosystem services if critical habitat is preserved and other ecosystem functions are preserved and restored with appropriate development. Development insensitive to ecosystem services and functions is often very costly because lost ecosystem services must either be replaced or costs incurred. For example flood damage, increased flood insurance or flood prevention engineering are necessary if the natural flood protection functions are lost.

2.1.3 Land Cover and Ecological Services

Ecological services are produced by ecosystems. A complete ecosystem field survey of WRIA 9 would be the best method for examining ecosystem services, but would also be very costly and time consuming. Instead, land cover classifications were used to define the ecosystems, while ecosystem health indicators are derived from remote sensed data and supported by experts on the ground within the WRIA 9 watershed. This is an accepted method for establishing a gage of ecosystem health and a range of values for ecosystem services (Darwin et al. 1996). A recent valuation of ecological services in Massachusetts indicated that 85 percent of the value created by ecological services was generated by wetlands, forests, and water bodies in contrast to land that had been altered by development (Breunig 2003). In general, forests, coastal and estuarine areas, and wetlands are some of the most prolific generators of ecological services (Costanza et al. 1997). Because the greatest threat to ecosystem services is habitat destruction caused by changes in land use (Pearce 2001; Heal 2000), it is valuable to examine trends that may impact the ecological services produced within WRIA 9 over time.

The tables presented below were derived from landcover estimates based on Landsat imagery from 1995 and 2001, supplemented with 2022 Planned Land Use based on the 2003 Puget Sound Regional Council Composite Land Use Designations. Due to the discrepancies in the classification of developed area between 1995 and 2001, the two sets of satellite data were interpreted differently, as is indicated by data for the Upper Green Subwatershed's change in developed area from 1995 to 2001, and the planned change in developed area from 2001 to 2022. More detailed methodological notes are available from the King County Water and Lands Division.

Table 3. WRIA 9 Subwatershed Developed/Undeveloped Area (1995)

Subwatershed	Developed Acres	Undeveloped Acres	Percent Undeveloped
Duwamish Estuary	9,972	4,271	30
Lower Green River	19,472	21,337	52
Middle Green River	7,986	104,259	93
Nearshore (incl. Vashon)	19,666	34,108	63
Upper Green River	671	141,128	99.5
Subtotal	**57,766**	**305,102**	**84**

Table 4. WRIA 9 Subwatershed Developed/Undeveloped Area (2001)

Subwatershed	Developed Acres	Undeveloped Acres	Percent Undeveloped
Duwamish Estuary	11,509	2,734	19
Lower Green River	27,904	12,907	32
Middle Green River	20,302	91,944	82
Nearshore (incl. Vashon)	26,919	26,856	50
Upper Green River	1,940	139,860	99
Subtotal	**88,574**	**274,300**	**76**

Table 5. Projected WRIA 9 Subwatershed Developed/Undeveloped Area 2022 (Planned Future)

Subwatershed	Developed Acres	Undeveloped Acres	Percent Undeveloped
Duwamish Estuary	13,016	468	4
Lower Green River	37,737	1,189	3
Middle Green River	77,890	32,449	29
Nearshore (incl. Vashon)	48,091	2,308	5
Upper Green River	0	141,726	100
Subtotal	**176,734**	**178,140**	**55**

Table 6. Change in Developed Area 1995-2001

Subwatershed	Acres	Percent
Duwamish Estuary	1,538	15%
Lower Green River	8,432	43%
Middle Green River	12,316	154%
Nearshore (incl. Vashon)	7,253	37%
Upper Green River*	1,269	189%
Subtotal	**30,808**	**53%**

Table 7. Change in Developed Area 2001-2022 (Planned Future)

Subwatershed	Acres	Percent
Duwamish Estuary	1,507	13%
Lower Green River	9,833	35%
Middle Green River	57,588	284%
Nearshore (incl. Vashon)	21,172	79%
Upper Green River*	-1,940	-100%
Subtotal	**30,808**	**100%**

Source: King County DNRP, Water and Land Resources Division GIS

*There are discrepancies in classification of developed area, as indicated by data for this subwatershed.

As Table 7 indicates, if the planned future is realized, between 2001 and 2022 WRIA 9 will experience a net increase of 100 percent in developed land. This land conversion has always been assumed to be economically positive because the houses and other developments have conventional market values. Traditionally, the loss in ecological services has not been counted during development decisions, causing increased costs for the replacement of lost ecosystem services including storm water drainage, waste assimilation, flood protection, threatened species restoration and others. The land cover shift will decrease the ecological services produced within WRIA 9. It is vital for economic development to maintain a sustainable scale of critical natural capital, ecosystems and their functions. Otherwise, the benefits of ecological services in the present and through time will be eroded and the costs of either replacing these services or doing without them will escalate substantially. To more fully understand the importance of natural capital, it is important to value it.

2.2 Valuation of ecological services

2.2.1 Background

Valuation Units

To measure the value of ecological services, scientists and economists often describe the service-flux in terms of the dollar value it generates per unit of area over a given time period. In order to standardize the language in which ecological services are described, researchers are increasingly expressing the value yielded by ecological services in dollars per hectare per year (De Groot et al. 2002). One hectare is equivalent to 2.471 acres (Metric Conversions n.d.). However, because a number of valuation studies were conducted before researchers began working to standardize measures of ecological services, most but not all of the studies cited in this report use this standardized methodology.

Difficulties in Dollar Valuation and Service Identification
Although easily identified as valuable, many ecological services are difficult to value. The cultural value of salmon—Tribal and for all other residents—is obvious, very large, and difficult to tie to dollar values. Aesthetic value faces the same issues. Further, many ecological services may not yet be identified. The full importance of the ozone layer was not known until the 1980s, while destructive chemicals have been produced since the 1930s.

Differences between Natural Capital and Human Built Capital
Unlike human built capital, ecosystems are self-organizing. They require no inputs of human labor and capital for maintenance and do not naturally depreciate like all human produced capital does. To provide the service of transportation, a car must be maintained, requiring oil changes and someone's labor. Healthy, fully restored ecosystems do not require these inputs. In addition, human built capital eventually breaks down and loses value.

Value through Time
The vast majority of value provided by a healthy ecosystem is held in the indefinite future. Today, we reap a thin annual slice of benefits from this continuous stream of 23 services. The vast majority of the benefits an ecosystem provides are in the future. This is unlike non-renewable resources which are converted to unusable products, such as burning gasoline, or a new car, which will depreciate and eventually land in the dump. The primary benefits of non-renewable and human built capital are held much closer to the present. This is an important distinction from human-built capital. In addition, value is not fixed in time. Overall, the values of many ecological services are rapidly increasing as they become increasingly scarce (De Groot et al. 2002).

Ecosystems have qualities that are different from human produced capital goods. Ecosystems are self-organizing, they do not depreciate. If healthy, ecosystems provide goods and services virtually in perpetuity. Ecosystems hold vast amounts of value in the distant future. For these reasons, it has been suggested that production of value by ecosystem services be treated with a very low, zero, or even negative, discount rates.

The current owner of a car will be the primary beneficiary from the use of that car, not future generations. Most of the value of a car will be garnered within twenty years or less. However, most of the water provided by the Green River Watershed across the geologic life of the watershed, in the distant future, and in the next twenty years represents only a very small slice of the total water benefits which will be produced.

The vast majority of value that a car produces is to the current user, while the vast majority of value that a healthy ecosystem produces is realized by future generations. This does not mean that the current benefits of ecosystem services are trivial. However, as this study indicates, it is quite the contrary, as there is a great deal more value yet to be gained by future generations if ecosystems are healthy. With this in mind, valuating ecosystems requires an alternative economic perspective from valuing market goods because they are self-maintaining and rapidly increasing in value.

We are Our Grandparent's Future Generation
Eventually, long-term costs come to rest on someone, and the cost of losing ecosystem health comes full circle. Current costs for salmon restoration, water purification, storm water, flood protection and toxic waste clean up in WRIA 9 are in part the result of past decisions that discounted the costs to future generations, including our own.

Value Ranges are Underestimates
The dollar estimates of the value produced by natural systems are inherently underestimates. Not all values identifiable are valued. Many studies used are dated, and the values of ecosystem services have risen faster than inflation. Most of the value is held in the future. For these reasons, the high and low ranges in value are underestimates of the true range in value of ecosystems. For example, dollar values can be established for water filtration services provided by a forest, whereas it is very difficult to fully capture the dollar value of aesthetic pleasure that humans gain from looking at the forest, nor every aspect of the forest's role in supporting the intricate web of life.
Ecological service valuations are not intended to capture all value, but rather to serve as markers somewhere below the minimum value of the true social, ecological and economic value of an ecological service.

2.2.2 Valuation techniques

The valuation techniques used to value ecological services developed within environmental and natural resource economics are widely accepted by the economics profession and in US Courts of Law. All of the reference papers and valuation studies for this study were peer reviewed and published in academic journals. Table 8 shows the valuation techniques. A majority of the valuation techniques used in studies referenced in this document involve direct market pricing, replacement and avoided costs, and travel costs. In a few cases, contingent valuation figures are used.

Table 8. Valuation Methods and Methodology

Direct Values	
Market Price	Prices set in the marketplace appropriately reflects the value to the "marginal buyer" The price of a good tells us how much society would gain (or lose) if a little more (or less) of the good were made available.
Indirect Values	
Avoided Cost	Value of costs avoided by ecosystem services that would have been incurred in the absence of those services. The forested upper watershed of WRIA 9 naturally purifies the water for free. Were this removed, much more expensive filtration and treatment plants would be needed.
Replacement Cost	Cost of replacing ecosystem services with man-made systems. For example, nutrient cycling waste treatment can be replaced with costly treatment systems.
Factor Income	The enhancement of income by ecosystem service provision. For example, water quality improvements increase commercial fisheries catch and incomes of fishermen.
Travel Cost	Cost of travel required to consume or enjoy ecosystem services. Travel costs can reflect the implied value of the service. For example, recreation areas attract distant visitors whose value placed on that area must be at least what they were willing to pay to travel to it. The expenses identify a lower boundary of what visitors are willing and able to pay.
Hedonic Pricing	The reflection of service demand in the prices people will pay for associated goods. For example, housing prices along Puget Sound exceed the prices of similar inland homes.
Contingent Valuation	Value for service demand elicited by posing hypothetical scenarios that involve some valuation of land use alternatives. For example, people would be willing to pay for increased preservation of beaches and shoreline.
Group Valuation	Discourse based contingent valuation, usually bringing a group of stakeholders together to discuss values to depict society's willingness to pay.

Direct Use Value

Direct use value involves immediate interaction with the ecosystem rather than via the services it provides. It may be **consumptive** use, such as the harvesting of trees or fish, or it may be **non-consumptive**, such as hiking, bird watching or educational activities.

Indirect Use Value

Indirect use value is a benefit received without direct interaction with the ecosystem. For example, this includes flood prevention, the services of filtration, storage and release of water, and providing a clean, dependable water supply to those downstream. People downstream that benefit from flood protection need not go to the upper watershed to get it. Studies may derive values from associated market prices, such as property values or travel costs. Values can also be derived from substitute costs—for instance from the cost to build a water filtration plant when the natural ecosystem services of water filtration are lost. Contingent valuation is an additional method that involves asking individuals or groups what they are willing to pay for a good or service.

2.2.3 Ecosystem Services Literature Review

A great number of studies examine the economic value of ecological services. These studies can be land use, vegetation type, or service based. A few services and valuation studies are discussed below.

Storm Protection and Flood Protection

Storm water management and flood protection provided by wetlands and other ecosystems are of vast value (Farber et al. 1987; Kenyon et al 2001; Thibodeau et al. 1981). Wetlands between Gulf States and the Gulf of Mexico, for example, buffer from hurricanes and tidal surges. As wetland buffers between the Gulf of Mexico and New Orleans have been lost, storm damage has increased dramatically. Existing wetlands prevent billions of dollars in storm damage from each storm.

A Washington State wetlands study within WRIA 9 assessed the value of flood protection provided by wetlands in Renton finding that Renton wetlands yielded flood protection benefits worth $41,300 per acre to $48,200 per acre (Leschine et al. 1997). Similarly, a draft study conducted in Portland, Oregon indicates that creation of a wetland to prevent flooding in a frequently flooded area of Southeast Portland would prevent damage amounting to more than $500,000 per flood. This figure is based on actual damages to local homeowners in previous floods in the area (Rojas-Burke 2004).

Water Quality and Supply

Regulation of the quality and supply of water is perhaps the most recognized and studied ecosystem service. Studies have shown that the value of marginal improvements in water quality for specific areas range from $100 to over $1,000 per hectare (Bockstael et al. 1988; Bouwes et al. 1979; Ribaudo et al. 1984; d'Arge 1989; Desvousages et al. 1987; Cho 1990). Riparian forest buffers are estimated to reduce runoff nitrate levels by 84 percent and reduce sediment by more than 80 percent (Northeast Midwest Institute 2004).

Water purification services provided by natural ecosystems are far less expensive than water filtration and treatment facilities. New York City provided over $1.5 billion in watershed conservation measures to restore natural ecosystem filtration to meet water quality standards, rather than deciding to spend $8 billion (plus annual maintenance costs) to build a filtration plant (Krieger 2001). Other jurisdictions have followed a similar pattern. To avoid the need to build a $200 million water filtration plant with additional maintenance and operating expenses, Portland, Oregon spends $920,000 annually to protect and restore the Bull Run watershed, maintaining the natural filtration of its drinking water supply (Krieger 2001). Annual operating costs of artificial water filtration vary. The estimated annual operating costs alone of water filtration facilities in Portland, Maine were $750,000, $3.2 million in Salem, Oregon, and $300 million in New York City (Krieger 2001). Healthy watershed ecosystems permanently provide filtration services, largely for free without capital, maintenance or operating costs.

Trees: Storm Water, Climate Regulation, and Atmospheric Pollutant Removal

Healthy ecosystems provide many bundles of services. Within these systems, trees provide a number of critical ecosystem services, and climate and air regulation have also

been valued. One acre of forest can remove 40 tons of carbon from the air and produce 108 tons of oxygen annually (Northeast Midwest Institute 2004). Market values of carbon sequestration range from $10–100 per ton (Antle et al. 1999; McCarl et al. 2000; Haener et al. 2000) and $650 to $3,500 per hectare (Bishop et al. 2002).

The level of service will differ based on the ecosystem structure (Bishop et al. 2002). For example, a Douglas fir forest plantation, planted ten years ago will not produce the same services as a natural old natural forest with a variety of tree sizes and species. Carbon sequestration in King County was estimated at about 56 million metric tons in 2000, and is predicted to average about 68 tons per acre in 2005, but the service varies significantly between types of growth (Turnblom et al. 2002).

The environmental purification and recovery of mobile nutrients - waste treatment services - provided by forests have been valued at $35 per acre (Loomis et al. 2000). Using land cover analysis, a 1998 report by American Forests related changes in the amount of vegetation and tree cover in the Puget Sound region to storm water management and air quality. The report placed an economic value on the ecology of the most urbanized parts of the Puget Sound watershed. The analysis valued the air quality by pollutants removed by the canopy cover at $166.5 million annually, and estimated storm water benefits amounting to $5.9 billion. Forestland is estimated to save about $21,000 per acre in storm water retention costs by capturing up to 50% of rainfall in the region (American Forests 1998).

Waste Treatment

Wetlands provide another important function for purifying water. A 1990 study found that the 11,000-acre Congaree Bottomland Hardwood Swamp in South Carolina removed the same amount of pollutants as the equivalent of a $5 million wastewater treatment plant (EPA 2003). A study in Georgia revealed that a 2,500-acre wetland saves taxpayers $1 million in water pollution abatement costs (EPA 2003).

Agricultural lands

One land use and policy based study (Ribaudo et al. 1989) estimated the following average benefit per acre of agricultural land under the US Conservation Reserve Program: $36 for soil productivity, $79 for water quality, $12 for air quality and $86 for wildlife.

Pollination

Honeybees have been valued as natural pollinators for American cropland at $9 - $20 per hectare, and pollination services provided to US agriculture by all other pollinators are estimated at over $4 billion annually (Southwick et al. 1992).

Pest Control

Natural systems also provide pest control services. Estimates indicate that it would cost more than $7 per acre to replace the pest control services provided by birds in forests with chemical pesticides (Krieger 2001).

Recreational Value
Another valuable service that ecosystems provide is recreation. Uses such as fishing and hunting have been valued between $3 and $54 per trip (Adamowicz 1991). The fish and wildlife sector is a major economic force in Washington. Over $854 million was spent in 2002 on recreational fishing alone, while an additional $980 million was spent on wildlife viewing and $408 million on hunting (WDFW 2002). Commercial fishing added $140 million to the Washington economy in 2002 (WDFW 2002). Wildlife watching alone generates significantly more revenue for Washington's economy than the apple industry and supports over 21,000 jobs in the state—more than any other Washington employer besides Boeing (WDFW 1997). Studies have found water quality for recreational purposes to be valued at $10 and $80 per year (Adamowicz 1991).

