The Economic Impact of Restoring the Duckabush Estuary: Supplemental Report

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Purpose For internal use by Hood Canal Salmon Enhancement Group as documentation of Earth Economics methodology and detailed results for the jobs analysis and ecosystem services valuation of the Duckabush restoration project.

Audience Hood Canal Salmon Enhancement Group staff

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Our authors and analysts prepared this supplemental report and factsheet based on their understanding of economic systems, combined with information available in published literature, including peer-reviewed journals, official government reports, gray literature (e.g., reports by other reputable analysts), personal interviews, and other sources believed to be reliable. Any statements presented here may change as more information becomes available. We are not liable for any decisions or associated consequences made by third parties based on information contained in this report, including business transactions or investments.

1. Introduction

The purpose of this report is to provide supplementary information to the Hood Canal Salmon Enhancement Group (HCSEG) on the methodology and detailed results of Earth Economics' economic analysis of the benefits provided by the Duckabush estuary planned restoration project. Summarized results of the economic analysis can be found in the accompanying factsheet, "The Economic Impact of Restoring the Duckabush Estuary."

The Duckabush Estuary in eastern Jefferson County, Washington, has been bisected by U.S. Highway 101 for almost 100 years. A causeway severs the ecological connection of the estuary to the tidelands, save for two stretches of bridge. The estuary encompasses 506 acres, including open water and an aquatic vegetation bed, as well as 91 terrestrial acres that is predominantly estuarine emergent wetland. The estuary acts as a nursery habitat for keystone salmon species, including the Hood Canal summer chum and Chinook salmon. Shellfish harvesting is a significant activity in the estuary, though it is currently closed from May through October due to poor water quality.

Led by the Washington Department of Fish and Wildlife (WDFW), in partnership with the U.S. Army Corps of Engineers (Corps) and the Hood Canal Salmon Enhancement Group (HCSEG), the Duckabush Estuary Restoration Project is an effort to improve the estuary's ecosystem, creating more viable habitat for salmon, shellfish, and waterfowl. The project includes replacing the Highway 101 causeway that currently crosses the estuary with a 1,600-foot-long full spanning bridge, essentially raising the road profile. The project would reconnect the Duckabush River to neighboring floodplains and wetlands, reducing seasonal flooding, and create a wildlife corridor under the highway. The project is anticipated to increase salmon abundance by increasing the efficacy of the estuary's nursery habitat and boosting the smolt to adult return rate. It may improve shellfish abundance, though the impacts of sedimentation and change in hydrology following the project are unclear.

Earth Economics conducted an analysis of both market and non-market economic benefits of the Duckabush restoration project and the 100-year lifespan of the bridge. The analysis focused on jobs created by the project (both gray infrastructure and restoration activity) and the economic benefits that nature provides to humans (also known as *ecosystem services*) driven by restoration – for example, the avoided flood damage after the floodplain is reconnected, or the value of the increased populations of salmon and shellfish.

Figure 1. Planned project area: Duckabush Estuary boundary.

Duckabush Estuary Boundary

SOURCES: Pacific Marine and Estuarine Fish Habitat Partnership, WSDOT, Maxar
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MILES

2. Jobs Analysis

Demonstrating the ripple effect of project-related spending through the regional economy requires following spending effects through related industries in the supply chain. For this analysis, Earth Economics focused on the employment impact of the project.

Spending related to the Duckabush restoration project supports local employment beyond project staff: restoration spending will spur construction companies and retailers (among others) to expand and/or retain their full- and part-time positions. In turn, expenditures from these industries will support jobs in other industries that provide necessary services to these sectors, such as facilities maintenance, government services, real estate, and medicine. Lastly, employees working directly on the restoration project and in supporting industries will spend their wages within the regional economy for typical household expenses. This ripple effect of jobs supported by project spending is described as *direct*, *indirect*, and *induced* effects.

Direct effects measure the economic activity of industries directly supported by Duckabush restoration investments, such as construction, engineering services, and retail. Secondary effects are the shifts in the economy spurred by that initial investment and can be categorized further as either *indirect* or *induced effects*.

Indirect effects are the impacts on the industries that support those that contract with the restoration project directly. For instance, road construction is one industry directly supported by project spending. Because construction firms purchase supplies from retailers and manufacturers, construction contracts drive additional demand for materials and equipment. In this way, the construction supply industry indirectly benefits from restoration investments.

Induced effects measure the contribution of employee spending. Those who work in industries directly and indirectly supported by restoration investments spend their wages on goods and services in the regional economy. For example, a construction employee who spends her paycheck on rent, gas, and groceries benefits local businesses and the regional economy, at least to the extent that such spending remains local.[1] Depending on the level of interconnectivity within the regional economy, induced effects can ripple through the local economy many times before the money eventually leaves the region.

To calculate how many jobs the Duckabush restoration project will support, Earth Economics evaluated the project's budget for capital expenditures (i.e., CAPEX) and organized it into 3 main categories: gray infrastructure, green infrastructure, and operations and management (O&M). The category "gray infrastructure" included spending on bridge construction, utility relocation, and culvert replacement; the "green infrastructure" category included estuary restoration spending (e.g. channel reconnection); and the "operations and management" category included spending on WDFW operations and management.

It is important to note that maintenance spending was excluded from the analysis. Because any additional annual spending necessary to sustain the work done on the estuary (e.g., periodic monitoring, dredging, excavation, etc) would support additional positions every year, excluding maintenance expenses from the Jobs Impact Analysis results in an underestimate of the total jobs the project would support throughout its entire lifetime.

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[1] As money is injected into industries related to restoration projects, businesses and employees then re-spend this income on goods and services. The proportion of this income that is re-spent within the region is determined by each industries' Regional Purchase Coefficients (RPCs), representing the proportion of local demand for a commodity that is supplied from within the region.

Table 1 presents the project budget and timeline. As of December 2022, the capital budget for the project is roughly $115 million (USD 2021), which accounts for additional cost increases, contingencies, and inflation. The gray infrastructure construction timeline is three years, after which the landscape reconnection work can take place. For technical reasons, the estuary restoration piece of the project must follow the gray infrastructure component of the project (WDFW, 2022). Bridge construction and culvert replacement will take place throughout the first three years, while utilities and telecom relocations will occur during the first and third year of construction. There will be operations and management costs every year. The estuary restoration work will start on the fourth year and will last approximately one year.

Table 1. Project budget over the course of the Duckabush Estuary restoration project. Source: WDFW, 2022.

Project Year	Utilities and Other Relocations ($M)	Bridge Construction ($M)	Estuary Restoration ($M)	WDFW Ops & Mgmt ($M)	Total ($M)
Year 1	$ 1.7	$ 25		$ 0.4	**$ 27.1**
Year 2		$ 40		$ 0.4	**$ 40.4**
Year 3	$ 1.7	$ 15		$ 0.4	**$ 17.1**
Year 4			$ 30	$ 0.4	**$ 30.4**
Total	**$ 3.4**	**$ 80**	**$30**	**$ 1.6**	**$115**

Results from the job analysis are presented in Table 2 and Table 3. Table 2 shows how the project is estimated to support an average of 449 jobs per year—this estimate includes direct, indirect, and induced effects for all three categories of spending: gray infrastructure, green infrastructure, and O&M spending.

Table 3 shows the breakdown of jobs created by spending category (grey infrastructure, green infrastructure, and O&M) across the project timeline. As shown in Table 3, the gray infrastructure portion of the project would support an average of 450 jobs per year for the first 3 years of the project. During the fourth year—when estuary restoration would occur— 446 green infrastructure jobs would be supported. Over the duration of all 4 years of the project, operations and management for this project would have few WDFW and USACE staff requirements.

Table 2. Jobs that would be supported by the Duckabush Estuary project, by effect type. Source: Earth Economics, 2022.

Project Year	Direct	Indirect	Induced	Total
Year 1	139	128	162	**429**
Year 2	220	192	244	**656**
Year 3	84	80	102	**266**
Year 4	129	187	129	**446**
Annual Average*	**143**	**147**	**159**	**449**

***** It is appropriate to present the annual average as an estimate of jobs supported because some of the positions may be occupied by the same employee each year. In that sense, presenting annual averages ensures a conservative estimation of total jobs created by the project.

Table 3. Total jobs supported by the Duckabush Estuary project, by spending category. Source: Earth Economics, 2022.

Project Year	Gray infrastructure		Green Infrastructure	WDFW Operations and Management	Yearly Total
	Utilities and Other Relocations	Bridge Construction	Estuary Restoration		
Year 1	19	410		0.00000256	**429**
Year 2		656		0.00000256	**656**
Year 3	19	246		0.00000256	**265**
Year 4			446	0.00000256	**445**

Calculations

To arrive at supported jobs estimates, Earth Economics used a variety of job multipliers from a curated body of literature and applied them to spending estimates taken directly from the project budget (see Table 1, above). Table 4 shows the multipliers as jobs supported per million USD 2021 spent on the different spending categories of the Duckabush restoration project.

Table 4. Summary of job multipliers by spending category. Source: Earth Economics, 2022.

	Utilities and Other Relocations (/$M)	Bridge Construction (/$M)	Estuary Restoration (/$M)	WDFW Ops&Mgmt (/$M)	Total (/$M)
Multiplier	11.4	16.4	14.85	0.0000064	42.65

Gray Infrastructure Multipliers

For the gray infrastructure piece of the project (i.e., bridge construction and utilities relocation), Earth Economics used publicly available 2019 multipliers for Utilities and Construction reported by the Economics Policy Institute (EPI). Table 5 below shows the multipliers as jobs supported per million USD 2021 spent on gray infrastructure components of the Duckabush restoration project.