Aesthetic Value
Wetlands and other healthy ecosystems also provide aesthetic value, and the higher property prices around wetlands and forests reflect this phenomenon. A study in the Portland, Oregon area found that residential property values increased $436 for every 1,000 feet closer that a property was to a wetland (Mahan et al. 2000). Additional research has also assessed how other environmental amenities enhance property values (Crompton 2001; Anderson et al. 1988; Laverne et al. 2003; Dorfman et al. 1996).

2.2.4 Contingency Valuation, Restoration and Species Preservation

Contingency valuation establishes values for non-market goods by interviewing human stakeholders. Habitat valuations depend on the species that the habitat is for, and the use of those species for human demand. Many habitats are valued based on species used for consumption, such as oyster and other seafood production (Batie et al. 1978). Many other habitats are protected for valued megafauna (bear, elk, wolves) and protected endangered species. Studies of household values in the Pacific Northwest reflect strong preferences for protection of forests, fish and wildlife. In a study of estuarine function, residents of the Tillamook, Oregon area estimated the value of each additional acre of salmon habitat at approximately $5,000 (Gregory et al. 2001). Olsen and others (1991) found that households in the Pacific Northwest were willing to pay between $26 and $74 per year to double the size of the salmon and steelhead runs in the Columbia River (Quigley 1997). Another study found that Oregon households were willing to pay $2.50 to $7.00 per month to protect or restore salmon, a cumulative total of $2 million to $8.75 million dollars per month (ECONorthwest 1999). The mean annual value per household of river and fishery restoration on the Olympic Peninsula was $59 in Clallam County and $73 for the rest of Washington (Loomis 1996). Another study found Oregon households willing to pay $380 annually to increase preservation of old growth forests, $250 per year to increase endangered species protections, and $144 to increase protection for salmon habitat (Garber-Yonts et al. 2004).

3. Value Generating Capital

3.1 Human Capital, Human-Built Capital and Social Capital

There are various types of capital that, along with natural capital, play an important role in producing value in the economy. In addition to ecosystem services, people, their relationships between each other, and the economic infrastructure that they build are part of value production and should be considered in a complete socio-economic analysis. These include human and social capital, and human-built capital.

3.1.1 Human and Social Capital in WRIA 9

A key asset of the Green/Duwamish and Central Puget Sound Watershed are the people who live or work there. Human capital refers to the people in the watershed and the skills and training they possess. Measures of human capital within the watershed are imperfect, but several indicators provide a preliminary sketch. These indicators include population, education and employment data.

Population

In 1999, the population in WRIA 9 was estimated at 563,980 (Kerwin et al. 2000). The majority of these inhabitants were located in the Nearshore Subwatershed and the Lower and Middle Green River Subwatersheds.

Table 9. Subwatershed Population (derived from 2000 PSRC data)

Subwatershed	Total population	% of total watershed
Upper Green River	128	0%
Middle Green River	112,130	20%
Lower Green River	153,755	27%
Green/Duwamish Estuary	57,647	10%
Nearshore	230,718	41%
Vashon	9,602	2%
Total Population WRIA 9	**563,980**	**100%**

Source: Limiting Factors and Reconnaissance Assessment

Today the population of the watershed is closer to 600,000 people (WRIA 9 WCST 2004).

Education

The population of WRIA 9 has educational attainment roughly proportional to the United States population.

According to the 2000 census, of the non-institutionalized population of the United States, eighty-four percent of all adults ages 25 and over had completed high school and

26 percent had completed a bachelor's degree or more (United States Census Bureau 2000). As Table 10 indicates, 85 percent of all adults ages 25 and over in WRIA 9 had completed high school, and 25 percent had completed a bachelor's degree or more.

Because census and other data are not specifically collected by watershed boundaries, Table 10 was derived by identifying the census tracts within WRIA 9 with GIS data, and then by extracting the relevant tracts from the King County census data.

Table 10. Educational Attainment of Persons 25 Years or Older in WRIA 9

Level of Education	Percent of WRIA 9 populace
9th grade or below	7%
9th grade, but no high school diploma	7.5%
High school graduate	26%
Some college	34.5%
Bachelor's degree	17.5%
Graduate/professional degree	7.5%

Employment

Another indicator of the skills possessed by a population includes the jobs held by members of the population. No data on employment by sector within WRIA 9 are available, but data are available for South King County, which approximates the boundaries of the most populous portions of WRIA 9.

Table 11. Sub-area Employment by Sector (2000)

Sub-area	Const/ Res	Financial/ Ins./Services	Manuf.	Retail	Wholesale/ Transport	Gov/Educ	All sectors
King	69,950	440,360	147,930	189,460	158,310	145,000	1,151,010
Sea-Shore	25,790	231,750	41,200	77,790	63,910	92,330	532,760
East King	20,920	128,030	32,400	51,240	35,000	19,810	287,420
South King	**16,930**	**73,070**	**71,510**	**56,130**	**57,500**	**28,610**	**303,740**
Rural King	6,300	7,510	2,820	4,310	1,900	4,240	27,080
Kitsap	4,290	20,880	2,210	15,230	2,890	25,750	71,240
Pierce	17,880	79,030	22,720	45,980	21,240	48,210	235,060
Snohomish	17,670	50,890	54,610	40,070	13,300	31,620	208,160

Source: Puget Sound Regional Council 2002

Table 12. Distribution of Sub-area Employment across Sectors (2000)

Sub-area	Const/ Res	Financial/ Ins./Services	Manuf.	Retail	WTCU	Gov/Educ	All sectors
King	6.1%	38.3%	12.9%	16.5%	13.8%	12.6%	100%
Sea-Shore	4.8%	43.5%	7.7%	14.6%	12.0%	17.3%	100%
East King	7.3%	44.5%	11.3%	17.8%	12.2%	6.9%	100%
South King	**5.6%**	**24.1%**	**23.5%**	**18.5%**	**18.9%**	**9.4%**	**100%**
Rural King	23.3%	27.7%	10.4%	15.9%	7.0%	15.7%	100%
Kitsap	6.0%	29.3%	3.1%	21.4%	4.1%	36.1%	100%
Pierce	7.6%	33.6%	9.7%	19.6%	9.0%	20.5%	100%
Snohomish	8.5%	24.5%	26.2%	19.2%	6.4%	15.2%	100%
Region	6.6%	35.5%	13.7%	17.5%	11.8%	15.0%	100%

Source: Puget Sound Regional Council 2002

As compared to the region as a whole, workers in South King County were disproportionately active in the manufacturing sector (23.5% of employment in South King County versus 13.7% in the region as a whole) and the wholesale, transportation, communications and utilities (WTCU) sectors (18.9% versus 11.8% in the region as a whole). Other significant skill areas were in financial, insurance, real estate and services (FIRES) (24.1%) and retail (18.5%).

Unemployment rates reflect the human capital not fully deployed either people in transition between jobs, laid off, or chronically unemployed. No unemployment rates were available for WRIA 9 or South King County as a subset of the King County, but the October 2004 unemployment rate for King county was 4.9 percent, as compared to a total unemployment rate for Washington State of 5.6 percent. Employment is currently below a full employment level (Washington Workforce Explorer 2004).

3.1.2 Human-Built Capital in WRIA 9

Human-built capital refers to human-produced products, tools, and technology. Examples of human-built capital include factories that build products and airports that help to transport people. Because economic data is not specifically collected for the jurisdictional boundary of WRIA 9 they are not easily derived for WRIA 9. This document focuses on taxable human-built capital within the watershed as an indicator of built capital. This sketch, like the sketches of the other forms of capital, is incomplete. A full analysis would inventory all houses, buildings, and infrastructure. Understanding the flow of value would involve examining income flows in WRIA 9, which cannot currently be separated from King County.

A majority of the human-built capital in the watershed is located within cities in the watershed. WRIA 9 includes all or part of fifteen cities: Algona, Auburn, Black

Diamond, Burien, Covington, Des Moines, Enumclaw, Federal Way, Kent, Maple Valley, Normandy Park, Renton, SeaTac, Seattle, and Tukwila.

Table 13. WRIA 9 Jurisdiction in Acres as of April 2004

JURISDICTION	WITHIN WRIA 9		OUT OF WRIA 9		TOTAL
	Acres	%	Acres	%	
Algona	195	23%	642	77%	837
Auburn	8,499	61%	5,331	39%	13,830
Black Diamond	3,959	100%	0	0%	3,959
Burien	4,758	100%	0	0%	4,758
Covington	3,554	100%	0	0%	3,554
Des Moines	4,198	100%	0	0%	4,198
Enumclaw	1,357	56%	1,085	44%	2,442
Federal Way	2,913	52%	10,867	48%	13,780
Kent	18,004	97%	584	3%	18,588
Maple Valley	2,764	77%	834	23%	3,598
Normandy Park	1,633	100%	0	0%	1,633
Renton	4,041	37%	6,883	63%	10,924
SeaTac	6,574	100%	0	0%	6,574
Seattle	18,955	23%	65,122	77%	84,077
Tukwila	5,783	100%	0	0%	5,783
Lea Hill/Auburn Potential Annexation Area (PAA)	2,959	100%	0	0%	2,959
East Federal Way PAA	2,901	57%	2,145	43%	5,046
Kent NE PAA	3,466	100%	0	0%	3,466
Fairwood/Renton PAA	2,899	42%	3,977	58%	6,876
West Hill/Tukwila PAA	609	31%	1,333	69%	1,942
N Highline/Seatac PAA	3,870	100%	0	0%	3,870
TOTAL Acres	**103,892**	**51%**	**98,803**	**49%**	**202,695**

Source: King County DNRP GIS

Concentrations of human built capital within the watershed are located in the Kent Valley warehousing, distribution and manufacturing center, and the Duwamish industrial center. Centers of services, production, industry and commerce (human-built capital) include Boeing, King County International Airport (Boeing Field), the Port of Seattle including numerous marine cargo facilities, the Sea-Tac International Airport, the SuperMall of the Great Northwest and a large number of other retailers, Flow International, Hexcel Corporation, Mikron Industries, Starbucks Roasting Plant, REI, Fritz Companies, Burlington Northern Santa Fe and Union Pacific railroads, Puget Sound Energy and Seattle City Light electrical systems, municipal water and sewage systems, various shipyards, several Alaska freight forwarders and barge companies, cement factories, Nucor Steel (the only steel mill in Washington State), a variety of car dealerships, hotels and motels, and assorted additional businesses.

Impervious surfaces and roads also provide a good proxy for the total percentage of human built capital in each subwatershed. Table 14 below provides an initial measure of human-built capital within the watershed in the form of roads and impervious surfaces.

Table 14: Road Miles and Impervious Surfaces in WRIA 9

Subwatershed	Miles of Road	Impervious Surface %
Green/Duwamish Estuary	362	67%
Lower Green River	732	48%
Middle Green River	870	12%
Nearshore	1,117	55%
Upper Green River	489	2%
Vashon Island	203	10%
Total	**3,773**	**18%**

Source: King County DNRP GIS
(Methodological notes available)

3.1.3 Social Capital within WRIA 9

Social capital is the underpinning and core fabric of communities. When present, social capital has a stream of benefits, including safety and security, friendship and community, a sense of civic identity, etc. Healthy social capital is critical to attaining a high quality of life. To describe social capital within the watershed indicators such as the crime rate, and memberships in civic, religious and social organizations would be considered.

There are a great number of anecdotal examples of how salmon restoration brings communities and neighbors together helping to build greater social capital and healthy ecosystems. The cooperation of 15 cities, King County, and civic and business groups within WRIA 9 is a tremendous example of building social capital. Increased social capital increases economic efficiency. Problems solved at a watershed level, such as flood control and salmon restoration would be far more expensive, if not impossible at the level of individual jurisdictions acting independently. In addition, the many examples of neighbors and communities meeting and working together for restoration also build trust, greater security and neighborliness.

Examples of how salmon promote social capital are the salmon festivals in the area. The popular annual Issaquah Salmon Days (founded 1970) is well established. Every year thousands of people are drawn to Issaquah Creek and the Issaquah State Salmon Hatchery to join in a community-wide celebration of the icon fish of the Pacific Northwest. The Enumclaw Salmon Festival, inaugurated in 2003 and repeated in 2004 is another example. Neighbors and communities throughout WRIA 9 have been brought together by salmon restoration and a realization of how important ecosystem services are to our quality and way of life.

Social capital builds around norms and rules, forming the foundation for healthy societies, economies and ecosystems. Salmon is a not only important ecologically, but it

is also a very important social issue that people within WRIA 9 congregate around. The salmon is a "totem" animal in WRIA 9 and the Northwest. Social capital sets norms and rules that can and should be influential in preserving the ecosystems. WRIA 9 should keep promoting the strengthening of social capital and congregation around salmon and habitat issues.

Because social capital is not a central focus of this document, indicators of social capital will not be explored here, except to note that local collective action by stakeholders within the watershed to address declining salmon populations is one example of the presence and strengthening of social capital within the watershed. As WRIA 9 proceeds with restoration, there should be a greater consideration of the benefits for social capital.

3.2 Value Produced in WRIA 9

3.2.1 Value Produced by Ecological Capital

Economics has advanced in the last 20 years and the methods, tools, and techniques for measuring the value produced by natural systems have improved greatly.

The purpose of valuing ecosystem services is to assist decision makers in recognizing all costs and benefits associated with alternative actions. The ecosystem infrastructure is a capital asset, and decisions about ecosystem services impact the maintenance of ecosystem infrastructure. Without valuing ecological services, vast amounts of benefits and the systems that produce them may be overlooked, resulting in significant losses and costs born by individuals and communities over time. Often economic analysis has omitted ecological goods and services giving them an implicit value of zero. In turn, this error can lead to sub-optimal, if not very costly, decisions in land use and other areas.

Ecosystems provide benefits in two forms: goods and services. Timber, fish, water, and wildlife are classified as **goods** (things that you can drop on your foot). Most goods are *exclusive* (if you own or eat an apple, you can exclude others from owning and eating the same apple). Oxygen in the air is a good but is not excludable. Excludable goods can be traded and valued in markets. The production of goods can be measured by the physical quantity produced by an ecosystem over time, the gallons of water per minute, the board feet of timber produced in a fifty year rotation, or tons of fish produced each year. The current production of goods can be easily valued by multiplying the quantity produced by the current market price. The stream of goods provided by an ecosystem is called a *flow* of goods.

Services are benefits you cannot drop on your foot. These include flood protection, recreation (hiking, biking, boating, swimming, hunting, fishing, birding), nutrient recycling, biodiversity, aesthetic value, scientific and educational value, refugia, storm protection, water filtration and control, etc. Ecological services are more difficult to measure than goods, and more difficult to value. The full value of some services may be significantly higher than the value of goods provided. For example, in Orissa, India, mangrove forests provided a buffer between the Indian Ocean and low coastal areas

providing storm protection by absorbing storm impacts and their most devastating affect, the tidal surge. These mangrove forests were cut and replaced by lucrative shrimp aquaculture ponds. In 1999, a signal 4 cyclone brought in a tidal surge that devastated the entire coastal area, shrimp ponds, agriculture, industry, and housing. An estimated 40,000 people were killed. The storm protection provided by the mangroves was critical for this area to sustain people and any economic infrastructure. The Supreme Court of India ordered the mangrove buffer replanted. What was the storm protection value of the mangrove buffer worth?

3.2.1.1 Measuring the Value of Ecological Services

One method for measuring the value of ecological services is done by estimating the service value produced per acre of a particular land cover per year. This entails knowing the particular ecosystems associated with the land cover.

There are eight accepted methodologies for measuring the value of ecological services. Some services can only be measured by estimating costs avoided or incurred with the loss of the service, such as storm protection. Ecosystems produce streams of both goods and services simultaneously. These streams are very different in nature. A flow measures the stream of goods produced by an ecosystem, such as a yearly catch of fish, whereas the stream of service provided by an ecosystem is referred to as a "service flux." A flow of goods can be measured as quantitative productivity over time, but a service flux cannot. For example, the stream of benefits received from recreation or aesthetic information are not measured in stuff per minute produced.

One of the most critical issues to understand about the production of goods and services by ecosystems within a watershed is that the quality, quantity, reliability and the suite of goods and services provided is highly dependent on the particular structure and health of the ecosystems within a watershed.

Healthy, intact ecosystems are self-organizing and provide valuable ecological goods and services on an ongoing basis ("in perpetuity") at no cost to humans. This is very different than all forms of human produced goods and services (cars, houses, energy, telecommunications, etc.), which require maintenance costs. The delivery of ecosystem goods and services depends on maintenance of a specific arrangement of ecosystem components—of a particular "structure." For example, the steel, glass, plastic, and gasoline that comprise a car must retain a very particular structure in order to provide the service of transportation. If the same car were simply a pile of constituent materials, it could not provide the service of transportation, though all the necessary parts are present.