Table 5. Gray infrastructure multiplier. Source: Earth Economics GI Jobs tool, 2022.

Multiplier Description	Direct (/$M)	Indirect (/$M)	Induced (/$M)	Total (/$M)
Utilities multipliers	1	4.5	5.9	11.4
Construction multipliers	5.5	4.8	6.1	16.4

Green Infrastructure Multipliers

For the estuary restoration component of the project, Earth Economics used its Green Infrastructure (GI) Jobs tool. The GI Jobs tool uses a curated database of job multipliers to estimate direct, indirect, induced, and total jobs supported by spending on various types of green infrastructure projects, including wetland restoration.

The job multipliers used in this analysis correspond to those reported by Nielsen-Pincus and Mosely (2010) in their study of publicly funded wetland restoration projects in Oregon. To understand the employment effects of public investments in restoration projects in Oregon, Nielsen-Pincus and Moseley analyzed fiscal data from a sample of Oregon Watershed Enhancement Board grants and collected survey data from businesses that provide services to forest and watershed restoration projects and watershed councils that manage forest and watershed restoration projects. Using these data, the authors developed production function profiles for various types of restoration activities, including wetland restoration, to then create a customized economic model for Oregon that described the new patterns in economic activity, including employment, in the state and the region triggered by the restoration projects. Results from this study include job multipliers for wetland restoration projects. These estimates were adjusted to account for regional income differentials and used to calculate the employment impact of the Duckabush restoration project. Table 6 shows the multipliers as jobs supported per million USD 2021 spent on wetland restoration projects.

Table 6. Green infrastructure multipliers, in jobs per million dollars in spending. Source: Earth Economics GI Jobs tool, 2022.

	Direct (jobs/$M)	Indirect (jobs/$M)	Induced (jobs/$M)	Total (jobs/$M)
GI multipliers	4.3	6.25	4.3	14.85

Government Spending Multipliers

Finally, for WDFW O&M spending, Earth Economics used 2020 Jefferson-County specific multipliers corresponding to the industry code for sector 531 (Other State Government) using the North American Industry Classification System (NAICS). These multipliers were purchased from the impact analysis software IMPLAN. In the selection of multipliers, regional impact multipliers were chosen as they account for jobs created in Jefferson County. Table 7 below shows those multipliers as jobs supported per million USD 2021 of government funds spent on regional operations.

Table 7. Government spending on other operations, in jobs per million dollars in spending. Source: IMPLAN, 2020.

	Direct (jobs/$M)	Indirect (jobs/$M)	Induced (jobs/$M)	Total (jobs/$M)
WDFW O&M	0.0000034	0.000002	0.000001	0.0000064

3. Ecosystem Services

Natural capital refers to the planet's stock of natural resources, or assets. This includes Earth's geology, chemistry, soil, water, air, flora, fauna, bacteria, and fungi. Forests, watersheds, mountains, and shorelines represent natural capital assets. These assets contain multiple ecosystems that perform a variety of ecosystem functions. These functions in turn provide beneficial services that enrich the human experience, such as water filtration, raw material production, flood risk reduction, recreation, climate regulation, and more. As natural capital degrades, ecosystem functions are impaired and the value of ecosystem goods and services that humans receive decreases. Ecosystem services—breathable air, drinkable water, fertile soils, disaster resiliency—are critical to human survival. When these services are lost, the economic impacts can be measured in a variety of ways, including adverse health impacts, decreased productivity, and property loss. The flow of ecosystem goods and services from natural capital is illustrated in Figure 2.

Figure 2. Natural capital, ecosystem function, and economically valuable ecosystem goods and services.

One distinguishing feature of most ecosystem services is that they are non-excludable, meaning that they can be used by multiple individuals. The flood protection benefit provided by upstream forested land benefits all downstream residents. One person benefitting from the natural flood protection will not inhibit other community members from gaining flood protection from the same forested land area. In this example, nature provides a valuable service—flood protection—for free, and everyone downstream enjoys the benefit.

In recent decades, considerable progress has been made in systematically linking functioning ecosystems with human well-being. Typologies created by De Groot, Wilson, and Boumans (2002);[ii] the Millennium Ecosystem Assessment (MEA); and The Economics of Ecosystems and Biodiversity (TEEB) have all established conceptual models for valuing natural capital and ecosystem goods and services. These models have allowed decision makers to account for the cost of environmental impacts in more comprehensive and systematic terms. Earth Economics uses a hybrid model based on these three sources. This model counts 21 ecosystem services categories that can be translated to dollar values for economic analysis (Table 8).

Table 8. Definitions of ecosystem services.

Service	Economic Benefit to People
Provisioning	
Energy and Raw Materials	Providing fuel, fiber, fertilizer, minerals, and energy
Food	Producing crops, fish, game, and fruits

Service	Economic Benefit to People
Medicinal Resources	Providing traditional medicines, pharmaceuticals, and assay organisms
Ornamental Resources	Providing resources for clothing, jewelry, handicraft, worship, and decoration
Water Storage	Providing long-term reserves of usable water via storage in lakes, ponds, aquifers, and soil moisture
Regulating	
Air Quality	Providing clean, breathable air
Biological Control	Providing pest, weed, and disease control
Climate Stability	Supporting a stable climate at global and local levels through carbon sequestration and other processes
Disaster Risk Reduction	Preventing and mitigating natural hazards such as floods, hurricanes, fires, and droughts
Pollination and Seed Dispersal	Pollinating wild and domestic plant species via wind, insects, birds, or other animals
Soil Formation	Accumulating soils (e.g., via plant matter decomposition or sediment deposition in riparian/coastal systems) for agricultural and ecosystem integrity
Soil Quality	Maintaining soil fertility and capacity to process waste inputs (bioremediation)
Soil Retention	Retaining arable land, slope stability, and coastal integrity
Water Quality	Removing water pollutants via soil filtration and transformation by vegetation and microbial communities
Water Capture, Conveyance, and Supply	Regulating the rate of water flow through an environment and ensuring adequate water availability for all water users
Navigation	Maintaining adequate depth in a water body to sustain traffic from recreational and commercial vessels
Supporting	
Habitat	Providing shelter, promoting growth of species, and maintaining biological diversity
Information	
Aesthetic Information	Enjoying and appreciating the scenery, sounds, and smells of nature
Cultural Value	Providing opportunities for communities to use lands with spiritual, religious, and historic importance
Science and Education	Using natural systems for education and scientific research
Recreation and Tourism	Experiencing the natural world and enjoying outdoor activities

Why Value Ecosystem Services?

Proper consideration of ecosystem service values ultimately strengthens decision-making. When natural capital and ecosystem services are not quantified, they are effectively valued at zero in the decision-making process. This leads to inefficient investments based on incomplete information that translates to higher future costs and poor asset-management strategies. The dynamic complexity of most ecosystems

— and the range of ecosystem goods and services they produce — makes it exceptionally difficult to substitute or replace these with humanmade infrastructure and technology. The short-term gains from activities that degrade or destroy ecosystem function are often dwarfed by the lost long-term economic value of functional ecosystems.[iii] Human activity and infrastructure development at the Duckabush estuary, for instance, has inhibited the natural flood protection benefit offered by healthy wetlands, which in turn required berms and culverts to protect highway infrastructure. Development has also impeded the ingress of chum salmon to their spawning grounds, a keystone species that provides for countless other species and the overall health and function of the coast. **Duckabush restoration is an investment in improving the estuary's ability to provide ecosystem goods and services by removing stressors that restrict its natural ability to support those functions.**

Translating the real-world benefits that ecosystems provide into dollars and ensuring that these values are properly accounted for in planning decisions is a growing best practice. This is perhaps best illustrated at the federal policy level, where ecosystem service values are increasingly being incorporated into benefit-cost analyses (BCA) as the understanding of the value of natural capital—and how to measure it—improves. In 2013, the Federal Emergency Management Agency (FEMA) announced a landmark policy change that allowed ecosystem services to be included in the formal BCA process for flood risk mitigation projects.[iv] In 2017, FEMA released BCA Toolkit Version 5.3.0, which provided explicit guidance for including ecosystem service values in BCA, doubled the number of ecosystem service values from the prior version, and extended the application of ecosystem services beyond flood risk mitigation to all FEMA project types. Subsequent guidance from FEMA updated the initial 2013 action to make it even easier to incorporate nature-based solutions for risk mitigation "… in recognition that the natural environment is an important component of a community's resilience strategy."[iv]