Similarly, ecological services ("service fluxes") are derived from the health and structure of ecosystems. Services appear to be more dependent on structure than the provision of goods. Ecological services such as pollination, water filtration, or flood protection are distinct from goods, (resource flows), such as timber extraction. For example, whereas a single-species timber plantation continues to yield resource-flows of goods, such as

timber, the plantation would likely provide reduced service-fluxes, such as biodiversity, aesthetic value, or recreation in comparison with an intact natural forest ecosystem.

3.2.1.2 Valuation of WRIA 9 Ecological Services

There are two steps to valuing the ecological services produced within the Green/Duwamish and Central Puget Sound Watershed (WRIA 9).

First, because specific land cover types provide specific ecological services, an analysis of land cover classifications within the watershed was completed using GIS technology. The GIS data set is a landcover interpretation performed by Marshall and Associates for King County using Landsat TM Landcover Classifications in 2001. Three grids were compiled, including a grid depicting 11 categories with various vegetation classes, a grid depicting wet areas, and a primary classification grid that was filtered and provided separately. Landcover interpretation was specifically designed to provide an up-to-date landcover assessment of the project area at a cell resolution of 30 meters, and is accurate at the watershed level. Classification was developed by Marshall and Associates and a working group of representatives from multiple county departments.

Second, a database developed by the University of Vermont Gund Institute for Ecological Economics of peer reviewed journal articles on the valuation of ecological services was searched and appropriate low and high ecosystem service valuation studies for associated landcover classifications were identified. Using a value transfer method developed by Dr. Roelof Boumans of the University of Vermont Gund Institute for Ecological Economics, the low and high dollar values for ecosystem services provided by WRIA 9 landcover was estimated. The Gund Institute, the leading ecological economics institution in the nation, has compiled published, peer-reviewed valuation studies of ecosystem services into a database that provides value transfer estimates based on land cover types. Value transfer is an accepted economic methodology that obtains an estimate for the economic value of non-market goods or services through the analysis of studies previously conducted in order to value similar goods or services. The "transfer" itself refers to the application of economic values and other information from the original "study site" to a "policy site". The critical underlying assumption of the value transfer approach is that the economic value of ecosystem goods or services at the study site can be inferred from the analysis of existing valuation studies. The database is continuously updated and reviewed for new literature.

Only rarely can governments and policy analysts afford the luxury of designing, funding and implementing a full set of original studies for estimating the economic value of ecosystem goods or services. When analyzed carefully, however, information from past studies published in the economic literature can form a meaningful basis for directing further study, environmental policy, and management.

Relatively little primary research has been conducted on estimating the economic value of ecosystems located in King County or Washington State. High and low values are

estimated in this study to give an indication of the potential range, which is based on the studies conducted for each service to date.

A general estimate of annual ecosystem service values is calculated based on land cover types, and weighted based on ecosystem health. Taking the low and high boundaries of the full suite of ecosystem service studies provides a range of possible values. The lowest global value in the literature for an appropriate ecosystem service is used to estimate the minimum value, while the highest global value determines the high boundary. As more local and accurate data about the values is placed in the model, the range narrows and more accurate figures emerge.

The land cover estimates from the 2001 GIS data used by WRIA 9 are shown below.

Table 15: Estimate of Land Cover in WRIA 9

Type	Acres	Total Acres	Total Hectares
Forests		**285,836**	**119,098**
Conifer Canopy	130,387		
Deciduous Canopy	4,251		
Mixed Tree Canopy	108,210		
Recent Clear Cuts	18,256		
Young Conifer	24,733		
Grassland and Shrublands		**54,906**	**22,878**
Herbaceous Vegetation	2,221		
Shrub/Scrub	52,685		
Agriculture and Pasture		**19,152**	**7,980**
Dairies	1,235		
Horticulture	1,287		
Livestock	15,643		
Multiple	17		
Unspecified	969		
Urban		**113,583**	**47,326**
High Density Urban	55,044		
Mixed Low Density	58,539		
Lakes, Rivers, Ponds and Reservoirs		**40,677**	**16,949**
Water	40,677		
Wetlands	No available data		
Coastal	No available data		
Rock		**16,353**	**6,814**
Bare Earth	16,353		
Total Combined		**530,506**	**221,044**

APEX has also examined the quality of ecosystems. For example, areas identified as forest areas that were recently clear-cut will not provide the same ecosystem services as those designated as forest areas and which have large trees. We used an adjustment estimate for ecosystem health to reduce the value of ecosystem services in recently clear-cut areas.

Tables 16 a-e show the calculation of preliminary valuations of ecosystem services in WRIA 9 in dollars per year, and the high and low levels are provided. It is important to note that both the high and low estimates are underestimates. Neither includes other identifiable ecosystem services that are not yet included in the valuation, due to either a lack of academic valuation work, incomplete GIS data, or other information gaps. The minimum value also reflects older studies and lower values in the Gund database. It is thus likely to underestimate the true minimum level of value.

Table 16 a. shows the default values and forest values. All figures presented in tables 16 a-e reflect 2001 GIS data, with reduced values for less healthy areas.

Table 16 a. WRIA 9 Forest Ecosystem Service Value Estimates *($ per year)*

Ecosystem Service	Default Values		Forest	
	Low	High	Low	High
Gas Regulation	108	286	7,899,956	20,934,883
Climate regulation	95	241	6,951,961	17,616,901
Disturbance Prevention	1,078	7,808	78,999,560	571,956,814
Water Regulation	1,078	5,872	78,999,560	430,152,604
Water Supply	1,078	8,197	78,999,560	600,396.656
Soil Retention	31	264	2,290,988	19,354,892
Soil Formation	1	11	78,999	789,995
Nutrient Regulation	11,631	22,756	789,995,600	1,666,890,716
Waste treatment	1,079	7,222	78,999,560	528,981,053
Pollination	15	27	1,105,994	1,974,989
Biological Control	2	84	157,999	6,161,965
Refugium function	539	1,643	39,499,780	120,316,329
Nursery function	153	210	11,217,938	15,404,914
Food	1,079	2,978	23,699,868	65,435,335
Raw Materials	108	1,094	7,899,956	80,105,554
Genetic resources	7	22	473,998	1,579,991
Medical resources			0	0
Ornamental resources	3	22	236,998	1,579,992
Aesthetic Information	8	156	552,997	11,454,936
Recreation	108	1,898	7,899,956	139,039,226
Cultural and artistic Information	1,079	6,471	78,999,560	473,997,360
Spiritual and Historic Information			0	0
Science and Education	1	2	78,999	157,999
Navigational services	11	22	789,996	1,579,992
Total Low			**$1,295,829,783**	
Total High				**$4,775,863,103**

Table 16 b. shows the estimates of grasslands and agricultural land covers.

Table 16 b. WRIA 9 Grassland and Agriculture Ecosystem Service Value Estimates *($ per year)*

Ecosystem Service	Grasslands and Shrublands		Agriculture and Pasture	
	Low	High	Low	High
Gas Regulation	1,859,256	4,927,028	34,995	92,736
Climate regulation	1,308,916	3,316,913	30,795	78,038
Disturbance Prevention	22,311,072	161,532,161	349,947	2,533,615
Water Regulation	21,071,568	114,734,688	649,901	3,538,713
Water Supply	19,832,064	150,723,686	349,947	2,659,596
Soil Retention	647,021	5,466,212	14,498	122,481
Soil Formation	24,790	247,901	600	5,999
Nutrient Regulation	185,925,600	392,303,015	3,499,468	7,383,878
Waste treatment	22,311,072	149,394,938	349,947	2,343,244
Pollination	260,296	464,814	3,500	6,249
Biological Control	29,748	1,160,176	700	27,296
Refugium function	8,056,776	24,540,940	149,977	456,831
Nursery function	1,936,105	2,658,737	42,593	58,491
Food	8,676,528	23,955,893	649,901	1,794,377
Raw Materials	619,752	6,284,286	74,988	760,385
Genetic resources	37,186	123,951	0	0
Medical resources	0	0	0	0
Ornamental resources	0	0	0	0
Aesthetic Information	173,531	3,594,562	3,500	72,489
Recreation	2,479,008	43,630,541	0	0
Cultural and artistic Information	24,790,080	148,740,480	199,970	1,199,818
Spiritual and Historic Information	0	0	0	0
Science and Education	16,114	32,227	750	1,500
Navigational services	0	0	0	0
Total Low	**$322,366,483**		**$6,405,978**	
Total High		**$1,237,833,147**		**$23,135,736**

Table 16 c. shows the values of urban areas, lakes, rivers and ponds.

Table 16 c. WRIA 9 Urban and Lake Ecosystem Service Value Estimates *($ per year)*

Ecosystem Service	Urban		Lakes, Rivers, Ponds, and Reservoirs	
	Low	High	Low	High
Gas Regulation	0	0	0	0
Climate regulation	8,327	21,102	0	0
Disturbance Prevention	0	0	0	0
Water Regulation	94,627	515,239	0	0
Water Supply	662,382	5,034,106	0	0
Soil Retention	21,953	185,467	0	0
Soil Formation	95	946	0	0
Nutrient Regulation	1,892,521	3,993,220	0	0
Waste treatment	851,634	5,702,544	0	0
Pollination	19,871	35,485	0	0
Biological Control	1,703	66,427	0	0
Refugium function	378,504	1,152,924	1,617,394	4,926,582
Nursery function	120,932	166,069	91,868	126,156
Food	94,627	261,262	0	0
Raw Materials	0	0	970,436	9,840,224
Genetic resources	0	0	0	0
Medical resources	0	0	0	0
Ornamental resources	0	0	38,817	258,783
Aesthetic Information	11,923	246,974	45,287	938,088
Recreation	208,177	3,663,920	129,392	2,277,290
Cultural and artistic Information	2,838,781	17,032,689	1,293,915	7,763,491
Spiritual and Historic Information	0	0	0	0
Science and Education	2,839	5,677	12,939	25,879
Navigational services	0	0	0	0
Total Low	**$7,208,896**		**$4,200,049**	
Total High		**$38,084,051**		**$26,156,493**

Table 16 d. identifies the values estimated for wetland and coastal ecosystems. The coastal and nearshore values are clearly underestimates, there are a great number of services and ecosystems in the Puget Sound nearshore for which there are no valuation studies available. In addition, the nearshore highlights one of the shortcomings of this methodology, the nearshore is more linear than area based in value production. Processes and value move through the coastal marine environment differently than terrestrial ecosystems, many of these processes and services have not been the subject of valuation studies.

Table 16 d. WRIA 9 Wetland and Coastal Ecosystem Service Value Estimates *($ per year)*

	Wetlands		Coastal	
Ecosystem Service	Low	High	Low	High
Gas Regulation	157,900	418,435	14,841	39,329
Climate regulation	138,952	352,117	26,120	66,190
Disturbance Prevention	1,579,001	11,431,965	1,484,084	10,744,768
Water Regulation	1,579,001	8,597,660	296,817	1,616,168
Water Supply	1,579,001	12,000,406	0	0
Soil Retention	45,791	386,855	0	0
Soil Formation	1,579	15,790	0	0
Nutrient Regulation	15,790,008	33,316,916	0	0
Waste treatment	1,579,001	10,572,990	0	0
Pollination	22,106	39,475	0	0
Biological Control	3,158	123,163	0	0
Refugium function	789,501	2,404,818	371,021	1,130,130
Nursery function	224,218	307,905	147,518	202,578
Food	789,501	2,179,810	1,484,084	4,097,556
Raw Materials	78,951	800,553	0	0
Genetic resources	0	0	0	0
Medical resources	0	0	0	0
Ornamental resources	473	3,158	0	0
Aesthetic Information	11,052	228,955	0	0
Recreation	47,370	833,713	148,408	2,611,988
Cultural and artistic Information	947,401	5,684,402	1,484,084	8,904,504
Spiritual and Historic Information	0	0	0	0
Science and Education	1,579	3,158	742	1,484
Navigational services	1,579	3,158	14,841	29,681
Total Low	**$25,367,120**		**$5,472,561**	
Total High		**$89,705,402**		**$29,444,374**

Table 16 e. shows the estimated value of rock ecosystems.

Table 16 e. WRIA 9 Rock Ecosystem Service Value Estimates *($ per year)*

	Rock	
Ecosystem Service	Low	High
Gas Regulation	0	0
Climate regulation	46,878	118,792
Disturbance Prevention	0	0
Water Regulation	0	0
Water Supply	0	0
Soil Retention	0	0
Soil Formation	0	0
Nutrient Regulation	15,981,120	33,720,164
Waste treatment	0	0
Pollination	0	0
Biological Control	5,327	207,755
Refugium function	2,663,520	8,113,082
Nursery function	0	0
Food	0	0
Raw Materials	0	0
Genetic resources	0	0
Medical resources	0	0
Ornamental resources	0	0
Aesthetic Information	37,289	772,421
Recreation	532,704	9,375,590
Cultural and artistic Information	5,327,040	31,962,240
Spiritual and Historic Information	0	0
Science and Education	5,327	10,655
Navigational services	0	0
Total Low	**$24,599,205**	
Total High		**$84,280,699**

The preliminary low estimates for ecosystem services within various categories, total over $1.7 billion annually, and are listed below. Again, this is at a level that is below the true minimum value. The "prices" or values of ecological services have increased since the studies consulted were completed, and several services identified as valuable have had no applicable studies conducted (this is particularly true regarding nearshore ecosystems). The high value of $6.3 billion is also an underestimate of the high

boundary, because some ecosystems cannot be reflected by a quantitative measure or have not yet been estimated, particularly on in the nearshore.

Table 17. WRIA 9 Total Ecosystem Service Value Estimates *($ per year)*

Ecosystem Category	Low Value	High Value
Forest	$1,295,829,783	$4,775,863,101
Grasslands and Shrub lands	322,366,481	1,237,833,147
Agriculture and Pasture	6,405,977	23,135,736
Urban	7,208,896	38,084,051
Lakes, Rivers, Ponds and Reservoirs	4,200,049	26,156,494
Wetland	25,367,121	89,705,403
Coastal	5,472,559	29,444,372
Rock	24,599,206	84,280,699
Total Values	**$1,691,450,072**	**$6,304,503,003**

This preliminary valuation indicates a range of **$1.7 billion to $6.3 billion in value generated annually by ecological services within WRIA 9**. The magnitude of this figure is not surprising given that the total value of global ecological services is believed to exceed global gross domestic product (Costanza et al. 1997).

Net present value calculations of the calculated value of ecosystem services are presented in Appendices A-C. Under any calculation of net present value, the ecosystem services provided within WRIA 9 are enormous and highly significant. The calculation of net present value is biased, as the title implies, toward present and not future value. When examining the benefits of a stream of value across time, discounting is commonly used. Value in the future is "discounted" exponentially based on a chosen discount rate.

There is a great deal of economic literature dealing with various discount rates to be used, the prime rate of interest, the market rate of interest, inferred social discount rate and others. We provide three calculations of the NPV with three discount rates: The Army Corps of Engineers' 3.5 percent discount rate, a lower 2.5 percent discount rate and a zero discount rate, all over 100 years. Calculation of the NPV and discounting is known to be intergenerationally inconsistent. In other words, a person living in the future and applying the same methodology would maximize their future "present" value. Without the use of a discount rate, the value of ecosystem services provided for free and in perpetuity is infinite.

Appendix A shows the net present value (NPV) of the stream of ecosystem service benefits over the next 100 years using the Army Corps of Engineers discount rate. The total NPV at a 3.5 percent discount rate is $48.5-180.7 billion.

Recognizing that the prime rate is low at present Appendix B shows the NPV using a 2.3% discount rate over a 100 year period to be $67.7-252.2 billion.

Finally, there are good reasons to consider ecosystem services across time with a zero discount rate. Ecosystems do not depreciate, or require maintenance costs as all human built capital. Ecosystems are self-maintaining, accelerating in value and from the perspective of a future generation will be of greater scarcity and higher value in the future. Increasingly, "sustainability" and ecological sustainability in particular are important social goals. Examining the sustainable flow of ecosystem service benefits with a zero discount rate provides a measure of intergenerational equity. Though benefits to people in 2005 may have been unimportant to decision-makers in 1900, it is now 2005, and they are important to us.

Using a zero discount rate, but truncating value arbitrarily at 100 years, Appendix C shows the NPV $170.8-636.8 billion. Considering that generations of people will live within WRIA 9 far beyond 100 years, this range of ecosystem service value is only a small slice of the total benefits provided for generations into the more distant future.

3.2.2 Value Produced by Human Capital in WRIA 9: Income

Income is an important economic measure. It reflects remittances for labor, investment, capital, and marketable natural capital. Significant amounts of value are not reflected in income accounts because value may be produced by non-market activities, not easily quantified and excluded from market-based accounts. For example, cooking, home childcare, and parenting are valuable, but not reflected by increases in income. However, these activities prove to be as, or more, valuable than gains in income. Despite these inadequacies, income does capture a critical aspect of the socioeconomic make-up of WRIA 9 and the potential impacts on valuation. The list of census tracts within WRIA 9, combined with 2000 Census data available from the Puget Sound Regional Council, form the basis for the calculation of average income figures within the watershed shown in Table 18.