Study Area and Land Cover Change Data

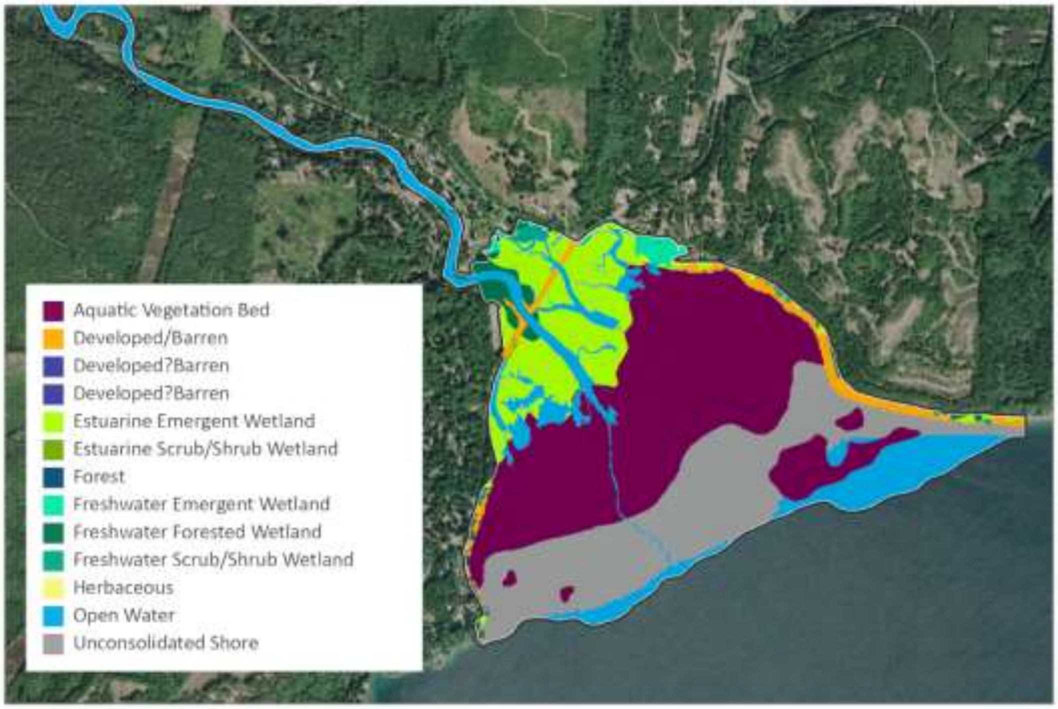
When land is converted from one type to another—like forest to cropland—ecosystem functions are altered, changing the suite of services provided. This change is important to measuring the ecosystem services impact of proposed restoration projects like the Duckabush estuary. Landcover change analysis is performed by identifying and categorizing landcover types, measuring how they change over time, and valuing those changes in monetary terms by mapping them on to the ecosystem services framework.

The area of analysis was determined using geospatial data provided by WDFW. The extent of the study area is based on estuary boundaries defined by the Pacific Marine and Estuarine Fish Habitat Partnership (PMEP). Three land cover datasets were used to ensure full coverage of the estuary: the PMEP Biotic Habitat dataset, Puget Sound Partnership Estuary Function dataset, and NOAA C-CAP 2015 land cover dataset. These datasets have slightly different spatial extents and do not always cover the whole study area. Where available, the PMEP Biotic Habitat dataset was prioritized because of its level of detail. If it doesn't cover a location, the PSP Estuary Function dataset was the next prioritized option. For all remaining gaps in land cover, the CCAP 2015 dataset was used. Once the current land cover was derived, we determined the land cover change based on restoration plan features. Proposed new channels were classified as open water in the post-restoration scenario. Areas where the current infrastructure will be removed are reclassified to adjacent land cover types.

The two maps in Figure 3. show minor land cover change confined to the footprint of the infrastructure removed i.e. converting the causeway and berms to estuarine emergent wetland and freshwater forested wetland. The limited converted acreage does not reflect the quality or improved function of the estuary post-restoration. We anticipate the estuary will undergo further land change and reach a natural equilibrium where function is enhanced. The land cover shown is immediately post project and does not attempt to predict how the site will evolve over time with increases to the channel network, sediment deposition pattern changes that may lead do different topographical elevations and, therefore, different vegetative communities and shellfish assemblages & locations. This final state is not possible to predict and cannot be measured at this time. As such, the estuary's total benefit is undervalued.

Figure 3. Projected changes in land cover pre- and post-restoration.

Pre-restoration Land Cover



SOURCES: WDFW, Puget Sound Partnership, NOAA, Pacific Marine and Estuarine Fish Habitat Partnership, Maxar
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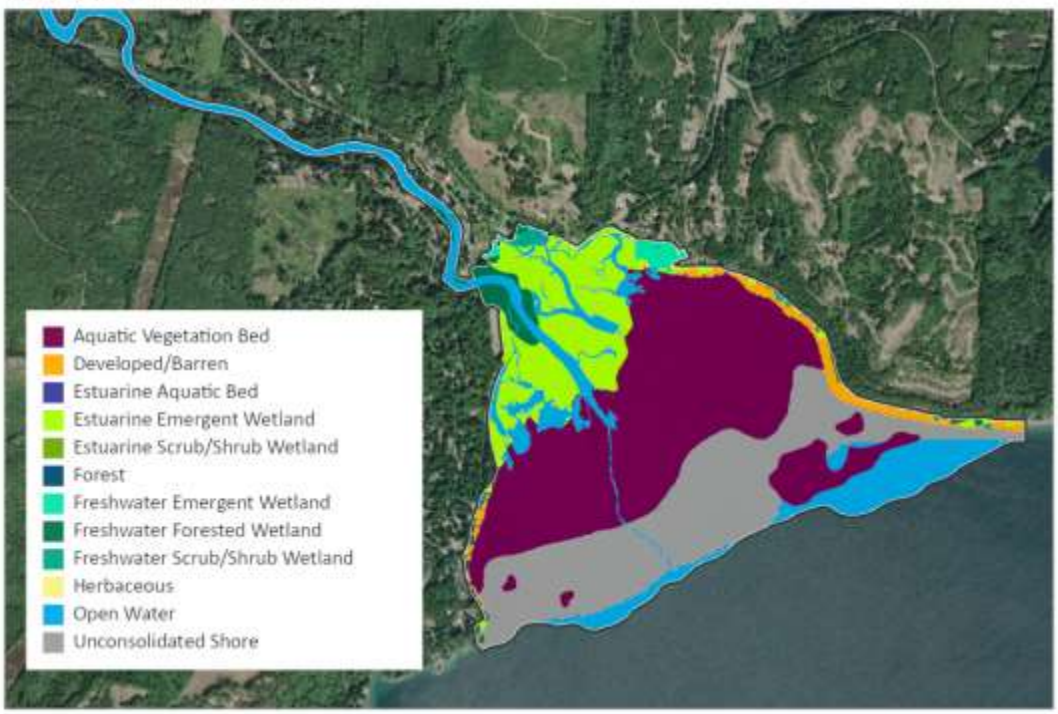
Post-restoration Land Cover



SOURCES: WDFW, Puget Sound Partnership, NOAA, Pacific Marine and Estuarine Fish Habitat Partnership, Maxar
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0.3
MILES

Benefit Transfer Method

After identifying changes in landcover using available geospatial data, the next step is to identify the value of the ecosystem services produced by the landcover types present in the study area.

To value ecosystem goods and services, Earth Economics employs the benefit transfer method (BTM), in which estimates of economic value are based on primary valuation studies of similar goods or services produced in comparable conditions (e.g., climate, terrain, soils, species). BTM is often the only practical, cost-effective option for producing reasonable estimates of the wide range of services provided by ecosystems. Criteria evaluated to select appropriate primary studies for the study area include geographic location and the ecological and demographic characteristics of the original primary study sites. Only primary studies or meta-analyses were included in the dataset. Additionally, studies were first limited to British Columbia and the states of Washington, Oregon, and California. If no appropriate studies could be found from those areas, U.S.-wide or global meta-analyses were included.

The application of BTM begins by identifying critical attributes of a landscape that determine ecological productivity and expected benefits. Primary valuations of similar ecosystems, geographies, and communities are then identified and assessed for their comparability with land cover types within the study area. Estimates from primary studies are then standardized (i.e., adjusted to common units, correcting for any inflation between the period of research and the present) to ensure "apples-to-apples" comparisons. In this sense, BTM is like a property appraisal, in which the features and pricing of similar properties nearby are used to estimate value prior to a sale. While each process has its limitations, they are rapid and efficient approaches to generating reasonable values for making investment and policy decisions.

Interest in certain ecosystem services and land cover types has generated a substantial body of research. Other ecosystem services and land cover types are less well-researched. For cases where Earth Economics was unable to identify a study suitable for transfer to the study area, no value was included. It is important to understand that this decision simply reflects the limitations of valuation research, not that those natural assets provide no value. Finally, all data was adjusted to 2021 USD using GDP deflator data estimated by the World Bank.[v] Table 9 shows which ecosystem services were able to be valued for each land cover types in this analysis. The following sections describe the methodologies used to value each ecosystem service, be it an acre-based benefit transfer method or something more unique.

Table 9. Ecosystem services valued, by land cover type.

Ecosystem Service	Forested Area	Grassland	Herbaceous Wetland	Shrub/Scrub Wetland	Total Area*
Aesthetic Information					
Air Quality					
Climate Stability					
Disaster Risk Reduction					
Food					
Habitat					
Recreation & Tourism					

Ecosystem Service	Forested Area	Grassland	Herbaceous Wetland	Shrub/Scrub Wetland	Total Area*
Science & Education					valued
Soil Quality					valued
Water Quality	valued		valued	valued	

*Some ecosystem service benefits used unique methodologies not tied to any land cover type

Key

(grey)	Ecosystem service valued in this report
(white)	Ecosystem service not valued in this report

Acre-Based Ecosystem Service Values

Benefit transfer is easily facilitated by Earth Economics' internal Ecosystem Valuation Toolkit (EVT), a repository of over 3,000 reviewed individual ecosystem service value estimates drawn from scholarly literature, government reports, and other gray literature. EVT helps to construct appropriate comparisons between these studies and the area of interest by making it easy to select for characteristics such as climate type, ecosystem, and location. Studies within the EVT have gone through multiple reviews and are standardized for use in BTM.

Two studies measured the value of air pollutant removal from natural vegetation in Washington state. Nowak et al. (2014)[vi] model improvements in air quality for forests at the state and county levels in the coterminous United States. Air pollution removal capacity of forests is estimated for NO2, O3, PM2.5, and SO2. Monetary air quality benefits are derived from the US EPA's BenMAP program, which calculates avoided costs of adverse health effects such as emergency room visits, hospital admissions from respiratory illness, and more. Values are calculated by state. Gopalakrishnan et al. (2018)[vii] model improvements in air quality for grasslands and shrublands at the state level in the coterminous United States. The authors use the i-Tree Eco model to estimate the air pollution removal capacity of these land cover types for NO_2, O_3, $PM_{2.5}$, and SO_2. Again, monetary air quality benefits are derived from the US EPA's BenMAP program.

Three studies estimated carbon storage and sequestration by native and restored coastal wetlands in Washington State: Crooks et al. (2014)[viii] in the Snohomish Estuary; Poppe and Rybczyk (2019)[ix] in the Stillaguamish River Delta; and Drexler et al. (2019)[x] in the Nisqually River Delta. All three studies found high rates of carbon storage in restoring wetlands, ranging from 164 to 230 grams of carbon per square meter per year. To estimate the value of this additional carbon sequestration, we used the social cost of carbon to value the avoided emissions and sequestered carbon. The social cost of carbon (SCC) represents the average societal costs associated with each additional ton of carbon emissions (measured in CO_2e[2]), such as losses to agriculture, impacts to human health and increased disaster risk. In the context of actions that reduce carbon emissions (e.g., energy efficiency) or actively sequester carbon

[2] Carbon Dioxide Equivalent (CO_2e) represents the number of metric tons of CO_2 emissions with the same global warming potential as one metric ton of another greenhouse gas.

(e.g., wetland restoration), the SCC represents the value of these actions in terms of avoided cost to society. The SCC is used by federal agencies in the U.S. and updated on a regular basis by the Interagency Working Group on the Social Cost of Greenhouse Gases (IWGSCGG). The value for carbon sequestration was derived from the IWGSCGG—a result of Executive Order 13990.[xi] Specifically, the 2022 value was used: $55/metric ton CO_2e.

Ghermandi et al. (2010)[xii] conducted a meta-analysis examining 170 studies to produce a comprehensive review of the valuation literature on wetlands. The authors include information on geography, climate, and socio-economic demographics for each study examined into the meta-analysis. The studies used avoided cost, hedonic pricing, contingent valuation, and market pricing to show the benefits of wetlands as an ecosystem services provider.

We used function transfer—a type of benefit transfer method—to create a customized value that is more site-specific to Washington coastal wetlands. Function transfer reapplies an equation estimated in an individual study with data from a new site to create a more customized value of ecosystem services at the new site. One inputs site-specific values for the variables estimated (e.g., for this application, type of wetland, wetland size, state GDP per capita, population density of the surrounding area, etc.) into the estimated function to calculate updated unit values. We used function transfer with the meta-analysis equation estimated by Ghermadi et al. to estimate the value of three ecosystem services for coastal wetlands present in the Duckabush Estuary: water quality improvement, non-consumptive recreation, and habitat. Table 10 presents the model coefficients estimated in the study and the inputs used.

Table 11 presents the annual ecosystem services values derived from the studies selected from EVT (described above) and multiplied by the number of acres of each land cover type.

Table 10. Inputs into the function transfer model estimated by Ghermandi (2010).

Variable	Coefficient	Input
Year of publication (Number of years since 1974)	-0.054	21.77
Estuarine	0.321	0/1
Palustrine	-0.38	0/1
Wetland size (ln)*	-0.247	2.3
Water quality improvement	0.677	0/1
Non-consumptive recreation	0.381	0/1
Natural habitat, biodiversity	0.58	0/1
Medium-low human pressure	0.564	1
GDP per capita (ln)*	0.295	13.5
Population density (ln)*	0.399	7.61
Wetland abundance (ln)*	-0.064	2.3
Constant	0.854	1

*natural log

Table 11. Annual ecosystem services values derived from EVT.

Land Cover	Ecosystem Service	Short Reference	2021$/year
Forested Wetland	Air Quality	Nowak et al. (2014)	23
Herbaceous Wetland	Air Quality	Gopalakrishnan et al. (2018)	1

Grassland	Air Quality		<0.01
Shrub/Scrub Wetland	Air Quality		0.39
Herbaceous Wetland	Climate Stability	Crooks et al. (2014); Poppe & Rybczyk (2019); Drexler et al. (2019)	15,044
Forested Wetland	Climate Stability		2,349
Grassland	Climate Stability		7
Shrub/Scrub Wetland	Climate Stability		326
Forested Wetland	Habitat	Ghermandi et al. (2010)	14,897
Shrub/Scrub Wetland	Habitat		3,517
Herbaceous Wetland	Habitat		187,705
Forested Wetland	Recreation, nonconsumptive		4,698
Shrub/Scrub Wetland	Recreation, nonconsumptive		1,109
Herbaceous Wetland	Recreation, nonconsumptive		59,197
Forested Wetland	Water Quality		9,827
Shrub/Scrub Wetland	Water Quality		2,320
Herbaceous Wetland	Water Quality		123,825

Value of Recreational Shellfishing

A range of recreational activities take place at the Duckabush Estuary. Waterfowl hunting and big game hunting—including a local population of elk—occur within the estuary and surrounding area. Recreational angling occurs in the estuary and in the nearby Hood Canal waters. Local wildlife—including elk, birds, and more—contribute to wildlife watching. The scenic area provides a picturesque location in which to participate in sightseeing, picnicking, photography, and more. More than 60 percent of visitors to the Duckabush Estuary reside outside of Jefferson County, and almost 10 percent outside of Washington State.[xiii] Due to lack of data for many of these activities, we focus on recreational shellfishing occurring on-site.

Recreational harvesting of clams, oysters, and other shellfish may be one of the largest sources of recreational activity at the site. WDFW tracks recreational shellfish effort on public lands in the Estuary (Table 12). The past five years has seen an average of 580 harvester days at the site. The year 2018 was the first year of regular Department of Health closures due to water quality, which limited recreational harvest seasons in the area—the site is currently closed from May through October. Prior to 2018, the 5-year average totaled about 2,500 harvester days, meaning closures have decreased harvester days by approximately 77 percent.

Table 12. Shellfish harvester days estimated by WDFW.

Year	Harvester Days
2018	581
2019	332
2020	771
2021	826
2022	391
Average	**580**

To estimate the value of recreation to visitors, we used consumer surplus estimates. Consumer surplus describes the value gained by recreationists when they engage in recreation at a cost lower than they are willing to pay for it. Consumer surplus is the difference between what people value their recreational experience at (their total willingness to pay), and what they actually spend (e.g., entry fees, transportation). For example, if someone was willing to pay $100 for a shellfishing trip, but it only cost them $60, the consumer surplus value of that trip would be $40.

Anderson and Plummer (2016)[xiv] valued recreational shellfish trips in the Puget Sound, finding that people value a shellfishing trip at $149 per person per day (2021 USD). Applying this value to the average number of harvester days per year results in **a total consumer surplus value of shellfishing at the Duckabush Estuary of $86,000 each year.**

This value does not include the value of other recreational activities, however. While we know other activities occur on the site, we don't have accurate visitation information from which to estimate consumer surplus values. Therefore, this value should be treated as an underestimate of the value of recreation at the site.

Value of Salmon Population Increases

The project is expected to be very beneficial for chum salmon—an ESA-listed species dependent on estuaries for rearing purposes—and is expected to contribute to the species' recovery in Hood Canal. We used data from recent salmon monitoring efforts[xv] and guidance from experts to estimate the value of an increased salmon population in the Duckabush River.[xvi]

Weinheimer (2022)[xv] reported the estimated juvenile migration, returning adults, and smolt-to-adult return ratio (SAR) for summer and fall chum from 2010 to 2016. The average SAR over this period was 1.50 percent (Table 13).

Table 13. Summer and fall chum abundance and survival by Weinheimer (2022).

Brood Year	Outmigration Year	Estimated Juvenile Migration	Estimated Returning Adults	SAR
2010	2011	347,597	7,897	2.27%
2011	2012	290,891	3,280	1.13%
2012	2013	285,468	5,905	2.07%
2013	2014	480,202	11,142	2.32%
2014	2015	130,126	1,326	1.02%
2015	2016	47,479	573	1.21%
2016	2017	200,712	925	0.46%

2017	2018	365,203	*	*
2018	2019	379,002	*	*
2019	2020	180,213	*	*
2020	2021	213,789	*	*
Average		**265,517**		**1.50%**

**Not available*

Experts we spoke to thought that, after restoration, the SAR for Duckabush may be comparable to that of the Union River, which has an average SAR of 3.15 percent estimates for the 2017-2018 brood year, and that SAR could be achieved after two to three brood cycles (approximately 8 to 12 years).[xvii]

We compared the difference between estimated returning adults currently and under a SAR of 3.15 percent. Beginning in the last year of construction, we increased the SAR each year from the current average to 3.15 percent over ten years and estimated the additional number of adult fish that could return each year. At a 3.15 percent SAR, this results in about 4,300 additional returning adults each year.

To compare benefits to the population, we must forecast the number of returning individuals with and without the Duckabush project. However, the number of juveniles and SAR varies for any given year. As we see in Table 13, the estimated juvenile migration ranges from 47,000 to 480,000 individuals, and the SAR ranges from 0.46 percent to 2.32 percent. We used Monte Carlo simulation to vary the estimated juvenile migration and SAR for 100 years post-project construction using the data in Table 13. Juvenile migration is drawn from a normal distribution, using the mean, standard deviation, and range of estimated juvenile migration from Table 13. SAR is drawn from a uniform distribution using the range of values in Table 13. To estimate the increase in returning adults from an increased SAR due to the project, we increase the SAR from the average (1.50%) to the Union River average (3.15%) using a sigmoidal curve over 12 years. For each year, we then compare the difference in estimated returning adults between the "business as usual" SAR and "restored" SAR over 10,000 trials.