Table 18. Average Family and Non-Family Household Income in WRIA 9

Average family household income	$73,617
Average non-family household income	$45,649

Source: 2000 Census

Table 19 shows the numbers of 2000 Census tracts with ranges in average family incomes.

Table 19. Census Tracts in WRIA 9 by Average Family Income

Average family income	Number of tracts with this average income
25,000-29,999	1
30,000-34,999	2
35,000-39,999	2
40,000-44,999	2
45,000-49,999	6
50,000-59,999	28
60,000-74,999	33
75,000-99,999	55
100,000-124,999	5

Table 20 shows the number of Census tracts in WRIA 9 within non-family income ranges.

Table 20. Census Tracts in WRIA 9 by Average Non-Family Household Income

Average non-family income	Number of tracts with this average income
15,000-19,999	1
25,000-29,999	2
30,000-34,999	2
35,000-39,999	10
40,000-44,999	20
45,000-49,999	31
50,000-59,999	26
60,000-74,999	22
75,000-99,999	19
100,000-124,999	1

3.2.3 Value Produced by Human-Built Capital within WRIA 9

Another tool for understanding economic value within the watershed is the examination of the value of built capital stock. The total assessed value for property within WRIA 9 serves as a proxy for the total amount of capital that humans have built and maintained over time. This built capital can then be compared to the amount of value that is produced by nature's ecosystem services. Table 21 shows the assessed value of taxed property within cities that are located in WRIA 9.

Table 21. Value of Built Capital in WRIA 9: Assessed Value by Jurisdiction

CITY	# Parcels	Appraised Land Value	Appraised Improvement Value	Total Appraised Value
Algona	182	$ 25,891,400	$ 61,685,300	$ 87,576,700
Auburn	8,116	$ 1,030,490,760	$ 1,846,979,840	$ 2,877,470,600
Black Diamond	1,827	$ 191,014,600	$ 222,508,900	$ 413,523,500
Burien	9,921	$ 970,998,100	$ 1,888,920,440	$ 2,859,918,540
Covington	5,943	$ 429,394,650	$ 832,695,990	$ 1,262,090,640
Des Moines	8,494	$ 668,445,300	$ 1,364,945,726	$ 2,033,391,026
Enumclaw	1,952	$ 157,292,800	$ 260,429,650	$ 417,722,450
Federal Way	14,595	$ 1,107,611,716	$ 2,380,885,952	$ 3,488,497,668
Kent	18,738	$ 2,537,879,420	$ 4,936,161,685	$ 7,474,041,105
Maple Valley	5,326	$ 364,913,300	$ 678,420,500	$ 1,043,333,800
Normandy Park	2,521	$ 327,923,500	$ 588,792,100	$ 916,715,600
Renton	3,540	$ 764,097,300	$ 1,386,674,800	$ 2,150,772,100
SeaTac	6,538	$ 1,141,139,600	$ 1,776,043,995	$ 2,917,183,595
Seattle	48,121	$ 12,174,286,412	$ 16,135,394,646	$ 28,309,681,058
Tukwila	5,146	$ 1,084,937,200	$ 1,937,321,320	$ 3,022,258,520
Uninc. KC	56,252	$ 4,621,792,559	$ 7,580,060,610	$ 12,201,853,169
Total	197,212	$ 27,598,108,617	$ 43,877,921,454	**$ 71,476,030,071**

Source: King County DNRP

The total estimated value of taxed property within WRIA 9, as tax appraised value, is $71 billion fiscal year 2003. This figure does not include churches, government buildings, the port or other public, or private non-taxed property or improvements. This value also represents two overall values. First, the appraised land value without improvements is $27 billion. Secondly, the appraised improvement value of $43 billion represents the value of human built capital.

It is interesting to note that the value of land without improvements is a "social" value. It is what society through markets has established as the value of the land for aesthetic,

resource, use and other values. For example, the value of an empty unimproved lot in the center of Seattle is high due to the improvements that private individuals and government have put in around that unimproved lot, or the aesthetic or other ecosystem values inherent in the property. In this way the $27 billion value for appraised land value within WRIA represents the social and some aspects of the natural capital value of the land.

4. Outcomes

4.1 Identification of Ecological Services Enhanced by Actions based on the Conservation Hypotheses within WRIA 9

Conservation actions which secure viable salmonid populations in the Green/Duwamish and Central Puget Sound Watershed also protect and restore a great number of other highly valuable ecosystem services and goods. Actions will affect a different array of ecosystem services differently. Understanding the relationship between salmon habitat preservation or restoration and added ecosystem services is important. This process begins with identifying the ecological services associated with actions based on the conservation hypotheses.

Table 22 shows ecological services that would be enhanced in the Green/Duwamish and Central Puget Sound Watershed through implementation of the salmon habitat conservation steps outlined in the WRIA 9 Draft Conservation Hypotheses. Based on the conservation hypotheses, Dr. Roel Boumans of the Gund Institute performed this analysis.

Table 22. Ecological Services Enhanced by Particular Habitat Conservation Hypotheses

Habitat Protection/Conservation Measure	Ecological Services Expected to be Enhanced
Water quality: Address point and non-point pollution from urban areas impacting main stem and tributaries	*8 Nutrient regulation:* Role of biota in storage and recycling of nutrients *9 Waste treatment:* Role of vegetation & biota in removal or breakdown of xenic nutrients and compounds *20 Recreation*: Variety in landscapes with (potential) recreational opportunities
Stream edges: Protect, restore and improve riparian corridor on main stem and tributaries.	*1 Gas regulation:* Role of ecosystems in bio-geochemical cycles *2 Climate regulation:* Influence of land cover and biol. mediated processes on climate *3 Disturbance prevention:* Influence of ecosystem structure on dampening environmental disturbances, Flood prevention *4 Water regulation:* Role of land cover in regulating runoff & river flow, Drainage and natural irrigation. *5 Water supply:* Filtering, retention and storage of fresh water *6 Soil retention:* Role of vegetation root matrix and soil biota in soil retention *7 Soil formation:* Weathering of rock, accumulation of organic matter *8 Nutrient regulation:* Role of biota in storage and re-cycling of nutrients, Maintenance of healthy

	soils and productive ecosystems *9 Waste treatment:* Role of vegetation & biota in removal or breakdown of xenic nutrients and compounds, Pollution control/detoxification *10 Pollination:* Role of biota in movement of floral gametes *12 Refugium function:* Suitable living space for wild plants and animals, Maintenance of commercially harvested species *13 Nursery function:* Suitable reproduction habitat *14 Food:* Conversion of solar energy into edible plants and animals *15 Raw materials:* Conversion of solar energy into biomass for human construction and other uses *19 Aesthetic information:* Attractive landscape features *20 Recreation:* Variety in landscapes with (potential) recreational uses *23 Science and education:* Variety in nature with scientific and educational value
Stream edges: Increase the availability of vegetated shallow nearshore and marsh habitats; increase high inter-tidal zone access.	*1 Gas regulation:* Role of ecosystems in bio-geochemical cycles *2 Climate regulation:* Influence of land cover and biol. mediated processes on climate, Maintenance of a favorable climate *3 Disturbance prevention:* Influence of ecosystem structure on dampening environmental disturbances, Storm protection , Flood prevention *4 Water regulation:* Role of land cover in regulating runoff & river flow *5 Water supply:* Filtering, retention and storage of fresh water *6 Soil retention:* Role of vegetation root matrix and soil biota in soil retention *7 Soil formation:* Weathering of rock, accumulation of organic matter *8 Nutrient regulation:* Role of biota in storage and re-cycling of nutrients *9 Waste treatment:* Role of vegetation & biota in removal or breakdown of xenic nutrients and compounds, Pollution control/detoxification. *10 Pollination:* Role of biota in movement of floral gametes, Pollination of wild plant species, Pollination of crops *12 Refugium function:* Suitable living space for wild plants and animals, Maintenance of commercially-harvested species *13 Nursery function:* Suitable reproduction habitat, Production Functions, Provision of natural resources *14 Food:* Conversion of solar energy into edible plants and animals *15 Raw materials:* Conversion of solar energy into biomass for human construction and other use *16 Genetic resources:* Genetic material and evolution in wild plants and animals *18 Ornamental:* Variety of biota in natural ecosystems with (potential) ornamental use *19 Aesthetic information:* Attractive landscape features *20 Recreation:* Variety in landscapes with (potential) recreational *21 Cultural and artistic information:* Variety in natural features with cultural and artistic value *22 Spiritual and historic information:* Variety in natural features with spiritual and historic value *23 Science and education:* Variety in nature with scientific and educational value
Implement the Low Impact Development technique of allowing more vegetation among residential dwellings	*1 Gas regulation:* Role of ecosystems in bio-geochemical cycles *2 Climate regulation:* Influence of land cover and biol. mediated processes on climate, Maintenance of a favorable climate *3 Disturbance prevention:* Influence of ecosystem structure on dampening environmental disturbances, Storm protection *4 Water regulation:* Role of land cover in regulating runoff & river, Drainage and natural irrigation *5 Water supply:* Filtering, retention and storage of fresh water, Provision of water for consumptive

	use (e.g., drinking, irrigation and industrial use) *6 Soil retention:* Role of vegetation root matrix and soil biota in soil retention, Maintenance of arable land, Prevention of damage from erosion/siltation *7 Soil formation:* Weathering of rock, accumulation of organic matter, Maintenance of productivity on arable land, Maintenance of natural productive soils *8 Nutrient regulation:* Role of biota in storage and re-cycling of nutrients, Maintenance of healthy soils and productive ecosystems *9 Waste treatment:* Role of vegetation & biota in removal or breakdown of xenic nutrients and compounds, Pollution control/detoxification. Filtering of dust particles, Abatement of noise pollution *10 Pollination:* Role of biota in movement of floral gametes, Pollination of wild plant species, Pollination of crops *11 Biological control,* Population control through trophic-dynamic, Control of pests and diseases, Reduction of herbivory (crop damage) relations *12 Refugium function:* Suitable living space for wild plants and animals, Maintenance of commercially harvested species *13 Nursery function:* Suitable reproduction habitat, Hunting, gathering of fish, game, fruits, etc., Small-scale subsistence farming & aquaculture *14 Food:* Conversion of solar energy into edible plants and animals *15 Raw materials:* Conversion of solar energy into biomass for human construction and other uses, Improve crop resistance to pathogens & pests. *17 Medicinal resources:* Variety in (bio)chemical substances in, and other medicinal uses of, natural biota, Other applications (e.g. health care) *18 Ornamental:* Variety of biota in natural ecosystems with ornamental use, Resources for fashion, handicraft, jewelry, pets, worship, decoration & souvenirs (e.g. furs, feathers, ivory, orchids, butterflies, aquarium resources fish, shells, etc.) *19 Aesthetic information:* Attractive landscape features, Enjoyment of scenery (scenic roads, housing, etc.) *20 Recreation:* Variety in landscapes with (potential) recreational use *21 Cultural and artistic information:* Variety in natural features with cultural and artistic value *22 Spiritual and historic information:* Variety in natural features with spiritual and historic value *23 Science and education:* Variety in nature with scientific and educational value, Use of natural systems for school excursions, etc., Use of nature for scientific research
Minimize impervious surfaces	*3 Disturbance prevention:* Influence of ecosystem structure on dampening environmental disturbances, Flood prevention *4 Water regulation:* Role of land cover in regulating runoff & river flow, Drainage and natural irrigation *5 Water supply:* Filtering, retention and storage of fresh water *6 Soil retention:* Role of vegetation root matrix and soil biota in soil retention *7 Soil formation:* Weathering of rock, accumulation of organic matter, Maintenance of productivity on arable land, Maintenance of natural productive soils *8 Nutrient regulation:* Role of biota in storage and re-cycling of nutrients, Maintenance of healthy soils and productive ecosystems *9 Waste treatment:* Role of vegetation & biota in removal or breakdown of xenic nutrients and compounds, Pollution control/detoxification, Filtering of dust particles, Abatement of noise pollution *19 Aesthetic information:* Attractive landscape features, Enjoyment of scenery (scenic roads, housing, etc.)
Forest retention	*1 Gas regulation:* Role of ecosystems in bio-geochemical cycles, Maintenance of air quality *2 Climate regulation:* Influence of land cover and biol. mediated processes on climate, Maintenance of a favorable climate

	3 Disturbance prevention: Influence of ecosystem structure on dampening env. disturbances *4 Water regulation:* Role of land cover in regulating runoff & river flow, Drainage and natural irrigation. *5 Water supply:* Filtering, retention and storage of fresh water *6 Soil retention:* Role of vegetation root matrix and soil biota in soil retention *7 Soil formation:* Weathering of rock, accumulation of organic matter, Maintenance of natural productive soils *8 Nutrient regulation:* Role of biota in storage and re-cycling of nutrients , Maintenance of healthy soils and productive ecosystems *9 Waste treatment:* Role of vegetation & biota in removal or breakdown of xenic nutrients and compounds *10 Pollination:* Role of biota in movement of floral gametes *11 Biological control:* Population control through trophic-dynamic *12 Refugium function:* Suitable living space for wild plants and animals: Maintenance of commercially harvested species *13 Nursery function:* Suitable reproduction habitat *14 Food:* Conversion of solar energy into edible plants and animals *15 Raw materials:* Conversion of solar energy into biomass for human construction and other uses *16 Genetic resources:* Genetic material and evolution in wild plants and animals *18 Ornamental:* Variety of biota in natural ecosystems with (potential) ornamental use *19 Aesthetic information:* Attractive landscape features *20 Recreation:* Variety in landscapes with (potential) recreational value *21 Cultural and artistic information:* Variety in natural features with cultural and artistic value *22 Spiritual and historic information:* Variety in natural features with spiritual and historic value *23 Science and education:* Variety in nature with scientific and educational value
Stream conditions: Protect and improve access to tributaries; restore tributary mouths	*3 Disturbance prevention:* Influence of ecosystem structure on dampening environmental disturbances *4 Water regulation:* Role of land cover in regulating runoff & river flow *12 Refugium function:* Suitable living space for wild plants and animals, Maintenance of commercially harvested species *13 Nursery function:* Suitable reproduction habitat *16 Genetic resources:* Genetic material and evolution in wild plants and animals *19 Aesthetic information:* Attractive landscape features
Enlarge the estuary; create/restore side channels, off channels, and tributary access	*3 Disturbance prevention:* Influence of ecosystem structure on dampening env. disturbances *4 Water regulation:* Role of land cover in regulating runoff & river flow *5 Water supply:* Filtering, retention and storage of fresh water *6 Soil retention:* Role of vegetation root matrix and soil biota in soil retention, Prevention of damage from erosion/siltation *8 Nutrient regulation:* Role of biota in storage and re-cycling of nutrients, Maintenance of healthy soils and productive ecosystems *9 Waste treatment:* Role of vegetation & biota in removal or breakdown of xenic nutrients and compounds *12 Refugium function:* Suitable living space for wild plants and animals, Maintenance of commercially harvested species *13 Nursery function:* Suitable reproduction habitat *19 Aesthetic information:* Attractive landscape features, Enjoyment of scenery (scenic roads, housing, etc.)