Lewis et al. (2022)[xviii] estimate the willingness to pay (WTP) of residents of the greater Pacific Northwest (Washington, Idaho, Oregon, and Northern California) for increasing populations of ESA-listed threatened Coho salmon along the Oregon coast. The authors estimate WTP for households with and without college degrees, finding college households are willing to pay $0.19 per 1,000 fish per year, and non-college households $0.08 per 1,000 fish per year.

We chose to scale the WTP estimates by both households within the Puget Sound as well as Statewide. From a fisheries management perspective, everyone in the Puget Sound region who fishes or uses Puget Sound fisheries in some way benefit from the fate of ESA-listed species.[xix] On the other hand, the cost of the project is borne by the state legislature, so any benefits accruing from the project affect everyone in the state.[xx] Furthermore, people outside the Puget Sound and even Washington State borders may be willing to pay for population increases of salmon in the Duckabush system—Lewis et al. (2022) found positive WTP values outside of Oregon state borders for Oregon coast salmon populations, and other contingent valuation studies have found similar distributions of positive WTP far outside their study areas (e.g., Stefanski & Shimshack, 2016).[xxi] Therefore, even the statewide estimates of total WTP estimated here should be considered underestimates.

We obtained educational status and number of households by county from the U.S. Census American Community Survey. Table 14 shows the number of households and college degree attainment statewide as well as for counties surrounding the Puget Sound.

Table 14. Households and college attainment in the Puget Sound and statewide.

County/Region	Percent of Population With College Attainment	Total Households	Households With College Degree	Households Without College Degree
Jefferson	42.50%	15,051	6,397	8,654
Mason	18.10%	25,242	4,569	20,673
Kitsap	34.40%	105,758	36,381	69,377
Thurston	35.00%	112,323	39,313	73,010
Pierce	27.70%	330,999	91,687	239,312
King	53.40%	900,061	480,633	419,428
Snohomish	32.80%	298,815	98,011	200,804
Island	34.10%	35,326	12,046	23,280
Total Puget Sound	**34.75%**	**1,823,575**	**769,037**	**1,054,538**
Statewide	**36.70%**	**2,905,822**	**1,066,437**	**1,839,385**

We combine the change in simulated adult returns with the WTP values from Lewis et al. (2022) and the number of households in the region. We present WTP values using a 0% discount rate (undiscounted) and a 3% discount rate. See section, "Asset Valuation of the Proposed Project Study Areas," for more information.

Table 15. Total value over 100 years for increases to salmon populations in the Duckabush River across 10,000 simulations (millions, 2021 USD).

Region – Discount Rate	Minimum (million $)	Maximum (million $)	Mean (million $)
Puget Sound – 0%	$88	$126	$109
Puget Sound – 3%	$24	$36	$30
Statewide – 0%	$130	$191	$163
Statewide – 3%	$36	$54	$45

This value doesn't reflect the benefits stemming from other populations of fish that might benefit from the project, which include chinook, the primary prey of the critically endangered Southern Resident orcas pink and coho salmon, along with steelhead.

Nutrient Cycling

Morton et al. (2017)[xxii] use the replacement cost approach to value the benefit of salmon-based nutrient cycling in the Columbia River basin. The authors estimate that salmon are net importers of roughly 23 percent of total nitrogen contained in returning adult salmon. Using a replacement cost of nitrogen fertilizer used in forest restoration efforts, the authors estimate a total annual value of $3.13 per river mile. Multiplied by the number of river miles in the restored Duckabush Estuary amounts to an annual benefit of $27 per year.

Commercial Shellfishing

We obtained shellfish harvest and population estimates from WDFW (Table 16).[xxiii] This data included reported commercial harvest on public lands in the Duckabush estuary, from 2003 to 2022 (preliminary reporting). Recreational harvest is valued separately. We estimate the 5-year average harvest and assume harvest levels will remain stable into the future. Since there has been no commercial clam harvest in the past three years, we decided to only estimate value for commercial oyster harvest.

Table 16. Average commercial shellfish harvest in the Duckabush Estuary.

Year	Clam Harvest (lbs)	Oyster Harvest (singles)
2018	3,829	30,300
2019	1,861	48,300
2020	0	393,360
2021	0	1,022,484
2022	0	635,616
Average Harvest Post-Closures	N/A	**426,012**

We looked to ex-vessel prices—the price paid to fishermen at the first point of sale—to understand the economic value of this harvest. While producer surplus—the amount a producer benefits from selling goods—would be a more comparable amount to other ecosystem service values, this amount is not generally available, as it depends on knowing fisher's harvesting costs. Therefore, ex-vessel price is the next-best estimate, as other prices (wholesale, retail) include inflations to account for company profits.

The NMFS reports commercial landings by year, state, and species across the United States. Landings for oysters are reported in pounds of meat (excluding shell weight) and total nominal price. We used the ex-vessel price for Pacific Oysters in 2021 to value average post-closure harvest by Tribes ($5.88 per pound). To convert oyster harvest to pounds of meat, we used the meat yield ratio (the ratio of meat to whole weight, including shell) from a global meta-analysis, which estimates a 10.75 percent meat yield[xxiv] and an average total oyster weight (including shell) of 0.17 pounds per oyster (assuming a dozen oysters weigh 2 pounds).[xxv] **The oyster harvest then translates to about 8 thousand pounds of meat, valued at $46,000 per year.**

Flood Risk Reduction

Roads

High-tide flooding (or nuisance flooding) affects traffic in many US coastal areas. Due to their higher frequency, nuisance flooding events carry comparable economic impacts to large storm surge events. Moreover, sea level rise and changing raining patterns are likely to make the issue more problematic in the future. Impacts include traffic delays, damage to vehicles, and roadway maintenance costs. Raising road profiles in coastal areas can help prevent these impacts.

The Duckabush restoration project replaces the Highway 101 causeway that currently bisects the estuary with a full spanning bridge, raising the road profile of Highway 101. To measure the benefits that raising the road profile would have in terms of reduced road maintenance, Earth Economics used results from a study by Fant et al. (2021)[xxvi] on risks and impacts of high-tide flooding on vulnerable traffic corridors. The study uses hourly tide gauge water levels and sea-level rise projections to conduct a spatial analysis that quantifies avoidable costs of high-tide flooding (i.e., the difference between no adaptation and proactive adaptation such as raising the road profile).

Results from Fant et al. (2021) include projected annual avoidable road maintenance costs for decades 2020, 2030, 2040, 2050, 2060, 2070, 2080, 2090, and 2100. The avoidable costs are also modeled for 6 different sea-level rise scenarios (0.3m, 0.5m, 1m, 1.5m, 2m, and 2.5m) and for 2 different adaptation scenarios: "Reasonably Anticipated Adaptation," and, "Direct Adaptation." Earth Economics focused on the results corresponding to the Direct Adaptation scenario because raising the road profile was considered a Direct Adaptation by the authors. The results are spatially explicit and specific to Jefferson County, which has 1,354.12 road miles.[xxvii]

To arrive at the estimated avoidable costs from raising the portion of Highway 101 that bisects with the estuary, Earth Economics calculated the average avoidable road maintenance costs across the 6 different sea-level rise scenarios and for each projected decade. Then, using information on road miles from WA DOT, Earth Economics calculated a per-mile avoidable road maintenance cost. Finally, this number was multiplied by 0.32 miles, the length of Highway 101 the Duckabush restoration project intervenes. The estimated decadal avoidable road maintenance costs were appropriately adjusted to present net present value in terms of USD 2021.

Table 17. Decadal avoided road maintenance costs.

Decade	Annual cost (not discounted)
2020	$7
2030	$13
2040	$34
2050	$109
2060	$265
2070	$476
2080	$614
2090	$722
2100	$845

Benefit-Cost Analysis

The Duckabush restoration project includes replacing a section of Highway 101 with modern structures engineered to pass 100-year river flood events and account for projected sea-level rise. Thus, the project will have some flood mitigation effects. To measure flood risk reduction benefits from the restoration project, Earth Economics used findings from a preliminary evaluation of the cost-effectiveness of the Duckabush restoration project conducted by WDFW[xxviii]. The study examines the project's flood mitigation benefits as avoidable property damage under several statistical flooding events (10-, 50-, 100-, and 500-year flood). **The study finds that removal of the bridges and embankment due to the project provide a total annualized benefit of $897 per year in avoided flood damage** (see Table 18). The project would remove 1 structure from the 10-year floodplain, two structures from the 500-year floodplain, but the 50-

year floodplain has an increase in the square footage affected by flooding. Overall, the project results in a net positive benefit.

Table 18. Flood risk reduction benefits provided by the Duckabush project, by flood recurrence interval.