	20 Recreation: Variety in landscapes with (potential) recreational uses, Travel to natural ecosystems for eco-tourism, uses outdoor sports, etc.
Create floodplains, marshes, flats, deltas, spits and side channels	*1 Gas regulation:* Role of ecosystems in bio-geochemical cycles *2 Climate regulation:* Influence of land cover and biol. mediated processes on climate *3 Disturbance prevention:* Influence of ecosystem structure on dampening env. disturbances, Storm protection, Flood prevention *4 Water regulation:* Role of land cover in regulating runoff & river discharge *5 Water supply:* Filtering, retention and storage of fresh water *8 Nutrient regulation:* Role of biota in storage and re-cycling of nutrients, Maintenance of healthy soils and productive ecosystems *9 Waste treatment:* Role of vegetation & biota in removal or breakdown of xenic nutrients and compounds *12 Refugium function:* Suitable living space for wild plants and animals, Maintenance of commercially harvested species *13 Nursery function:* Suitable reproduction habitat, Hunting, gathering of fish, game, fruits, etc., Small-scale subsistence farming & aquaculture *19 Aesthetic information:* Attractive landscape features, Enjoyment of scenery (scenic roads, housing, etc.) *20 Recreation:* Variety in landscapes with (potential) recreational uses
Flow conditions: Allow natural disturbance-type flows in a relatively unconstrained river channel	*3 Disturbance prevention:* Influence of ecosystem structure on dampening env. disturbances, Storm protection, Flood prevention *4 Water regulation:* Role of land cover in regulating runoff & river flow *5 Water supply:* Filtering, retention and storage of fresh water *12 Refugium function:* Suitable living space for wild plants and animals, Maintenance of commercially harvested species *13 Nursery function:* Suitable reproduction habitat *19 Aesthetic information:* Attractive landscape features *20 Recreation:* Variety in landscapes with (potential) recreational value
Flow conditions: maintain adequate flows during low flow periods	*4 Water regulation:* Role of land cover in regulating runoff & river flow, Drainage and natural irrigation, Medium for transport discharge *12 Refugium function:* Suitable living space for wild plants and animals, Maintenance of commercially harvested species *13 Nursery function:* Suitable reproduction habitat, Hunting, gathering of fish, game, fruits, etc., Small-scale subsistence farming & aquaculture *19 Aesthetic information:* Attractive landscape features, Enjoyment of scenery (scenic roads, housing, etc.)
Flow conditions: create and restore side flow conditions to provide a range of flow conditions at the mainstream, channel edge, river bends, and tributary mouths	*4 Water regulation:* Role of land cover in regulating runoff & river flow *12 Refugium function:* Suitable living space for wild plants and animals *13 Nursery function:* Suitable reproduction habitat
Sediment issues: Increase sediment delivery and transport of suitable substrate sizes by reconnecting sediment sources to the river	*4 Water regulation:* Role of land cover in regulating runoff & river flow *5 Water supply:* Filtering, retention and storage of fresh water *7 Soil formation:* Weathering of rock, accumulation of organic matter *12 Refugium function:* Suitable living space for wild plants and animals *13 Nursery function:* Suitable reproduction habitat
Sediment issues: Protect and improve sediment quality through removal and source control	*4 Water regulation:* Role of land cover in regulating runoff & river flow *5 Water supply:* Filtering, retention and storage of fresh water

	7 Soil formation: Weathering of rock, accumulation of organic matter *12 Refugium function:* Suitable living space for wild plants and animals *13 Nursery function:* Suitable reproduction habitat
Fish population issues: Harvest hatchery salmon and release natural salmon	*11 Biological control:* Population control through trophic-dynamics *20 Recreation:* Variety in landscapes with (potential) recreational
Modify hatchery practices	*11 Biological control:* Population control through trophic-dynamics *20 Recreation:* Variety in landscapes with (potential) recreational value
Improve the attractiveness of hatcheries to returning salmon	*11 Biological control:* Population control through trophic-dynamics
Reduce harvest of non-salmonid commercially/recreationally important species	*12 Refugium function:* Suitable living space for wild plants and animals, Maintenance of commercially harvested species *13 Nursery function:* Suitable reproduction habitat *14 Food:* Conversion of solar energy into edible plants and animals *20 Recreation:* Variety in landscapes with (potential) recreational uses, Travel to natural ecosystems for eco-tourism, outdoor sports, etc.

4.2 Summary of Ecosystem Services Enhanced by Salmon Protection/Conservation

Considering the full scope of protection and conservation measures being considered, Table 23 contains a list of ecosystem services expected to be enhanced by achieving the conservation hypotheses, ranked by the number of conservation hypotheses that will enhance those services. The ecological services of greatest importance and deserving of further analysis within WRIA 9 include:

- Water regulation,
- Nursery and Refugium functions,
- Recreation/Aesthetic information,
- Water supply,
- Disturbance prevention.
- Waste treatment/nutrient regulation may also be of significant interest.

Table 23. Ranking of Ecological Services Most Impacted by Conservation Hypotheses

Ecological Service	Number of Appearances
Water regulation	13
Refugium function	13
Nursery function	13
Recreation	11
Water supply	10
Aesthetic information	10
Disturbance prevention	9
Waste treatment	8
Nutrient regulation	8
Soil formation	7
Soil retention	6
Gas regulation	5
Food	5
Climate regulation	5
Biological control	5
Science and education	4
Raw materials	4
Pollination	4
Spiritual and historic information	3
Ornamental resources	3
Genetic resources	3
Cultural and artistic information	3
Medicinal resources	1

4.3 Examination of specific recommended actions

In the original scope with WRIA 9, the APEX team agreed to conduct two hypothetical ecological economics examinations of salmon restoration alternatives. The WRIA 9 team requested that this be adjusted and delayed to consider actual restoration actions. The APEX team agreed that this would be more useful, though it required much more effort.

4.3.1 Case Transition Zone: the North Winds Weir Project

4.3.1.1 The Importance of the Transition Zone to Salmon

In coastal river systems, the confluence between fresh water flowing downstream and salt water pushed inland by the tides creates an estuarine transitional zone. Transition zone wetlands and off channel areas are a critical ecosystem in the lifecycle of salmon. The transition zone is where juvenile salmon adapt from fresh to salt water.

Sufficient time and habitat must be available in the transition zone for salmon to linger and grow to survive for salt water conditions. Increasing numbers of juvenile salmon

may survive the freshwater journey downstream but find inadequate habitat in size and dynamics, bottle-necking in the transitional zone. Under these conditions, increased salmon productivity upstream is lost. Current conditions in the transition zone suggest it is a critical threshold point: upstream increases in salmonid survival rates are dependent on the transition from fresh to salt water; beyond this bottleneck, or threshold point, increases in survival are dependent on other habitat factors, such as marine nearshore habitat, water quality or genetic diversity.

In the Duwamish Estuary Subwatershed, the transitional zone has been significantly altered for human use, leading to considerable losses in critical transition zone salmon habitat. Freshwater flowing into the Duwamish estuary was greatly reduced when the White River was diverted in to the Puyallup. With a reduced freshwater flow, saltwater intruded, effectively pushing the transition zone upstream from its historical location to river miles 5.5-7.0. The establishment of heavy industrial use in the transition zone has replaced riverine-tidal, estuarine, and palustrine wetlands with impervious surfaces.

The original stream edge has been replaced by levees and channelization, turning slow-moving edge habitat into unrestrained downstream flows. In addition, now elevated above the stream edge and replaced by noxious weeds, the Duwamish estuary riparian vegetation is of low habitat quality. With these changes, the overall area of transition zone habitat has been degraded and confined from approximately river miles 5.5 to 7.0. High densities of fish have been observed utilizing this specific habitat. The effects of this constrained habitat area have negatively impacted spatial structure, residence time, and the habitat available for refugium and rearing functions in the Duwamish estuary (King County DNRP, *Necessary Future Conditions* 2004).

Given the reality of the Duwamish estuary transition zone today, it is clear that measures to expand and protect this habitat are necessary to the long-term survival of salmon. Further, actions specific to the transition zone have the ability to enhance the outcomes of other habitat measures. Any opportunity to increase the carrying capacity for salmon in a constrained transition zone means an opportunity to expand the carrying capacity of the entire watershed.

4.3.1.2 The North Winds Weir Project

The North Wind's Weir Intertidal Restoration Project, located in the Duwamish estuary transition zone, is one such measure that will address the need to expand the transitional zone. By excavating and replanting, with native vegetation, 2 acres of land at river mile 6.3, the North Winds Weir Project will increase off-channel wetlands and sloughs, and in-stream shallow and slow water habitat in the transition zone. This restoration will enhance the quantity and quality of habitat in the transition zone, ameliorating some problems created with filling in the area.

Due to the location of the transition zone within a prime industrial area, land to be targeted for actions is either already being used for economic production or valued at a very high market price. Land acquisition costs total about $1.9 million with estimated

ecosystem restoration at $1.79 million for a total restoration cost of $3.69 million (WRIA 9 WCST 2005).

However, this high development value must be compared with the habitat value. Industrial uses, although economically lucrative if located between river miles 5.5 and 7.0, can be located elsewhere. Critical transition zone salmon habitat absolutely must be located where freshwater meets tidal salt water between river miles 5.5 and 7.0. Because it is such a specific and very limited area, actions targeted for the transition zone do not have the luxury of multiple options and opportunities. Instead, large-scale and intensive restoration—such as the excavation and replanting of 2 acres at North Winds Weir—is necessary for the creation of the prime off-channel and shallow-water habitat.

Salmon throughout the watershed depend on the transition zone for survival. Habitat of adequate quantity and quality in the transition zone is vital to salmon populations in the Green/Duwamish watershed and would meet the criteria for critical natural capital discussed below (Ekins 2003). Further, given the relative scarcity of native vegetation, wetlands and floodplains in the industrial areas of the Duwamish estuary, the value added with a project like North Winds Weir is significantly greater than an action occurring where there pervious surfaces, healthy vegetation, and shallow habitat already exist to some degree. Actions specific to the industrial area around the transition zone are both high value-added and indispensable to salmon survival.

4.3.1.3 Critical Natural Capital

Marginal economic analysis is appropriate when change occurs in small amounts along smooth paths. However, at crisis points, thresholds or discontinuities, marginal economic analysis fails to identify potentially sudden and vast rises in costs. The March 2003 issue of Ecological Economics, the Transdisciplinary Journal of the International Society for Ecological Economics, was devoted to identifying critical natural capital. Critical natural capital enables the functioning of important environmental functions, and without which there is no substitute form of capital, natural or human made (Ekins 2003). With the loss of a sufficient quantity or function of critical natural capital, environmental sustainability fails (Ekins et. al. 2003). Environmental sustainability encompasses four critical functions: sink, source, life support and human health and welfare. With the loss of critical natural capital ecological functions fail and any or all of the following occur: wastes pile up, resources disappear, life support systems fail (ecosystems collapse or species become extinct), and human quality of life is impacted (Ekins et al. 2003). In the case of WRIA 9 salmonid species, as identified in the Necessary Future Conditions for WRIA 9, increasing habitat in the transition zone is essential. Current habitat is insufficient to ensure future salmonid viability (WRIA 9 WCST 2004).

Thus transition zone salmon habitat clearly meets the definition of critical natural capital because it is essential to the sustainability of salmonid life support functions and there is no financially viable substitute capital. A failure of salmon life support systems would likely occur without restoration actions in the transition zone.

Valuing Critical Natural Capital

The valuation of ecosystem services conducted in this study, and the academic studies upon which it relies are based on marginal analysis—that is they, assume that threshold changes of great magnitude, such as extinction, are not near. Marginal valuation analysis may be inappropriate and potentially misleading when considering critical natural capital. To understand the importance of applying an appropriate valuation of critical natural capital, an example may help.

During any normal day, the smooth functioning of a person's heart goes unnoticed. It contributes no measured amount to economic production and requires no extra-ordinary expenditures. However, during a heart attack, there is a crisis in physical bodily capital, all other priorities are eclipsed. To treat a heart attack (critical) condition as if the heart is in a healthy (marginal) state, could lead to death. During a heart attack crisis, care for the heart, a critical part of the body's capital, must supersede other priorities, otherwise the healthy functioning of all other organs and life itself are under threat. During a heart attack, relying on marginal analysis could lead to a catastrophic result. A crisis analysis is more appropriate.

Economic analysis requires examination of the "opportunity cost" of different actions. In this case, the opportunity costs are difficult to calculate because alternative solutions are highly limited. The opportunity cost of not taking action and risking the loss of restoration investments and the opportunity cost of further declines and of the Federal Government requiring restoration in the transition zone were examined.

Unfortunately, there is a significant lack of literature developed on the valuation of Critical Natural Capital. Thus, the APEX team applied four methods for examining the restoration value of the North Winds Weir Project. These included:

1. An examination of the potential losses of salmon restoration investments throughout the Green River/Duwamish watershed with the failure of salmon restoration due to lack of transition zone habitat.
2. The opportunity costs of pursuing restoration of viable salmonid species without securing adequate critical transition zone habitat with the risk of a later requirement to secure transition habitat due to further declines in salmonid populations.
3. An identification of additional ecosystem services provided by the two acre restoration project and ecological economics estimate of the marginal increase in ecological services created.
4. An analysis of the expenditure priorities based on achieving the Necessary Future Conditions (2004) identified by the WRIA 9 science team, with a $200 million budget over a twenty year period.

1. Risk of salmon restoration investment losses.

The cost of current salmon efforts to date, including WRIA 9 expenditures, the refitting of the Howard Hanson Dam to allow salmon passage, King Conservation District grants and Salmon Recovery Board expenditures, currently exceeds $59 million (WRIA 9 WCST 2005). In early 2005, the WRIA 9 Coordination Services Team prepared a preliminary cost estimate range for the Habitat Plan based on early concepts and current proposals for the whole suite of habitat projects. Although costs are subject to change, the preliminary assessment finds that a range of restoration costs within WRIA 9 will likely be $292-706 million for salmon habitat restoration over the next ten years (WRIA 9 WCST 2005). The establishment of viable salmonid populations may not be possible without securing sufficient critical natural capital at the transition zone habitat. The North Winds Weir project is a first step in the restoration of the Duwamish River transition zone. However, it is important to note that numerous other strategic actions, in addition to the North Winds Weir project, are crucial for securing sufficient transition zone habitat to support increased salmon populations. Without the North Winds Weir expenditure of around $3.69 million, with many other subsequent restoration projects in the Duwamish River transition zone, the full $292-706 million in salmon restoration investments could be placed at the risk of failure.

2. Risk of salmonid declines and subsequent Federal requirement to secure transition zone

If salmonid restoration efforts go forward without the North Winds Weir Project and other actions in the transition zone, further declines of Chinook salmon populations could trigger an endangered listing. This would lead to the necessity for greater protection and restoration actions under the Federal requirements under the Endangered Species Act. At this point, the costs for acquiring and restoring transitional habitat would likely have increased significantly. Further, a larger expansion of habitat would be required for meeting population targets considering that the salmon populations would be further depressed.

3. Valuation of ecosystem services enhanced by the North Winds Weir Project

To establish the ecosystem services enhanced by the North Winds Weir Project, each habitat protection/conservation measure in the North Winds Weir Project was examined and the corresponding ecological services enhanced by the excavation and replanting project were identified. These are shown below in Tables 24 a-d.

Table 24 a. Transition Zone: Excavation and Replanting

Habitat Protection/ Conservation Measure *Ecosystem Service Enhanced*	Improve water quality by reducing point and non-point pollution	Protect, restore and improve riparian corridor
Gas regulation	*	*
Climate regulation	*	*
Disturbance prevention	*	*
Water regulation	*	*
Nutrient regulation	**	*
Waste treatment	**	*
Pollination		*
Refugium function	**	*
Nursery function	**	*
Food	*	*
Raw materials		*
Genetic resources	*	
Aesthetic information	*	*
Recreation	*	*
Science and education	*	*

Table 24 b. Transition Zone: Excavation and Replanting

Habitat Protection/ Conservation Measure *Ecosystem Service Enhanced*	Increase vegetated shallow water and marsh habitats; intertidal zone access	Minimize impervious surfaces
Gas regulation	*	
Climate regulation	*	
Disturbance prevention	*	*
Water regulation	*	*
Water supply		*
Nutrient regulation	**	*
Waste treatment	**	*
Refugium function	*	
Nursery function	*	
Food	*	
Genetic resources	*	
Aesthetic information	*	*
Recreation	*	
Cultural and artistic information	*	
Spiritual and historic information	*	
Science and education	*	

Table 24 c. Transition Zone: Excavation and Replanting

Habitat Protection/ Conservation Measure ***Ecosystem Service Enhanced***	**Improve and restore access to tributaries**	**Enlarge the estuary; create floodplains, marshes, flats, deltas, spits and side channels**
Gas regulation		*
Climate regulation		*
Disturbance prevention	*	*
Water regulation	*	*
Water supply		*
Nutrient regulation		*
Waste treatment		*
Refugium function	**	**
Nursery function	**	**
Food	*	*
Genetic resources	*	*
Aesthetic information	*	*
Recreation		*
Science and education	*	*

Table 24 d. Transition Zone: Excavation and Replanting

Habitat Protection/ Conservation Measure ***Ecosystem Service Enhanced***	**Allow natural disturbance-type flows in a relatively unconstrained river channel**
Disturbance prevention	*
Water regulation	*
Water supply	*
Refugium function	**
Nursery function	**
Food	*
Genetic resources	**
Aesthetic information	*
Recreation	*
Science and education	*

Increasing the transition zone habitat by two acres over the current grassland uses would provide increased ecosystem service benefits as described in Table 25.

Table 25. North Winds Weir Restoration Valuation

Service	**Underestimate of low value** ***($/year)***	**Underestimate of high value** ***($/year)***
Gas Regulation	83	221
Climate regulation	73	186
Disturbance Prevention	833	6,033
Water Regulation	833	4,538
Water Supply	833	6,333
Soil Retention	24	204
Soil Formation	1	8
Nutrient Regulation	8,333	17,583
Waste treatment	833	5,580
Pollination	12	21
Biological Control	2	65
Refugium function	417	1,269
Nursery function	118	163
Food	417	1,150
Raw Materials	42	423
Genetic resources	0	0
Medical resources	0	0
Ornamental respources	0	2
Aestethic Information	6	121
Recreation	25	440
Cultural and artistic Information	500	3,000
Spiritual and Historic Information	0	0
Science and Education	1	2
Navigational services	1	2
Total	**$13,388**	**$47,343**

The increase in ecosystem services provided by the North Winds Weir is based on a marginal analysis and does not fully reflect the benefits of bringing this ecosystem type out of a crisis condition. In addition, this analysis is based on a benefit transfer analysis, thus the range is wide. The ranges in discounted net present value and under a zero discount rate for the production of ecosystem services on the North Winds Weir Project are shown in tables 26, a and b, with varying time horizons.

26 a. Ecosystem service benefits for the North Winds Weir Project: 100 year horizon

Value estimates	**Net present value** *(3.5% discount rate over 100 years)*	**Value** *(zero discount rate over 100 years)*
High value	$1.36 million	$4.78 million
Low value	$384 thousand	$1.35 million

26 b. Ecosystem service benefits for the North Winds Weir Project: 500 year horizon

Value estimates	**Net present value** *(3.5% discount rate over 500 years)*	**Value** *(zero discount rate over 500 years)*
High value	$1.40 million	$23.72 million
Low value	$396 thousand	$6.71 million

In this case, the importance of the discount rate is clearly apparent. If the value to future generations is given greater weight, then the North Winds Weir Project has significantly greater economic justification. It is important to consider that this analysis is partial, not all ecosystem services are included, and that it does not account for the critical nature of the restoration. This is a marginal analysis assuming that the habitat is not scarce. The analysis would be correct if salmon were not threatened. Because no economic techniques exist to adjust these figures they are presented here as underestimates of the true values. This implies that the actual ecosystem service values are much higher.

4. Salmon restoration priorities based on best available science within a limited budget.

With a particular budget, where should investments be placed based on risk-averse choices and best available science to secure the ecosystem functions needed to meet the WRIA 9 goal of 35% salmon habitat restoration? APEX team member Dr. Roelof Boumans of the University of Vermont, Gund Institute developed a preliminary model for examining the optimal expenditure of funds assuming a $200 million budget for all actors within the watershed over the next twenty years. This analysis is a marginal analysis based on the need for securing the full suite of salmon habitats required for restoration of viable salmonid populations. The results of this analysis are highly preliminary, and further model refinement would be required to secure the level of confidence needed for decision-making. For these reasons, only the prices of the transition zone were included here. This preliminary approach demonstrates the importance of the transition zone habitat as it reaches a critical natural capital state.

Figure 4 shows the generalized relationships between the area of transition zone habitat (red), transition habitat functions realized (green), and the dollar value of transition zone habitat (pink). At large amounts of transition zone habitat (red line at left of graph), other

factors limit salmon populations, constraining habitat functions realized for salmon (green line). The value of investing to restore transition zone habitat is low (pink line to left of graph) because it is abundant and does not limit salmon populations.

As transition zone habitat and associated functions decline, the "price" of transition zone habitat, or value of investing in restoring transition zone habitat rises slowly, until the transition zone falls into a state of crisis, with habitat and functions approaching zero (green and red lines on right). The existence of salmon are threatened by the lack of transition zone habitat, and scarcity value rises exponentially (pink line on right), justifying much larger expenditures to secure critical transition zone habitat.

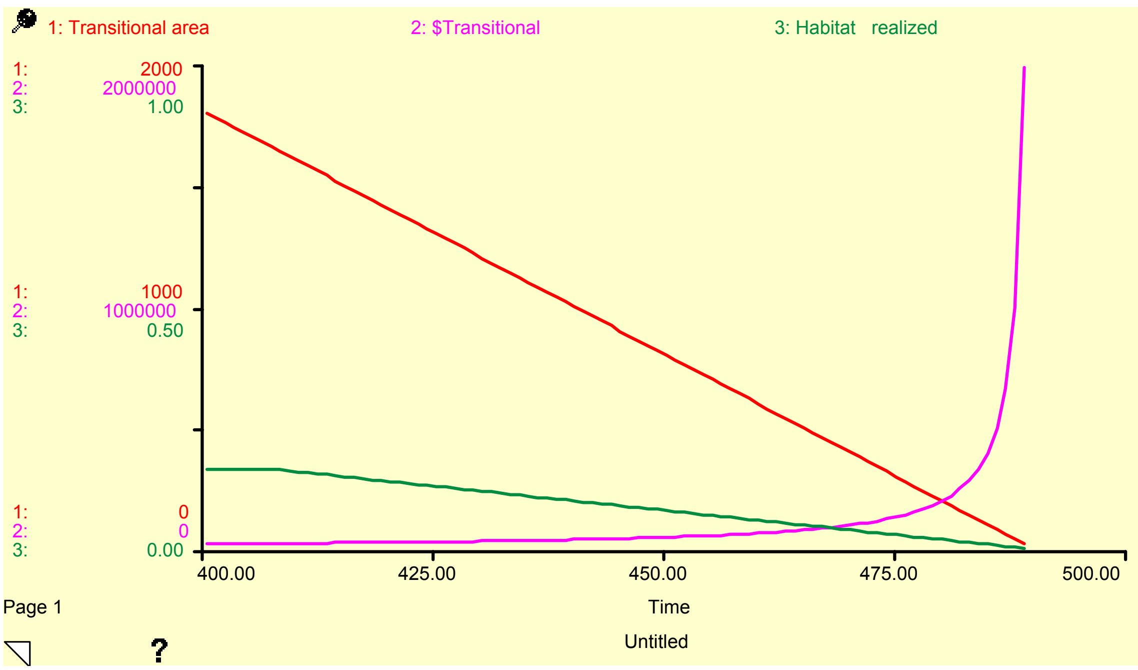

Figure 4. Relationship between area, function and value of transition zone habitat

Three cases were examined based on assumptions of how important and limiting the transitional zone, coastal, tributary and upland habitats are to threatened salmonids.

Using a modified Cobb-Douglass function and four critical ecosystem habitat types, modified with an ecological model assuming that the habitat type most constraining of the four will be the limiting biological factor, the marginal values (amount to be paid for each additional restored acre of each habitat type) were calculated for all habitat types. It was assumed that the overall combined expenditure by all salmon restoration actors within the watershed would be $200 million over the next 20 years. Purchasing the most constraining habitat will have the greatest biological pay-off per acre. Thus the expenditure per acre for this habitat type would be greatest.

Analysis 1: ***Ecosystem Functions Restored to 35% of Salmon Habitat***

Under this analysis, the full WRIA 9 goal of restoration to 35% of historic salmon habitat functions is achieved. Under this restored sustainable salmon scenario, there is no emergency. The Transition habitat is still the most constraining habitat and captures the highest price to be paid per acre for restoration, $11,389. Because the ecosystem health of the habitat was degraded this scenario requires more acreage than the final scenario.

Table 27. Ecosystem Functions Needed to Restore 35% of Salmon Habitat

	Habitat Type			
	Upland	*Tributary*	*Transition*	*Coastal*
Optimum Distribution of Habitat types (assumption)	.6	.2	.05	.15
Number of ecosystem functions	30	25	8	1.75
Acres of Habitat	50,000	60,000	3,500	16,000
Price to be paid per acre habitat restoration			$11,389	

Analysis 2: ***Transition Zone Crisis Scenario***

Under this scenario, most similar to the current situation within WRIA 9, the transition zone is severely constrained. Without increased acreage of transition zone habitat, wild salmonids are likely to become extinct. This crisis scenario implies tremendous gains with the acquisition of the first two acres of transition habitat. It would be worth paying over $19,000,000 to restore the first acre of critical transition zone habitat. All other habitats, though important, are far from becoming the constraining habitat types.

This is a marginal analysis, and does not capture the full risk and potential costs of crossing a critical threshold that would leave salmonid populations beyond recovery.

Table 28. Crisis Scenario: Critically Low Acreage of Transition Zone Habitat

	Habitat Type			
	Upland	*Tributary*	*Transition*	*Coastal*
Optimum Distribution of Habitat types (assumption)	.6	.2	.05	.15
Number of ecosystem functions	18	10	5	.001
Acres of Habitat	36,000	20,000	2	10,000
Price to be paid per acre habitat restoration			$19,930,000	

Analysis 3: ***Full Habitat Function Restoration***
Under conditions where sufficient habitat has been acquired, fully returning ecosystem functions, then it is still worth paying to purchase the most productive ecosystem types. Since the transition zone is not in severe shortage, the price has also fallen. The following value would be placed on restoration per acre of transition zone habitat.

Table 29. Success Scenario: Salmon Populations Restored

	Habitat Type			
	Upland	*Tributary*	*Transition*	*Coastal*
Optimum Distribution of Habitat types (assumption)	.6	.2	.05	.15
Number of ecosystem functions	60	20	5	15
Acres of Habitats	18,000	6,000	1,500	4,500
Price to be paid per acre habitat restoration			$26,667	

In fact, the North Winds Weir is a relative restoration bargain at $4 million, and based on the science of salmonid habitat needs, further investment to acquire more area for transitional habitat restoration or creation is justified. The ecological economics analysis must be rooted in the science of salmon restoration. As our understanding of what is most important to salmonids for restoration in WRIA 9 becomes more clear, then the ecological economics analysis of where funding should be placed is also clarified.

4.3.1.4 Summary: Transition Zone

Because the actual optimal scientific distributions of habitat types to increase salmonid productivity are not precisely known, this analysis is introductory and illustrative. However, the science is clear enough to know that the transition zone is a critical habitat for salmon. Very little of it exists, and more must be acquired to ensure restoration of viable salmonid species.

Unfortunately, current analytical economic techniques are insufficient for fully examining the value of critical natural capital in crisis. Four different approaches to the problem, however, demonstrate a policy objective and justify high levels of expenditure actions.

Transitional zone habitat meets the criteria of critical natural habitat. Salmon science within WRIA 9 shows that the loss of this critical habitat is likely a primary cause of wild salmonid declines and without restoration of this transitional habitat, threatened salmonid species will likely continue to decline.

A policy goal within WRIA 9 should be to protect and restore enough of the critical natural capital of all types to bring all forms of critical ecological capital out of a state of crisis.

In particular, transition zone habitat for salmonid species is clearly critical natural capital in a crisis state. By securing sufficient natural capital, society avoids catastrophic costs of eventually replacing or simply losing the benefits provided by critical natural capital, in this case wild salmonid species. Returning to the heart attack example, preventative measures to avoid a heart attack or return the heart to health are less expensive than either the option to replace the function of a healthy heart artificially or simply die. It is better to bring the transition zone habitat out of this "heart attack state" and into a healthy state, rather than try to substitute other habitat types or risk the further decline of threatened salmonid species into extinction.

Four methods for examining the transition zone were completed, including risk to current expenditures, risk of further decline and Federal requirements later to secure transition zone habitat, the increase in ecosystem service production and an expenditure analysis.

Expenditures for salmon restoration within WRIA 9 to date exceed $59 million. This is expected to rise as the WRIA 9 Habitat Plan is completed and further projects are funded by many actors within the watershed. Total expenditures in the coming decades will likely be $292-706 million. This investment could well be lost without securing sufficient transition zone habitat.

Without securing transition zone habitat, and if salmonid species continue to decline, the Federal Government may require the acquisition of transitional zone habitat at a future date. With fewer salmon at that date, a larger area of acquisition would likely be required at a much higher cost than acquiring habitat today with larger salmonid populations.

Ecosystem services would also be enhanced with increased transition zone habitat for salmon. On the basis of ecosystem service value from the North Winds Weir project alone, value would total $384 thousand to $1.40 million in net present value for the project depending on the time horizon. Taking the approach that once restored, these ecological services are produced without maintenance, these benefits are appreciating and do not depreciate (future generations will benefit from the flood protection value of the transition zone). Using a zero discount rate, and giving greater value to the ecosystem services future generations will benefit from provides values of $1.35-23.72 million, depending on the time horizon considered. It is critical to understand that these figures are clear underestimates of the true values. This is a marginal analysis assuming that there is no "critical" status of the transition zone habitat or that salmon are threatened. For these reasons the true value of these ecosystem services may be several times these figures.

Finally, considering the full suite of expenditures for salmon recovery and the critical habitat functions provided by the transition zone, expenditures far higher than the cost of the North Winds Weir would be justified.

4.3.2 Case Study: Ecosystem Services in the Nearshore

The nearshore is critical to salmonid lifecycle. It provides habitat for juvenile salmon as they leave the Green/Duwamish and enter the oceanic phase of their lives. Nearshore ecosystems where terrestrial and aquatic ecosystems meet (to a depth where light penetrates) are tremendously productive. Overall, they are the most productive ecosystems on a per acre basis in the world. Globally, coastal ecosystems were estimated to provide over $12.5 trillion in benefits in 1997 (Costanza et. al. 1997). Despite the great amount of value identified, there are still a great number of benefits the nearshore provides that are clearly valuable, but that have not yet been valued. Thus, all estimates of nearshore ecosystem service values are underestimates of the actual values, and we do not know how far below the actual values these estimates are.

Ecosystem services and goods are produced by both habitat and landscape features. Accurate analysis requires that studies delineate between habitat type and landscape feature, as it is possible for a habitat function to be devastated while maintaining other geomorphological and landscape functions. Boumans et al. (2004) provide an example of this scenario. A river system has the potential to lose its role as habitat if nutrient uptake and refugium functions are destroyed. At the same time, although the ecosystem services associated with habitat have been lost, the services provided by landscape features—such as transportation — are not necessarily affected. The possibility for double counting arises with this type of differentiation so the classification process requires full analysis and the clear identification of gaps in valuation.

Tables 30 and 31 below link the landscape and habitat features of coastal systems to the goods and services that are known to—or are likely to—provide ecosystem goods and services. The filled boxes represent economic values from coastal systems that are documented in peer-reviewed literature. The empty boxes show the potential values that have not yet been empirically measured. As the tables show, an immense amount of value is likely produced by coastal ecosystems, but there is limited empirical research.

Table 30: Ecosystem Goods and Services provided by Landscape Features

	cliffs	**Estuaries**	**tidal plains**	**lagoons**	**dunes**	**deltas**	**beaches**
Gas regulation	□	□		□	□	□	
Climate regulation				□		□	
Disturbance prevention		□	□	□	□	□	■
Water regulation		■	□	□		□	
Water supply		■			□	□	
Soil retention							□
Soil formation						□	
Nutrient regulation		■	□	□		□	
Waste treatment		■	□			□	
Biological control							
Habitat function	□	□	□	□	□		□
Refugium function	□	□	□	□	□	□	□
Nursery function	□	□	□	□	□	□	
Aesthetic info.	□	□	□	□		□	■
Recreation	□	■	□	□	□	□	■
Cultural and artistic info	□		□	□	□	□	□
Spiritual and Historic info				□		□	□
Science and education	□				□	□	
Food		■	□	□		□	
Raw materials	□	■			□	□	
Ornamental resources	□	□		□			

Source: Derived from Boumans et al. (2004)

■ = Economic Values Available in Peer-Reviewed Literature
□ = No Economic Values Available in Peer-Reviewed Literature, but Values Probable

Table 31: Ecosystem Goods and Services Provided by Habitat Types

	intertidal cliffs	shingle	kelp	seagrass	estuary	wetland	salt marsh	mud Flat	lagoon	dune	sandbank
Gas regulation			□	□	□	□	□		□	□	
Climate regulation					□	□	□		□		
Disturbance prevention	□	□	□	□	■	■	□	■	□	□	□
Water regulation						□				□	
Water supply						■					
Soil retention			□	□			□			□	
Soil formation						□	□			□	
Nutrient regulation			□	□	■	■	■	□	□		
Waste treatment					■	□					
Biological control			□		□	□					
Refugium function	□	□	□	□	□	□	□	□	□	□	□
Nursery function	□	□	□	□	■	□	□	□	□	□	
Aesthetic information	□	□		□	■	□			□	□	
Recreation	□	□			■	■			□		□
Science and education	□		□	□	□	□	□	□	□	□	□
Food		□	□	□	■	■	■	□	□	□	□
Raw materials			□							□	□
Ornamental resources			□								

Source: Derived from Boumans et al. (2004)

■ = Economic Values Available in Peer-Reviewed Literature
□ = No Economic Values Available in Peer-Reviewed Literature, but Values Probable

4.3.2.1 Analysis of the WRIA 9 Nearshore

WRIA 9 has a very diverse range of landscape and habitat features from mud flats to cliffs to beach, and grass to kelp and other submerged aquatic vegetation. On the other hand, this stretch of Puget Sound shoreline has also been most heavily impacted by filling, bulkheads, riprap and other modifications.

One action identified within WRIA 9 to restore salmonid habitat is the removal of coastline armory. This would have two primary effects:

1. Restoration of sedimentation processes.
2. Creation of floodplains, marshes, flats, deltas, spits and side channels.

Table 32 shows the ecosystem services enhanced by the restoration of sediment processes and creation of floodplains, marshes, flats, deltas, spits and side channels. The double star indicates a great increase in value.