Flood Recurrence Interval (years)	Annual Probability of Occurrence	Total Benefits ($)	Annualized Benefits ($/year)
10	10%	$40,080	$4,008
50	2%	-$213,840	-$4,277
100	1%	$0	$0
500	0.2%	$582,800	$1,166
Total			$897

Bioswale Method

Runoff from roads, parking lots, and roofs is one of the largest sources of contaminants flowing into the Puget Sound.[xxix] Low-impact development and nature-based solutions like bioswales have shown promising results for helping address the pollution problem by absorbing and filtering stormwater runoff from rooftops, decks, and other hard surfaces. The Duckabush restoration project includes 3 bioswales that together account for an area of approximately 174 square meters. To value the contribution of bioswales in terms of reduced stormwater management costs, Earth Economics applied the avoided cost method using results from a 2014 EPA-funded study prepared by King County Department of Natural Resources and Parks that projects capital and maintenance costs of stormwater.[xxx]

According to the report, a 30-year plan to address Puget Sounds' stormwater pollution problem could cost between $16.12 to $18.4 billion per year (USD 2013). These estimates would include construction and O&M expenses, of which a large portion would go to inspection and enforcement for private facilities. The study area covered 278 square miles of the Green/Duwamish watershed and portions of the Central Puget Sound watershed. Earth Economics converted these annual costs to a per acre basis. This yielded an estimated annual cost between $91,052.16 and $103,417.27 per acre. Finally, Earth Economics used this per acre estimate to calculate the value added by the restoration project's bioswales. **The resulting approximated annual ecosystem service value of the bioswales in terms of avoided costs of stormwater management ranges from $3,573.11 to $4,138.03 (USD 2021).**

Volunteer Time

Volunteers (a minimum of two per program) participate in four separate monitoring programs since 2020, and are expected to continue for five years post-construction:[xxxi]

- **Bird Monitoring:** Volunteers monitor birds in the project area once per month during the year. Each monitoring event takes approximately two hours.
- **Vegetation Monitoring:** Volunteers monitor the presence of plant species in the project area three times during the summer each year. Each monitoring event takes approximately 8 hours.
- **Water Quality Monitoring:** Volunteers monitor water quality in the project area once per month during the year. Each monitoring event takes approximately one hour.
- **Sediment Measuring:** Volunteers measure sediment added and eroded in the project area once per month during the year. Each monitoring event takes approximately one hour.

Using the assumptions above totals 144 volunteer hours per year. We assume that this monitoring effort happens for 12 years (assuming construction begins in 2023 and lasts for four years), for a total of 1,728 volunteer hours.

We valued the total hours of volunteer time using the value of volunteer time estimated by the Independent Sector for Washington State (34.87 USD/hour, in 2021 dollars).[xxxii] **The total value of volunteer time is estimated at about $60,000.**

Asset Valuation of the Proposed Project Study Areas

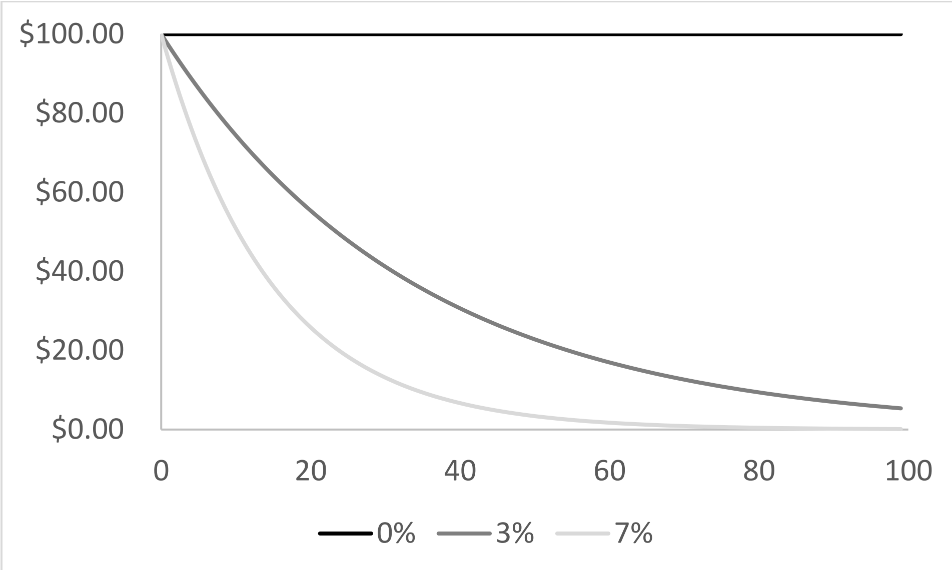
Asset values provide a measure of the expected benefits flowing from the study area's natural capital over time and are useful for comparing benefits produced at various points in the future. The asset value of built capital can be calculated as the net present value of its expected future benefits. Provided the Duckabush Estuary and its surrounding area do not degrade further, the annual flow of ecosystem services will continue into the future, and those benefits can be included in the asset value. In order for this to be accomplished, a discount rate must be used.

Discounting allows for sums of money occurring in different time periods to be compared by expressing the values in present terms. In other words, discounting shows how much future sums of money are worth today. Discounting is designed to consider two major factors:

1. **Time preference:** People tend to prefer consumption now over consumption in the future, meaning a dollar today is worth more than a dollar received in the future.
2. **Opportunity cost of investment:** Investment in capital today provides a positive return in the future.

However, the rate at which natural capital benefits should be discounted is a subject of debate. Public and private agencies vary widely in their standards for discount rates. The choice of discount rate is critical, however, as it heavily influences the outcome of the present values of benefits that occur over a long period of time. Figure 4 illustrates this issue. For example, $100 received in 100 years under a 0 percent discount rate (i.e., the undiscounted value) is still $100, but under a 3 percent discount rate, the same amount falls to $5.36, and a mere $0.12 under a 7 percent discount rate. This issue is particularly relevant for the benefits received from nature, which are typically very long-lived.

Figure 4. Illustration of the effect of a discount rate on $100 over 100 years



This study presents results using two discount rates: 3 percent and 0 percent. The use of multiple discount rates allows for comparison of the sensitivity of the asset value calculated. Net present values can be calculated over different timeframes depending on the purpose of the analysis and nature of the project. In the case of natural capital valuations, ecosystems, if unimpaired, are self-maintaining, display long-term stability, and are continuously productive. A 100-year timeframe was chosen, as it best reflects the longevity of a healthy ecosystem's productivity. If kept healthy, the Duckabush Estuary can provide benefits for much longer than 100 years.

The asset value calculated in this study is based on a snapshot of the current and projected land covers, consumer preferences, population base, and productive capacities. As such, it does not consider environmental degradation that may occur in the future, or changes in value due to scarcity. Rather, it assumes that the ecosystems in the study area remain the same over the entire duration of the calculation. For more information on the limitations of this report, see Appendix A.

Summary of Values

The values presented in this section have been aggregated in Table 19. The value of ecosystem services protected, maintained, and gained by the Duckabush restoration project are significant. **Over 100 years, ecosystem services values add up to $249 million ($75 million when discounted at a 3% discount rate).**

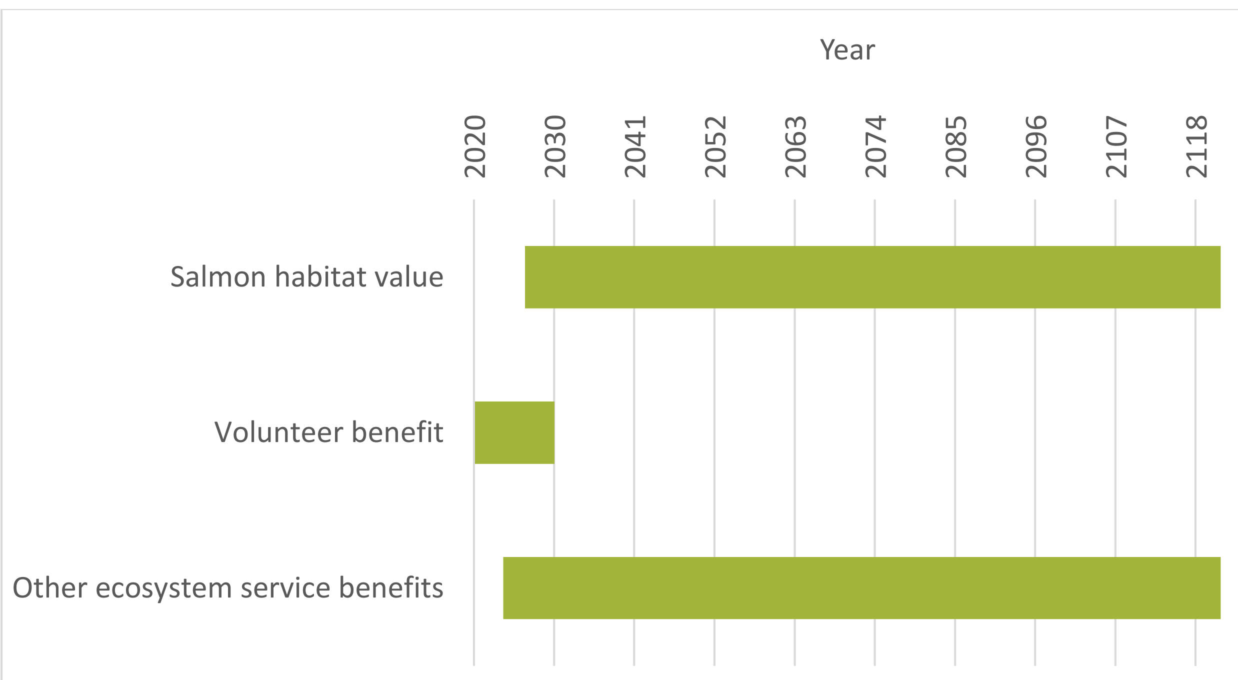
Table 19. Present value of benefits over 100 years, thousands of 2021 USD.

	0% Discount Rate		3% Discount Rate	
Benefit	Value Maintained	Value Gained	Value Maintained	Value Gained
Aesthetic benefits		$84,486		$27,497
Air quality improvement	$2		$1	
Climate stability	$1,773		$577	
Commercial fishing	$4,576		$1,489	
Flood risk reduction		$90		$29

Benefit	0% Discount Rate		3% Discount Rate	
	Value Maintained	Value Gained	Value Maintained	Value Gained
Habitat	$20,612		$6,709	
Salmon population value (Puget Sound region)		$108,888		$29,545
Recreation (shellfishing)	$8,615		$2,804	
Recreation (Non-consumptive activities)	$6,500		$2,116	
Road flooding avoided cost		$54		$8
Nutrient cycling		$3		$1
Volunteer benefit		$60		$54
Water quality improvements (wetlands)	$13,597		$4,425	
Water quality improvements (bioswale)		$386		$125
Subtotal	**$55,675**	**$193,967**	**$18,121**	**$57,259**
Grand Total	**$249,642**		**$75,380**	

These benefits accrue at different times during and after the project lifespan. Figure 5 shows when the benefits of each ecosystem service might accrue, up to 100 years post-project.

Figure 5. Timeline of ecosystem service benefits



Underestimates

Earth Economics' study underestimates the full value of the restoration. The study measured land cover immediately post-restoration, not the final state of equilibrium the estuary will reach after channels are reconnected, which may create further value. The study also excluded certain ecosystem services where data for the target land cover was limited. These include -

- Energy and raw materials
- Medicinal resources
- Ornamental resources
- Biological control
- Pollination and seed dispersal
- Soil formation
- Cultural value
- Soil retention
- Water Capture, Conveyance, and Supply
- Navigation

The importance of the Duckabush estuary as part of the larger Hood Canal and Puget Sound ecosystem should not be underestimated. The estuary plays a role as a stopping point for salmon populations migrating further into the sound, and its restoration will support an increase salmon abundance, ultimately removing the need for protected status for certain species. Everyone benefits when we move towards delisting a species.

Our valuation focuses only on chum salmon to the residents of the Puget Sound. Other salmon species, like the Chinook, a main food source for endangered Southern Resident Killer Whales, should increase post-restoration. It could be argued that all residents of Washington state would benefit from increased numbers of these keystone species.

It's difficult to predict how the estuary's hydrology will change. Shellfishing is a significant recreational and tribal activity at Duckabush, and restoration may affect distribution of shellfish and their abundance. If water quality improves, the estuary may open for shellfishing all year round, increasing the value of recreational and commercial harvesting.

A range of recreational activities take place at the Duckabush Estuary—our valuation focuses on shellfishing and non-consumptive activities such as wildlife viewing. Due to lack of data for many of the recreational activities that occur on-site, we focused on recreational shellfishing occurring on-site. Not every ecosystem service provided by the Duckabush estuary and its restoration were able to be valued due to lack of available data. This does not mean additional benefits beyond those laid out in this report do not exist or are not valuable—only that the data in which to estimate their value could not be found. Thus, **the total ecosystem service value presented here should be viewed as a minimum value of what would be provided.**

Conclusion

A preliminary benefit-cost analysis of the Duckabush restoration project identified $14.4m in benefits, largely based on avoidance of property loss and the value of damages from flooding events. Earth Economics expanded the services measured in the BCA to include ecosystem services provided by the restored wetlands and found the project to be far more cost-effective. The value of the wetlands protected by the Duckabush restoration is $249.6m ($75.4m at a 3% discount rate) over the 100-year lifespan of the bridge.

Most of the value derives from the ecosystem services created by the existing wetland with a smaller proportion of value generated by the land change from causeway to estuarine wetlands. We anticipate that as the channels are connected, there will be further change in landcover, and that the estuary will reach an equilibrium that improves its efficiency, though this was not measured.

The estuary is an important nursery habitat for the endangered chum salmon, and the expected improvement in salmon abundance will create $108.9m in value for the residents of the Puget Sound.

The annual value of shellfish recreational and commercial harvesting is $132,000. We did not assume an increase in shellfish population, as it's unclear if the population would increase. Therefore, we did not estimate the additional value in shellfish harvesting from opening the estuary for more harvesting days, annually, which is expected to be significant.

In addition, WDFW estimated that at least 433 jobs[3] would be supported by the project. Earth Economics calculates that the bridge alone will support an average of 450 total jobs per year for 3 years (including indirect and induced jobs), and the estuary restoration work would support another 446 during the year the restoration work would occur. These findings constitute a substantial increase from what was originally calculated.

The importance of the Duckabush estuary as part of the larger Hood Canal and Puget Sound ecosystem should not be underestimated. Our value didn't include other populations of fish that might benefit from the project, such as the Chinook salmon, a main food source for endangered Southern Resident Killer Whales, nor did we attempt to value the estuary's role as a stopping point for salmon populations migrating further into the sound.

[3] The 433 estimate is derived from the original estimate by WDFW which is 1,300 job-years. A job-year is one job for one year. Since the construction project is scheduled to occur during 3 years, 1,300 job-years could represent a minimum of 433 jobs per year (1,300 divided by 3).

Appendix A: Limitations

Economic Impact Estimation

Economic impact analyses are never perfect. When projecting economic impact of projects that have yet to take place, assumptions must be made that each come with their own set of limitations.

The production functions from Nielsen-Pincus and Moseley were built using compiled data from Oregon's public sector for calendar years 2002 to 2008. We believe applying them to the Hood Canal case is valid on three accounts:

1. The two geographies are relatively similar.
2. The non-profit sector and the public sector do not have widely different interests and objectives as neither engage in private profit-seeking activities but rather in activities that maximize social and ecological value.
3. The forest and watershed restoration subsector is a generally static subsector—that is, the type of technologies used by the subsector do not tend to see rapid changes. Thus, using 2002–2008 information about this sector would not have negative repercussions for an analysis of the same sector 20 years later.

Jobs are not reported as full-time equivalents but instead calculated in terms of "job years," or the total number of full- and part-time jobs annualized over the course of the year (e.g., one employee working twelve months or two employees working six months each equal one job year, because one employee working half the year equals 0.5 jobs years). This calculation only takes into account duration of employment, not hours worked. This number is also based on number of positions within a business; if one person works two jobs in the same business, they would be counted twice.

Estimating the results based on eastern Jefferson County's resident population assumes that the resident population reflects employed population and where industries reside. We do not see this as problematic for this analysis considering the western census block groups require long travel times to the Hood Canal area.

Finally, recall that property acquisitions were not included in estimating economic effects – while recognizing that land is critical to carry out any watershed restoration project, IMPLAN does not recognize land itself as initiating further economic contributions to an economy. Ignoring land as an input of production is, for technical reasons, the best practice among IMPLAN users.

Ecosystem Service Valuation and the Benefit Transfer Method

Valuation exercises have limitations, yet these limitations should not detract from the core finding that ecosystems produce significant economic value for society. It's important to note that this ESV does not include all possible ecosystem services produced by the Hood Canal Salmon Enhancement Group's Moon Valley and Lower 1 Mile projects. Due to limitations of conducting a primary valuation, several gaps exist in the academic literature analyzing the economic value of ecosystem services. Therefore, not all ecosystem services identified as valuable for each land cover class can currently be assigned a dollar value.

Like any type of economic analysis, the benefit transfer method (BTM) has strengths and weaknesses. One argument against benefit transfer is that every ecosystem is unique and therefore has unique value. While this is undoubtedly true, this implies that the only option for understanding the true value of a given ecosystem is to fund resource-intensive primary studies. In fact, benefit transfer—applying knowledge from one place to learn about another, based on key variables—is a widely accepted practice.

Consider the example of property assessment: county governments across the U.S. regularly update property values so that they can collect property tax revenue. This is achieved not by sending assessors to visit every built structure, but by examining key variables that influence home value—number of bedrooms, bathrooms, square footage, views, and more—and updating values accordingly. This analysis, focused on evidence from the Pacific Northwest to limit geography-based variance, and also considered variables including ecosystem type, urban/rural proximity, climate type, and more.

Many of the chosen studies provide a range of estimated values rather than single-point estimates. The present study preserves this variance; no studies were removed from the database because their estimated values were deemed too high or too low. The study results are displayed in a way that allows one to appreciate the range of values and their distribution. It is clear from inspection of the tables that the final estimates are not precise. However, they are preferable to the alternative of assuming that ecosystem services have zero value, or, alternatively, of assuming they have infinite value. From a decision-making perspective, in estimating the value of ecosystem services, it would be better to be approximately right than precisely wrong.

Appendix B: Commonly Asked Questions

Question	Answer
Ecosystem Services Valuation	
Do you value all ecosystem services in every land cover type?	Due to limitations of conducting a primary valuation, several gaps exist in academic literature on economic analysis of ecosystem services. Therefore, not all ecosystem services identified as valuable for each land cover class can currently be assigned a dollar value.
Why do ecosystem services valuations typically return a range of values?	To conduct an original complete valuation would require more than 100 unique scientific studies for a single study area. Due to the extremely high costs associated with conducting original research for ecosystem services, we use the benefit transfer method for providing a range of values for ecosystem service benefits. This type of valuation is based on peer-reviewed academic articles and on research in each case study. The wide range in value will narrow and the values rise as more primary studies are completed, filling valuation gaps and adding precision. The estimates represent the range of the lowest and highest values in peer-reviewed literature. Though a great deal of research has been completed on ecosystem services in the last 30 years, this is still an emerging field that's constantly yielding new values.
Why is the range of values so wide?	Using the lowest and highest estimates in the literature provides a range of values of ecosystem services examined in the study area. The low valuation boundaries are underestimates of actual value, but they can demonstrate that ecological services in an area are worth at least a certain dollar amount. This is usually sufficient to inform policy decisions such as restoring or maintaining those systems.
Does the wide range imply inaccuracy?	Not necessarily, because economic values are volatile, and decision-makers are accustomed to this. Like ESVs, economic values are often presented in an appraisal format. For example, Washington Mutual Bank was valued at $306 billion in January 2008. The bank became insolvent and was quickly sold. One appraisal had the value over $100 billion, another at less than $1 billion. It was sold to J.P. Morgan for $1.3 billion in November 2009. The error of excluding the value of natural capital is greater than the inherent and unknown error of an ESV value estimate.
Could an ESV overestimate natural goods and services?	Built, natural and human capital are complementary – all are required in combination to provide useful services such as drinking water supply or stormwater management. With a finite budget, highlighting the value of natural capital may provide the rationale for investing in more natural capital over equally important operations. For example, in the case of utilities, investment may be shifted from fixing old pipes to restoring the watershed, although fixing pipes brings the greatest marginal benefit. However, ESVs may also open up novel, outside revenue streams that expand the budget.
How do you make sure that double counting is avoided when evaluating ecosystem services?	Each study applied under the benefit transfer method is carefully reviewed for each case study to avoid double-counting.