Table 32. Ecosystem Services enhanced by Habitat Protection and Conservation Measures in the Nearshore

Habitat Protection/ Conservation Measure ***Ecosystem Service Enhanced***	**Restore Sediment Processes**	**Creation of floodplains, marshes, flats, deltas, spits and side channels**
Gas regulation		*
Disturbance prevention	*	*
Nutrient regulation		*
Waste treatment		*
Refugium function	**	**
Nursery function	**	**
Food	*	*
Ornamental resources	*	*
Aesthetic	**	**
Recreation	**	**
Cultural and artistic information	*	*
Spiritual and historic information	*	*
Science and education	*	*

Table 33 below shows the nearshore valuation results derived from a recent study for King County (King County DNRP 2004), on Maury Island. Many ecosystem services deriving from nearshore landforms and habitat types were included in this study, due to the lack of peer reviewed literature. Thus, both the lower bound and upper bound are underestimates of the actual values. In addition, the study did not account for the value of submerged aquatic vegetation including seagrasses and kelp.

Table 33. Value estimates for Nearshore Ecosystem Services in $/yr/ha (standardized to $2001)

Land Cover	Ecosystem Service	Lower Bound	Upper Bound
Beach	Recreation	77,016.00	99,391.00
Beach near dwelling	Aesthetic and Amenity	45,504.00	92,004.50
	Soil Retention and Formation	48,500.00	48,500.00
Saltwater wetland	Disturbance Prevention	353.00	765.30
	Water Regulation and Supply	310.70	908.70
	Waste Assimilation	171.80	265.60
	Recreation	18.51	32.83
Coastal Riparian	Disturbance Prevention	230.00	504.08
	Water Regulation and Supply	395.30	4,353.20
	Waste Assimilation	83.00	368.00
	Habitat Refugium	2657.14	5,0353.20
	Recreation	30.22	131.80
	Aesthetic and Amenity	1,691.00	1,691.00
	Soil Retention and Formation	456.21	1,171.95
Nearshore Habitat	Habitat Refugium	239.80	12,209.77
	Recreation	720.62	12,045.23
	Food and Raw Materials	3,680.48	3,680.48
Coastal Open Water	Nutrient Regulation	720.62	1,674.52
	Recreation	574.38	226.96
	Aesthetic and Amenity	162.50	162.5

Source: King County, June 2004

The original study estimated lower and upper bounds and totaled an average of these values. This produces a single value estimate, but loses the range, and as mentioned earlier, both upper and lower bounds are underestimates. We total the lower and upper estimates separately (Table 33). Where only one value exists, it was used for both the upper and lower boundary.

Table 34. Ecosystem Service valuation totals $/ha/yr for Nearshore Landcover derived from King County study (June 2004)

Land Cover	Low Underestimate	High Underestimate
Beach	$77,016	$99,391
Beach near dwelling	94,000	140,505
Saltwater wetland	854	1,972
Coastal Riparian	5,543	7,852
Nearshore habitat	4,641	27,936
Coastal Open Water	1,458	2,064

This analysis gives an idea of the value of a relatively small subset of ecological services on a per acre basis in the nearshore, many landscape and ecosystem services have not been valued and are not included. Because barriers like riprap, bulkheads and fill disrupt or change natural wave action and sediment transport, they have an influence far beyond the immediate area affected. Seagrass beds naturally shift as sediments shift. However, if sediments are cut off or severely disrupted, by a barrier, then there may be great cumulative effects and the losses of ecosystem service and the benefits from restoration may be several magnitudes larger than estimated within a static analysis.

To fully understand the value of these ecosystem services requires a dynamic analysis beyond the scope of this study. This would provide a much clearer understanding of the full ecosystem service effects of disrupting coastal processes and restoring them.

To provide an example of the interaction between the disruption of coastal processes and critical salmon habitat, Dr. Roelof Boumans of the Gund Institute for Ecological Economics ran a regression model to relate submerged aquatic vegetation and shoreline disturbance due to boat access and shoreline armoring.

Based on Puget Sound coastal GIS data, a regression analysis of the area of submerged aquatic vegetation (SAV) to launches and docks, and armoring was conducted. For every foot of launch/dock, and armoring along the coast, SAV area was reduced by .000028 acres. For every foot of armoring along the coast, the SAV was reduced by .00003 acres.

Data from the Washington State Coastal Zone Inventory on submerged aquatic vegetation coverage, and lengths of anthropogenic impact on coastal sections were examined. The effect of anthropogenic alteration of the coastal zone, specifically docks, launches and armoring, was tested against the percent area coverage of submerged aquatic vegetation. A significant relationship exists indicating that with each additional foot of boat launch or dock the SAV coverage decreased 0.0028 percent, while with each foot of armoring the SAV area decreased 0.003 percent.

From the Ramsar Convention webpages (Ramsar Convention Bureau 2002) and Costanza (1997), the partial ecosystem service value of SAV is estimated to be 19,004 $US per hectare per year. A partial value of ecosystem services SAV beds along the full 16,193,321 feet of Puget Sound shoreline is estimated to be $481,676,670 per year. Not all of the ecosystem services of SAV were estimated in this analysis therefore it represents a partial estimate, underestimate, of the total annual value of ecosystem services provided by SAV. In addition, these values are likely to be much higher in the WRIA 9 area where SAV is very scarce.

The Washington State Coastal Zone Inventory GIS polygons show the SAV coverage for Puget Sound by percentage and the relationship of SAV coverage per linear foot of coastline. The data also shows the percentage and length of the coastline impacted by armoring, launches and docks. Using the polygon data, the regression model estimates that for each foot of armored shoreline SAV beds are reduced by 0.00156 hectares. This

results in a loss in SAV ecosystem service value for each additional linear foot of armored coastal zone. A partial estimate of the value of that loss can be estimated by multiplying the area of SAV lost by the 0.00156 * $19,004 = $22.995/linear foot/year ($1997) of shoreline in SAV bed ecosystem service values. With 1,476,379 feet of modified shoreline at $29.75/foot a partial estimate of the losses of SAV ecosystem services due to armoring totals: $43,922,275 annually.

This may be a very significant underestimate of the true losses of ecosystem services for several reasons:

1. Scarcity principles are not considered in these calculations, and WRIA 9 is highly armored with a greater scarcity of SAV than other locations in Puget Sound.
2. Increased armoring within WRIA 9 likely has a cumulative effect on reducing SAV. Thus, within WRIA 9, SAV losses for each additional area of armoring may be larger than within all of Puget Sound.
3. Valuations of SAV ecosystem services are incomplete and dated, therefore current values are certainly higher.
4. SAV represents only one of many habitat types affected by armoring and coastal alterations. The full loss of ecosystem services from the loss of all habitat types reduced by armoring has not been calculated.
5. Coastal modifications alter coastal processes such as wave action, sediment movement, etc. These processes have profound implications for habitats, landforms and nearshore ecosystem services. This analysis is not a dynamic analysis and likely underestimates the cumulative impact of armoring, launches and docks.

4.3.2.2 Summary: Nearshore

The nearshore is important habitat for salmonids, particularly young Chinook salmon. Restoring near shore habitat also contributes to greater ecosystem service production. Ecosystem service values in the nearshore of WRIA 9 are high, though there many gaps in the literature and in research, thus any valuation is far from the full nearshore ecosystem service values. Ecosystem services most likely to be enhanced by removal of coastal armoring were identified as were the ecosystem services associated with two conservation hypotheses associated with removal of armoring.

There are peer-reviewed valuation studies representing 25 ecosystem services associated with particular land forms and habitats in the nearshore. There are 161 other identified ecosystem service/habitat/landform associations for which no valuation studies exist. The value of ecosystem services produced in the nearshore is high. This indicates that our understanding of the scope of nearshore ecosystem service value is still significantly underestimated. A significant part of this problem is our lack of understanding the dynamic oceanographic and biological processes that relate structure, function, process and value in the nearshore.

WRIA 9 conservation hypotheses in the nearshore, as throughout WRIA 9, support the strengthening of healthy ecosystems and corresponding rises in the value of increased ecosystem goods and services. A partial estimate of the total value of ecosystem services provided by submerged aquatic vegetation shows that armoring, docks and launches have contributed to the loss of over $45 million annually in Puget Sound. WRIA 9 is the most heavily armored and affected area along the Sound and accounts for a large portion of those losses. Removal of armoring supports two conservation hypotheses which would also increase the quantity and value of ecological services provided. Depending on the site and oceanographic affects on siltation, SAV, and other dynamics these salmon restoration actions would have a high value.

4.4 Conclusions

The Water Resource Inventory Area 9 (WRIA 9) Habitat Plan is a long-term, comprehensive plan to protect and restore salmon in the Green/Duwamish and Central Puget Sound Watershed. WRIA 9 is within the boundary of King County and includes all or part of 15 cities as well as lands with accustomed fishing and hunting rights from the Muckleshoot and Suquamish Tribes. The Green/Duwamish and Central Puget Sound Watershed is one of the most altered hydrological ecosystems in the Puget Sound basin including river diversions, straitening, water removal, a shifting of the salt gradient up stream and loss of natural gravel supply behind dams.

WRIA 9 Habitat Plan actions implemented to restore viable salmonid populations will also preserve and restore 23 categories of ecosystem goods and services identified in the Green/Duwamish and Central Puget Sound Watershed. Healthy ecosystems produce goods and services for free and in perpetuity and are essential to maintaining a healthy economy and livable communities within WRIA 9. Ecosystem goods and services enhanced by Habitat Plan actions include: flood protection, natural storm water maintenance, drinking water production and filtration, reduction of pathogens and pollutants, waste absorption, storm protection, biodiversity preservation, nutrient regulation, increased production of fish, shellfish and other foods and raw materials, erosion control, biodiversity, aesthetic value, recreational fishing, hunting, hiking, bird watching, educational and scientific benefits.

To understand the value of goods and services provided by ecosystems within WRIA 9, geographic information system (GIS) data for WRIA 9 was compiled for the acreages of forest, grass and shrublands, agriculture and pasturelands, wetlands, urban areas, lakes, ponds, rivers and streams, ice and rock. Peer reviewed journal articles were selected for each land use type and the value of associated ecological services. A benefit transfer methodology was applied to WRIA 9 to calculate a range of dollar value of ecosystem services provided annually within WRIA 9.

The full value of the benefits provided by ecosystems within WRIA 9 has never previously been estimated. A partial estimate of the value of ecosystem goods and

services currently produced in WRIA 9 shows that ecosystems produce $1.7-6.3 billion dollars of value annually for individuals, communities, businesses, and governments within WRIA 9.

The net present value of ecosystem goods and services within WRIA 9 is estimated to be between $48-180 billion applying a 3.5 percent discount rate, (used by the Army Corps of Engineers) over a 100 year period. If the non-depreciating, self-maintaining nature of ecosystems is recognized and future generations are given equal weight to present, a zero discount rate yields benefits of $170-636 billion over a 100 year period. The dollar value of salmon restoration and healthy ecosystems to future generations is far greater.

As a marker of value, the total value of taxed property within WRIA 9 was calculated at $71 billion. Of this, $44 billion is improvements on property, which clearly represents built human capital and has taken 150 years to accumulate. Over $23 billion in taxed property value is land value which represents social, speculative, aesthetic and ecological values, separate from the built capital.

Ecosystems are the most economically efficient production systems for many critical goods and services. For example, healthy riparian areas move the vast majority of storm water, recharge aquifers, filter drinking water, channel flood waters and replenish surface waters. Replacing these services with engineering solutions requires costly capital projects like levees, storm water systems and water filtration facilities, as well as maintenance costs thereafter. The associated costs to cities, the County, State and Federal Government of allowing salmon habitat to further degrade in terms of increased costs for storm water, drinking water, flood damage, endangered species and other lost ecosystems was not calculated, but would be vast.

The WRIA 9 conservation hypotheses are based on the best available science and identify what habitat conditions are important or critical for salmon recovery. The APEX, Gund Institute team examined the WRIA 9 conservation hypotheses and determined for each conservation hypothesis the ecosystem services likely to benefit from salmon recovery actions.

A specific salmon restoration project, the North Winds Weir was examined as well as the removal of nearshore armoring were examined using ecological economics analysis for their value added contribution to ecosystem services.

The North Winds Weir Project expands salmon habitat in the transition zone. Transitional zone habitat meets the criteria of critical natural habitat, without which extinction may result. Though economic methods are marginal analyses and not well suited at a threshold for extinction, four different approaches to valuing the expansion of transition zone habitat justify high levels of expenditure actions to reclaim transition zone habitat.

Expenditures for salmon restoration within WRIA 9 to date exceed $59 million, and are expected to rise. Total expenditures over the next 10 years are likely to be $292-706

million. This investment could be lost without projects that will secure sufficient transition zone habitat.

Continued salmonid declines are likely without additional transition zone habitat. As a result, the Federal Government may require the acquisition of transitional zone habitat at a future date requiring a larger acquisition to restore further reduced populations. In addition, ecosystem services would also be enhanced with increased transition zone habitat for salmon. On the basis of ecosystem services provided by the North Winds Weir project alone, net present value would total $384 thousand to $1.40 million for the project, depending on the time horizon. Using a zero discount rate, (giving equal value to the flood protection of future generations) will provide values of $1.35-23.72 million, depending on the time horizon considered. This is clearly an underestimate of the true value of the project because it is a marginal analysis assuming that the habitat is not in a "critical" state. Thus the true ecosystem service values are likely much higher. Finally, considering the full suite of expenditures for salmon recovery overall and the critical habitat functions provided by the transition zone, expenditures on the order of $19 million—far higher than the cost of the North Winds Weir Project—would be justified.

The nearshore is important habitat for salmonids, particularly young Chinook salmon. Restoring near shore habitat also contributes to greater ecosystem service production. Ecosystem service values in the nearshore of WRIA 9 are high, though there many gaps in the literature, many nearshore ecosystem services have simply never been valued. Peer-reviewed valuation studies representing 25 ecosystem services associated with particular land forms and habitats in the nearshore. There are 161 other identified ecosystem service/habitat/landform associations for which no valuation studies exist. The value of ecosystem services produced in the nearshore is high. Thus any benefit transfer valuation of nearshore ecosystem service values is necessarily significantly below the true value. Ecosystem services most likely to be enhanced by removal of coastal armoring were identified as were the ecosystem services associated with two conservation hypotheses associated with removal of armoring.

Another critical factor for the nearshore is our lack of understanding of the dynamic oceanographic and biological processes that relate structure, function, process and value. WRIA 9 conservation hypotheses in the nearshore, as throughout WRIA 9, support the strengthening of healthy ecosystems and corresponding rises in the value of increased ecosystem goods and services.   A partial estimate of the total value of ecosystem services provided by submerged aquatic vegetation alone shows that armoring, docks and launches have contributed to the loss of over $45 million annually in Puget Sound. WRIA 9 is the most heavily armored and affected area along the Sound and accounts for a large portion of those losses. Removal of armoring supports two salmon conservation hypotheses which would also increase the quantity and value of ecological services provided. Depending on the site and oceanographic affects on siltation, SAV, and other dynamics, these salmon restoration actions would likely have a high value.

Results and Conclusion: 10 Points

1. Implementation of the WRIA 9 Habitat Plan will enhance the economy and quality of life for citizens within WRIA 9 by enhancing natural capital. Three forms of capital: natural capital, human built capital, and social capital must be healthy to maintain a healthy economy high quality of life.

2. WRIA 9 Habitat Plan actions implemented will enhance and increase the value of ecosystem services provided within the watershed including: flood protection, natural storm water maintenance, drinking water production and filtration, reduction of pathogens and pollutants, waste absorption, storm protection, biodiversity preservation, nutrient regulation, increased production of fish, shellfish and other food and raw materials, erosion control, biodiversity, aesthetic value, recreational fishing, hunting, hiking, bird watching, educational and scientific benefits.

3. WRIA 9 investments in ecosystem protection and restoration (natural capital), will produce a large number of highly valuable goods and services. These ecosystem services are rising in value (increasing in scarcity and economic importance) relative to built capital. Preserved and restored ecosystems are self-maintaining and produce value into perpetuity.

4. The alternative of allowing degradation of natural capital in WRIA 9 is to replace lost ecosystem services with engineering projects (flood control structures, for example), which require large capital investments and maintenance, or to forgo the services and suffer damage (flood damage, for example), which requires reconstruction costs and higher insurance premiums.

5. A partial estimate of the value of ecosystem goods and services within WRIA 9 is $1.7-6.3 billion annually with a net present value of $48-180 billion over 100 years at a 3.5 percent discount rate or a value of $170-636 billion over 100 years with no discount rate. The value to future generations is far greater.

6. As markers of social capital, the population, educational level, employment levels and distribution of labor between sectors were examined. The WRIA 9 process and initial restoration projects have brought governments, communities and individuals together, strengthening social capital within WRIA 9.