Why does EE methodology look at total ecosystem service value and not marginal value?	The level of specificity in marginal valuation is very difficult to implement when the science is not readily available, especially in small cases. For example, General Motors does not calculate marginal value because it is very costly to measure the marginal value of developing a new car. GDP doesn't use marginal value for the same reason: it is too costly to review the marginal value of economy gains in such a large market.
How is changing scarcity addressed?	Original primary valuations may underestimate shifts in the relevant demand curves as the sources of ecosystem services become more limited. The values of many ecological services rapidly increase as they become increasingly scarce. If the ecosystem services of a study site are scarcer than assumed (which is likely), their value will have been underestimated in the study. Such reductions in "supply" appear likely as land conversion and development proceed. Climate change may also adversely affect ecosystems, although its precise impacts are more difficult to predict.
Has Earth Economics' BTM been peer reviewed in professional journals?	No, although BTM has been a topic of many journal articles and several best practice guides exist.
Benefit Transfer Method	
Why not use primary valuation methods?	A primary study generally looks at one or a few ecosystem services and takes up to two years, costing upwards of $100,000 for a single study. Using the Benefit Transfer Method to do a secondary valuation, Earth Economics can value up to 21 ecosystem services at a fraction of the cost and in less time.
What is Benefit-Transfer Methodology?	Benefit transfer involves obtaining an estimate for the value of ecosystem services through the analysis of a group of primary valuation studies which have been previously carried out to value similar goods or services in similar geographies and contexts. The transfer itself refers to the application of derived values from the original study site to a different analysis site.
Is Benefit Transfer Method commonly used?	ESV using BTM has been used by federal agencies such as the EPA in the past for benefit-cost analysis for rule making and continues to gain acceptance. Earth Economics has recently worked with FEMA to help the agency incorporate ecosystem service values into their benefit-cost tool for hazard mitigation projects, a move that shifted millions towards sustainable projects. Earth Economics' EVToolkit presents results in an accepted "appraisal" format, analogous to a house appraisal. Nearly every property that is sold goes through an appraisal process that is similar to BTM – an estimate is determined for a house based on the value of similar houses (similar square footage, number of bedrooms and bathrooms, etc.) sold in the area. Also, studies that are transferred to the study site are peer-reviewed in scientific journals and vetted for transferability.
Can selection bias be prevented?	Bias can be introduced in choosing the valuation studies, as in any appraisal methodology. The use of a range partially mitigates this problem.
Are statistically derived values more accurate than benefit transfer values?	BTM analyses are a static, partial equilibrium framework that ignores interdependencies and dynamics, though new dynamic models are constantly being developed and refined (e.g., ARIES, InVEST, MIMES). The effect of this omission on valuations is difficult to assess, however when BTM is used as an appraisal, the assumption that the valuation is temporally limited is made clear, as with other forms of appraisal (e.g., a house or business appraisal).

Why would BTM be implemented if there are better methodologies out there?	A primary study generally looks at one or a few ecosystem services and takes up to two years, costing upwards of $100,000. A benefit transfer can now be completed by Earth Economics in less than six weeks, assess up to 21 ecosystem services, and cost a fraction of a primary study. The deployment of Earth Economics' EVT will further reduce the cost and increase the accessibility and leveraging of the data.
Under the Benefit Transfer Method, what watershed scale is appropriate for accurate valuation figures?	A set of primary studies can be appropriately applied at the smallest watershed scale if the study attributes match those in the supposed case study. Applicability of primary studies for benefit transfer is largely dependent on the similarities between physical features applied in each study and the given case study.
Valuation Methods	
How are dollar values placed on non-monetary goods and services?	There are eight primary valuation methodologies commonly used to calculate ecosystem service value. Statistical models and benefit-cost tools typically provide values using the following methods: **Market Pricing:** The current market value of items produced in the ecosystem (e.g., water, fish, and wood). **Replacement Cost:** The cost of replacing a functioning natural system with man-made infrastructure (e.g., natural water filtration versus a water treatment plant). **Avoided Cost:** Services allow society to avoid costs that would have been incurred in the absence of those services (e.g., reduction in flood damage due to natural water storage and flood mitigation provided by wetlands and riparian buffers). **Production Approaches:** Services provide for the enhancement of incomes (e.g., productivity of crops after irrigation in agricultural systems). **Travel Cost:** Service demands may require travel, which have costs that can reflect the implied value of the service; recreation areas can be valued at least by what visitors are willing to pay to travel to it, including the imputed value of their time (e.g., tourists visiting national parks). **Hedonic Pricing:** The change in property value by virtue of being within proximity of a service (e.g., a beautiful grassland or river view). **Contingent Valuation:** Value estimates based on survey methods (e.g., people's willingness to pay to protect watersheds).
Are marginal values better than total values for answering conservation questions?	Suppose you have $10. If you consider a marginal value of an investment, it answers questions like: how can I get the biggest bang for the buck in spending each of my ten dollars? The total asset value is about answering questions like: is this asset this worth a $10 investment? A $10 million investment? A $10 billion investment?
What questions do marginal values and total values answer?	The biggest problem in most conservation programs is not really 'how can I spend my limited $10?' but 'how do I get funding at the scale to solve the problem?'. Most watersheds just don't have the money to do what they know would pay off (Marginal Benefits > Marginal Costs). That is an asset and/or investment scale problem, not a marginal benefit and cost problem. Giving nature zero asset value is just one reason contributing to underinvestment in conservation. Marginal values are also important, but don't answer all important economic questions.

How can we put a value to nature when many consider it priceless?	Considering something as priceless generally has one of two possible outcomes: an extremely high value, or, as in traditional economic analyses of nature's benefits, a value of zero. Because the latter outcome has generally prevailed and was often the default value in decision making, the ability of many ecosystems to continue to provide these benefits has deteriorated because of development and pollution. Pricelessness may not be a practical value when it comes to decisions about development and natural resource extraction. On the other hand, like a human life, the watershed is priceless and this perspective is worthy of further exploration through the use of ecosystem valuation techniques. Ecosystem services can be measured just as the value of peoples' work can be measured in economic measures, such as a paycheck.
Discounting	
What are the most common uses of discount rates?	Discount rates are most often used in Benefit-Cost and Return on Investment analyses where costs and benefits occur over time. They are also used in calculated asset values, which provide a measure of the expected net benefits flowing from capital over time and are often calculated using the net present value formula.
What is the purpose of a discount rate?	Discounting allows for sums of money occurring in different time periods to be compared by expressing the values in present terms. In other words, discounting shows how much future sums of money are worth today.
Why may a lower discount rate be more appropriate for environmental project/decisions?	Constant discounting works against solutions to long-term environmental problems, or projects whose benefits mainly occur far into the future. For example, projects addressing climate change, biodiversity loss, and nuclear waste need to be evaluated over a time horizon of several hundred years. If evaluated under constant discounting, these projects will have heavily discounted benefits, which occur far into the future. In comparison, costs are largely borne in the near-term and will not be discounted as heavily. Under standard market interest rates, such as 7%, it is almost never worth conducting any project that will have an influence in hundreds of years' time, even though decision makers still have these considerations to make.
Using ESVs	
Who can use Earth Economics' studies?	Earth Economics' studies can be used by land managers, local government agencies including cities, counties, water agencies, transportation commissions and special purpose districts to assist with strategic planning and natural resource management through an integrated investment approach that includes natural systems. Findings can also be used to secure state and federal funding for projects and programs that support key aspects of the local and regional economy, including jobs, health and quality of life that attracts and retains business interests. Beyond the public sector, this work can be used to communicate impacts to private investors, as well.
How can an ESV be used to develop funding mechanisms?	Identification, valuation, and mapping of ecosystem services is used to develop sustainable, fair, and efficient funding mechanisms for maintenance and restoration of natural capital, linking (often upstream) ecosystem service provisioners with (often downstream) ecosystem service users. Funding mechanisms can be developed based on the physical nature of the ecosystem service, and can include tax districts, payments for ecosystem services (PES), tradable credits, and fees and surcharges.

How can an ESV be used to justify investment?	The outcome of estimating ecosystem services is to provide a better valuation than the implicit value of zero – or infinity. Just as human life is priceless, so are ecosystems, yet we value the services that people provide to the economy. What is not valued is often lost, and the advantage of a valued asset is that a sufficient budget for its operations and maintenance can be justified. A valuation of a natural asset may also enable or facilitate borrowing against the asset.
How can ecosystem service analysis inform state/local legislation?	The realization of ecosystem service value is the first step to inform policy makers of the inherent value of their governing land. Once this message is conveyed to decision makers, key opportunities to directly inform policy can follow. Local, state, and federal law were enacted on ethical, economic, and scientific knowledge based on historic thought. Ecosystem service analysis has only come to light in recent decades but can begin to inform our current policies.

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