7. Markers of built capital examined include roads, buildings, businesses and other property. The total value of taxed property within WRIA 9 is $71 billion. Of this, $44 billion consists of improvements on property (built capital) and $28 billion of land value (social and natural capital). It has taken about 150 years to accumulate the $44 billion of taxed built capital stock in WRIA 9.

8. All 18 WRIA 9 Conservation Hypotheses with habitat protection/conservation measures were evaluated and the ecological services expected to be enhanced were identified. Ecosystem service categories enhanced by specific WRIA 9 Habitat Plan actions ranged from 1 to 23. Ecological services most enhanced by the Habitat Plan will be water regulation (flooding, storm water etc.), nursery and refugium functions, recreation/aesthetic values, water supply and filtration, disturbance prevention, waste treatment and nutrient regulation. These are significant ecological services with large values.

9. The North Winds Wier project ($3.69 million) was evaluated with four methodologies and found to be economically justified based on the protection of current (over $59 million) and future investments ($292-706 million); the risk of Federal requirements for transition zone acquisition; an underestimate of the value of ecosystem services provided by the North Winds Weir project ($384 thousand to $23.72 million, depending on the discount rate and time horizon); and an analysis expenditure priorities based on a limited budget ($19 million in expenditures on the transition zone were justified). The transition zone meets the criteria of critical ecological capital in crisis. No current marginal valuation methodology alone can gage the value of critical natural capital at a threshold of nearly total loss. A policy objective throughout WRIA 9 should be to keep all ecosystems healthy enough to remain outside crisis status.

10. Nearshore removal of armory will increase the quantity and total value of the nearshore ecosystem. Valuation studies for some ecosystem service/habitat/landform associations for the nearshore exist, but over 160 nearshore systems identified as valuable lack peer-reviewed valuation studies. Despite this, the value of ecosystem services produced per acre in the nearshore is among the highest of any ecosystem type. Two habitat/conservation measures related to armory removal were examined and the ecosystem services enhanced identified. Some land cover types produce over $140,000/year/hectare considering two categories of ecological services. A regression analysis of armoring, launches, and docks to subaquatic vegetation shows that one foot of armoring reduces SAV coverage/hectare by .003 percent, based on Puget Sound coastal GIS data. Subaquatic vegetation is valued at producing $19,004/hectare ($1997). Armoring results in losses of $29.75/foot which means a loss of over $43.9 million annually across Puget Sound from subaquatic vegetation ecosystem services alone. The costs of armoring for perhaps one hundred other services/habitat/landform associations are yet unmeasured.

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Appendix A. Present Value of Ecosystem Services in WRIA 9 Accrued Over 100 Years **Discount Rate = 3.5%**					
Year	Minimum	Maximum	Year	Minimum	Maximum
0	$1,691,450,072	$6,304,503,003	51	$292,618,206	$1,090,669,118
1	$1,634,251,277	$6,091,307,249	52	$282,722,904	$1,053,786,588
2	$1,578,986,741	$5,885,321,014	53	$273,162,226	$1,018,151,292
3	$1,525,591,054	$5,686,300,496	54	$263,924,856	$983,721,056
4	$1,474,001,019	$5,494,010,141	55	$254,999,861	$950,455,126
5	$1,424,155,574	$5,308,222,359	56	$246,376,678	$918,314,132
6	$1,375,995,723	$5,128,717,255	57	$238,045,099	$887,260,030
7	$1,329,464,467	$4,955,282,372	58	$229,995,265	$857,256,068
8	$1,284,506,731	$4,787,712,437	59	$222,217,647	$828,266,732
9	$1,241,069,306	$4,625,809,118	60	$214,703,041	$800,257,712
10	$1,199,100,778	$4,469,380,790	61	$207,442,551	$773,195,857
11	$1,158,551,477	$4,318,242,309	62	$200,427,586	$747,049,138
12	$1,119,373,408	$4,172,214,791	63	$193,649,842	$721,786,606
13	$1,081,520,201	$4,031,125,402	64	$187,101,296	$697,378,364
14	$1,044,947,054	$3,894,807,152	65	$180,774,199	$673,795,520
15	$1,009,610,680	$3,763,098,698	66	$174,661,062	$651,010,165
16	$975,469,256	$3,635,844,152	67	$168,754,649	$628,995,328
17	$942,482,373	$3,512,892,901	68	$163,047,970	$607,724,955
18	$910,610,988	$3,394,099,421	69	$157,534,271	$587,173,869
19	$879,817,380	$3,279,323,112	70	$152,207,025	$567,317,748
20	$850,065,101	$3,168,428,128	71	$147,059,928	$548,133,090
21	$821,318,939	$3,061,283,215	72	$142,086,886	$529,597,188
22	$793,544,868	$2,957,761,560	73	$137,282,016	$511,688,105
23	$766,710,018	$2,857,740,638	74	$132,639,629	$494,384,642
24	$740,782,626	$2,761,102,066	75	$128,154,231	$477,666,321
25	$715,732,005	$2,667,731,465	76	$123,820,513	$461,513,354
26	$691,528,508	$2,577,518,323	77	$119,633,346	$445,906,622
27	$668,143,486	$2,490,355,868	78	$115,587,774	$430,827,654
28	$645,549,262	$2,406,140,935	79	$111,679,008	$416,258,603
29	$623,719,093	$2,324,773,850	80	$107,902,424	$402,182,225
30	$602,627,143	$2,246,158,310	81	$104,253,549	$388,581,860
31	$582,248,448	$2,170,201,265	82	$100,728,067	$375,441,411
32	$562,558,887	$2,096,812,817	83	$97,321,804	$362,745,324
33	$543,535,156	$2,025,906,103	84	$94,030,728	$350,478,574
34	$525,154,740	$1,957,397,201	85	$90,850,945	$338,626,642
35	$507,395,884	$1,891,205,025	86	$87,778,691	$327,175,499
36	$490,237,569	$1,827,251,232	87	$84,810,330	$316,111,593
37	$473,659,487	$1,765,460,128	88	$81,942,347	$305,421,829
38	$457,642,017	$1,705,758,577	89	$79,171,350	$295,093,555
39	$442,166,200	$1,648,075,920	90	$76,494,058	$285,114,546
40	$427,213,720	$1,592,343,884	91	$73,907,303	$275,472,991
41	$412,766,879	$1,538,496,506	92	$71,408,022	$266,157,479
42	$398,808,579	$1,486,470,055	93	$68,993,258	$257,156,985
43	$385,322,298	$1,436,202,951	94	$66,660,152	$248,460,855
44	$372,292,075	$1,387,635,702	95	$64,405,944	$240,058,797

45	$359,702,488	$1,340,710,823	96	$62,227,966	$231,940,867
46	$347,538,636	$1,295,372,776	97	$60,123,638	$224,097,456
47	$335,786,122	$1,251,567,899	98	$58,090,472	$216,519,281
48	$324,431,036	$1,209,244,347	99	$56,126,060	$209,197,373
49	$313,459,938	$1,168,352,026	100	$54,228,077	$202,123,066
50	$302,859,843	$1,128,842,537	**Present Value**	**$48,469,221,359—$180,658,215,499**	

Appendix B. Present Value of Ecosystem Services in WRIA 9 Accrued Over 100 Years **Discount Rate = 2.3%**

Year	Minimum	Maximum	Year	Minimum	Maximum
0	$1,691,450,072	$6,304,503,003	51	$530,397,983	$1,976,940,218
1	$1,653,421,380	$6,162,759,534	52	$518,473,101	$1,932,492,882
2	$1,616,247,684	$6,024,202,868	53	$506,816,326	$1,889,044,850
3	$1,579,909,759	$5,888,761,357	54	$495,421,628	$1,846,573,656
4	$1,544,388,816	$5,756,364,962	55	$484,283,117	$1,805,057,337
5	$1,509,666,487	$5,626,945,222	56	$473,395,031	$1,764,474,426
6	$1,475,724,816	$5,500,435,212	57	$462,751,741	$1,724,803,935
7	$1,442,546,253	$5,376,769,514	58	$452,347,743	$1,686,025,352
8	$1,410,113,639	$5,255,884,178	59	$442,177,657	$1,648,118,624
9	$1,378,410,204	$5,137,716,694	60	$432,236,224	$1,611,064,148
10	$1,347,419,554	$5,022,205,957	61	$422,518,303	$1,574,842,765
11	$1,317,125,664	$4,909,292,235	62	$413,018,869	$1,539,435,743
12	$1,287,512,868	$4,798,917,141	63	$403,733,009	$1,504,824,773
13	$1,258,565,854	$4,691,023,598	64	$394,655,923	$1,470,991,958
14	$1,230,269,652	$4,585,555,814	65	$385,782,916	$1,437,919,802
15	$1,202,609,630	$4,482,459,252	66	$377,109,400	$1,405,591,205
16	$1,175,571,486	$4,381,680,598	67	$368,630,889	$1,373,989,447
17	$1,149,141,237	$4,283,167,740	68	$360,343,000	$1,343,098,189
18	$1,123,305,217	$4,186,869,736	69	$352,241,447	$1,312,901,455
19	$1,098,050,066	$4,092,736,790	70	$344,322,040	$1,283,383,632
20	$1,073,362,723	$4,000,720,225	71	$336,580,684	$1,254,529,454
21	$1,049,230,424	$3,910,772,458	72	$329,013,377	$1,226,324,002
22	$1,025,640,688	$3,822,846,978	73	$321,616,204	$1,198,752,691
23	$1,002,581,317	$3,736,898,316	74	$314,385,341	$1,171,801,262
24	$980,040,388	$3,652,882,030	75	$307,317,049	$1,145,455,779
25	$958,006,245	$3,570,754,672	76	$300,407,673	$1,119,702,618
26	$936,467,492	$3,490,473,775	77	$293,653,639	$1,094,528,464
27	$915,412,994	$3,411,997,825	78	$287,051,456	$1,069,920,297
28	$894,831,861	$3,335,286,242	79	$280,597,708	$1,045,865,393
29	$874,713,451	$3,260,299,357	80	$274,289,060	$1,022,351,313
30	$855,047,362	$3,186,998,394	81	$268,122,248	$999,365,897
31	$835,823,423	$3,115,345,448	82	$262,094,084	$976,897,260
32	$817,031,694	$3,045,303,468	83	$256,201,451	$954,933,783
33	$798,662,458	$2,976,836,235	84	$250,441,301	$933,464,109
34	$780,706,215	$2,909,908,343	85	$244,810,656	$912,477,134
35	$763,153,680	$2,844,485,184	86	$239,306,604	$891,962,008
36	$745,995,777	$2,780,532,927	87	$233,926,299	$871,908,121

37	$729,223,634	$2,718,018,501	88	$228,666,959	$852,305,104
38	$712,828,577	$2,656,909,581	89	$223,525,864	$833,142,819
39	$696,802,128	$2,597,174,566	90	$218,500,356	$814,411,358
40	$681,136,000	$2,538,782,567	91	$213,587,836	$796,101,034
41	$665,822,092	$2,481,703,389	92	$208,785,763	$778,202,380
42	$650,852,484	$2,425,907,516	93	$204,091,655	$760,706,138
43	$636,219,437	$2,371,366,096	94	$199,503,084	$743,603,263
44	$621,915,384	$2,318,050,924	95	$195,017,678	$726,884,910
45	$607,932,926	$2,265,934,432	96	$190,633,116	$710,542,434
46	$594,264,835	$2,214,989,670	97	$186,347,132	$694,567,384
47	$580,904,042	$2,165,190,293	98	$182,157,509	$678,951,500
48	$567,843,638	$2,116,510,551	99	$178,062,081	$663,686,706
49	$555,076,870	$2,068,925,269	100	$174,058,730	$648,765,108
50	$542,597,136	$2,022,409,843	**Present Value**	**$67,664,986,659—$252,206,150,600**	

Appendix C. Present Value of Ecosystem Services in WRIA 9 Accrued Over 100 Years **Zero Discount Rate**

Year	Minimum	Maximum	Year	Minimum	Maximum
0	$1,691,450,072	$6,304,503,003	51	$1,691,450,072	$6,304,503,003
1	$1,691,450,072	$6,304,503,003	52	$1,691,450,072	$6,304,503,003
2	$1,691,450,072	$6,304,503,003	53	$1,691,450,072	$6,304,503,003
3	$1,691,450,072	$6,304,503,003	54	$1,691,450,072	$6,304,503,003
4	$1,691,450,072	$6,304,503,003	55	$1,691,450,072	$6,304,503,003
5	$1,691,450,072	$6,304,503,003	56	$1,691,450,072	$6,304,503,003
6	$1,691,450,072	$6,304,503,003	57	$1,691,450,072	$6,304,503,003
7	$1,691,450,072	$6,304,503,003	58	$1,691,450,072	$6,304,503,003
8	$1,691,450,072	$6,304,503,003	59	$1,691,450,072	$6,304,503,003
9	$1,691,450,072	$6,304,503,003	60	$1,691,450,072	$6,304,503,003
10	$1,691,450,072	$6,304,503,003	61	$1,691,450,072	$6,304,503,003
11	$1,691,450,072	$6,304,503,003	62	$1,691,450,072	$6,304,503,003
12	$1,691,450,072	$6,304,503,003	63	$1,691,450,072	$6,304,503,003
13	$1,691,450,072	$6,304,503,003	64	$1,691,450,072	$6,304,503,003
14	$1,691,450,072	$6,304,503,003	65	$1,691,450,072	$6,304,503,003
15	$1,691,450,072	$6,304,503,003	66	$1,691,450,072	$6,304,503,003
16	$1,691,450,072	$6,304,503,003	67	$1,691,450,072	$6,304,503,003
17	$1,691,450,072	$6,304,503,003	68	$1,691,450,072	$6,304,503,003
18	$1,691,450,072	$6,304,503,003	69	$1,691,450,072	$6,304,503,003
19	$1,691,450,072	$6,304,503,003	70	$1,691,450,072	$6,304,503,003
20	$1,691,450,072	$6,304,503,003	71	$1,691,450,072	$6,304,503,003
21	$1,691,450,072	$6,304,503,003	72	$1,691,450,072	$6,304,503,003
22	$1,691,450,072	$6,304,503,003	73	$1,691,450,072	$6,304,503,003
23	$1,691,450,072	$6,304,503,003	74	$1,691,450,072	$6,304,503,003
24	$1,691,450,072	$6,304,503,003	75	$1,691,450,072	$6,304,503,003
25	$1,691,450,072	$6,304,503,003	76	$1,691,450,072	$6,304,503,003
26	$1,691,450,072	$6,304,503,003	77	$1,691,450,072	$6,304,503,003
27	$1,691,450,072	$6,304,503,003	78	$1,691,450,072	$6,304,503,003

28	$1,691,450,072	$6,304,503,003	79	$1,691,450,072	$6,304,503,003
29	$1,691,450,072	$6,304,503,003	80	$1,691,450,072	$6,304,503,003
30	$1,691,450,072	$6,304,503,003	81	$1,691,450,072	$6,304,503,003
31	$1,691,450,072	$6,304,503,003	82	$1,691,450,072	$6,304,503,003
32	$1,691,450,072	$6,304,503,003	83	$1,691,450,072	$6,304,503,003
33	$1,691,450,072	$6,304,503,003	84	$1,691,450,072	$6,304,503,003
34	$1,691,450,072	$6,304,503,003	85	$1,691,450,072	$6,304,503,003
35	$1,691,450,072	$6,304,503,003	86	$1,691,450,072	$6,304,503,003
36	$1,691,450,072	$6,304,503,003	87	$1,691,450,072	$6,304,503,003
37	$1,691,450,072	$6,304,503,003	88	$1,691,450,072	$6,304,503,003
38	$1,691,450,072	$6,304,503,003	89	$1,691,450,072	$6,304,503,003
39	$1,691,450,072	$6,304,503,003	90	$1,691,450,072	$6,304,503,003
40	$1,691,450,072	$6,304,503,003	91	$1,691,450,072	$6,304,503,003
41	$1,691,450,072	$6,304,503,003	92	$1,691,450,072	$6,304,503,003
42	$1,691,450,072	$6,304,503,003	93	$1,691,450,072	$6,304,503,003
43	$1,691,450,072	$6,304,503,003	94	$1,691,450,072	$6,304,503,003
44	$1,691,450,072	$6,304,503,003	95	$1,691,450,072	$6,304,503,003
45	$1,691,450,072	$6,304,503,003	96	$1,691,450,072	$6,304,503,003
46	$1,691,450,072	$6,304,503,003	97	$1,691,450,072	$6,304,503,003
47	$1,691,450,072	$6,304,503,003	98	$1,691,450,072	$6,304,503,003
48	$1,691,450,072	$6,304,503,003	99	$1,691,450,072	$6,304,503,003
49	$1,691,450,072	$6,304,503,003	100	$1,691,450,072	$6,304,503,003
50	$1,691,450,072	$6,304,503,003	**Present Value**	**$170,836,457,272**	**—$636,754,803,303**