APPENDIX B

Value of WHI Ecosystem Services

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B.1 INTRODUCTION

Ecological systems perform a variety of chemical, physical, and biological functions. These functions include provision of wildlife habitat, energy and nutrient cycling, sediment retention, water storage, water filtration, and waste decomposition. Society and our economic system depend on these ecological functions, and derive benefit from the natural resources and processes supplied by ecosystems. These benefits are typically referred to as ecosystem services.[1] This appendix evaluates the economic value of the ecosystem services provided by WHI natural areas. The appendix focuses on the current value of the primary ecosystem services provided on WHI, but also explores the potential change in ecosystem services values based on restoration or development.

The economic approach to valuation of ecosystem services is entirely anthropocentric; services are defined as those products or features of ecosystem function that are valued by individuals and society. While this report focuses on the economic valuation of ecosystem services, it is important to acknowledge that non-anthropocentric values of ecosystems, including the intrinsic value of species and nature that is not related to human considerations, can also play an important role in environmental decision-making.

There are 10 sections to this appendix. The introduction in **Section B-1** includes an overview of ecosystem services and their benefits as well as a discussion of the methodology for their quantification and valuation. **Sections B-2 to B-6** focus on quantification and valuation of each of the WHI ecosystem services analyzed in this study: cultural services associated with habitat and species, air purification, climate regulation, water purification, and flood regulation. **Section B-7** and **Section B-8** discuss potential changes to ecosystem services from restoration and development, respectively. **Section B-9** summarizes the valuation findings, while **Section B-10** provides the study references.

B.1.1 Overview of Ecosystem Services and Benefits

Economic value encompasses a broad range of benefits. Economic values include market-derived values such as commercial benefits as well as non-market values (values not established in a marketplace) such as recreation, aesthetic, cultural, and spiritual benefits. This section describes the types of ecosystem services as well as the types of values that are derived from them.

Ecosystem services are commonly defined as the benefits that people derive from natural ecosystems. The Millennium Ecosystem Assessment conducted by the United Nations defined four types of ecosystem services.[2]

- *Provisioning Services* or the provision of food, fresh water, fuel, fiber, pharmaceuticals, and other goods;
- *Regulating Services* such as climate, water, soil, and disease regulation as well as pollination;
- *Supporting Services* such as soil formation, primary plant production, and nutrient cycling; and

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1 *Ecosystem structure* refers to both the composition of the ecosystem (i.e., its various parts) and the physical and biological organization defining how those parts are organized. A leopard frog or a marsh plant such as a cattail, for example, would be considered a component of an aquatic ecosystem and hence part of its structure. *Ecosystem function* describes a process that takes place in an ecosystem as a result of the interactions of the plants, animals, and other organisms in the ecosystem with each other or their environment. Primary production (the process of converting inorganic compounds into organic compounds by plants, algae, and chemoautotrophs) is an example of an ecosystem function. Ecosystem structure and function provide various *ecosystem goods* and *services* of value to humans such as fish for recreational or commercial use, clean water to swim in or drink, and various esthetic qualities (e.g., pristine mountain streams or wilderness areas). From: Valuing Ecosystem Services: Toward Better Environmental Decision-Making (2004): Water Science and Technology Board (WSTB).

2 Millennium Ecosystem Assessment, 2005. Ecosystems and Human Well-being: Synthesis. Island Press, Washington, DC. Copyright © 2005 World Resources Institute

- *Cultural Services* such as educational, aesthetic, scientific, and cultural heritage values as well as recreation and tourism.

Of the broad array of ecosystem services provided by natural resources, this analysis focuses on five primary services provided by WHI. Four of these are regulating services: water purification, air purification, flood control, and climate regulation (carbon sequestration). The other broad category of services analyzed are cultural services related to habitat preservation, including the educational, aesthetic, recreation, and cultural value associated with the use and preservation of habitat and biodiversity. As the economic valuation of cultural services often overlaps, these services are assessed together as the direct value of habitat and biodiversity preservation. Provisioning and supporting services are not valued in this analysis. There are little to no direct provisioning services provided by WHI, as with potentially minor exceptions it is not a source of food, fuel, drinking water, or other natural resource goods.[3] Additionally, supporting services are not evaluated directly as these are the foundation for all other services, and in general the benefits from supporting services, like soil formation, accrue over a long period of time making their valuation difficult to compare to the other categories of benefits.[4] Finally, this analysis recognizes that additional regulating services may be supplied by WHI, including pollination and erosion control, but these services are expected to be relatively small and are excluded from the analysis.

B.1.2 Methodology to Value Ecosystem Services

Valuing ecosystem services requires several steps, each of which can be challenging. **Figure B-1** displays the process to assess ecosystem function and ultimately value the ecosystem service. First, the ecosystem under study must be assessed for structure (i.e. vegetation structure, species diversity, and non-living components such as rocks and sediments), and associated ecological function (i.e. nutrient cycling, energy cycling, sediment retention, water storage, waste decomposition, etc). Once the level of ecological functioning is understood, it is necessary to establish the link between the function of an ecosystem, and the ecosystem services that will be provided to people. This link is often referred to as the "ecological production function" and defines the level of services provided for a given level of function in the ecosystem. This ecological production function is often difficult to specify, as it requires not only determining the level of function in an ecosystem but also defining how function translates into services. Finally, valuation requires estimating the economic benefits to society of the ecosystem services. There is also a feedback mechanism, as the value of the ecosystem services provided by an ecosystem partly determines society's treatment of the ecosystem, which then affects the structure and function of that ecosystem.

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3 While there are fish caught in the Columbia River and elsewhere that likely use WHI aquatic habitat, it is not known how or whether WHI habitats increase the total catch in either commercial or recreational fisheries.

4 Millennium Ecosystem Assessment, 2005. Ecosystems and Human Well-being: Synthesis. Island Press, Washington, DC. Copyright © 2005 World Resources Institute

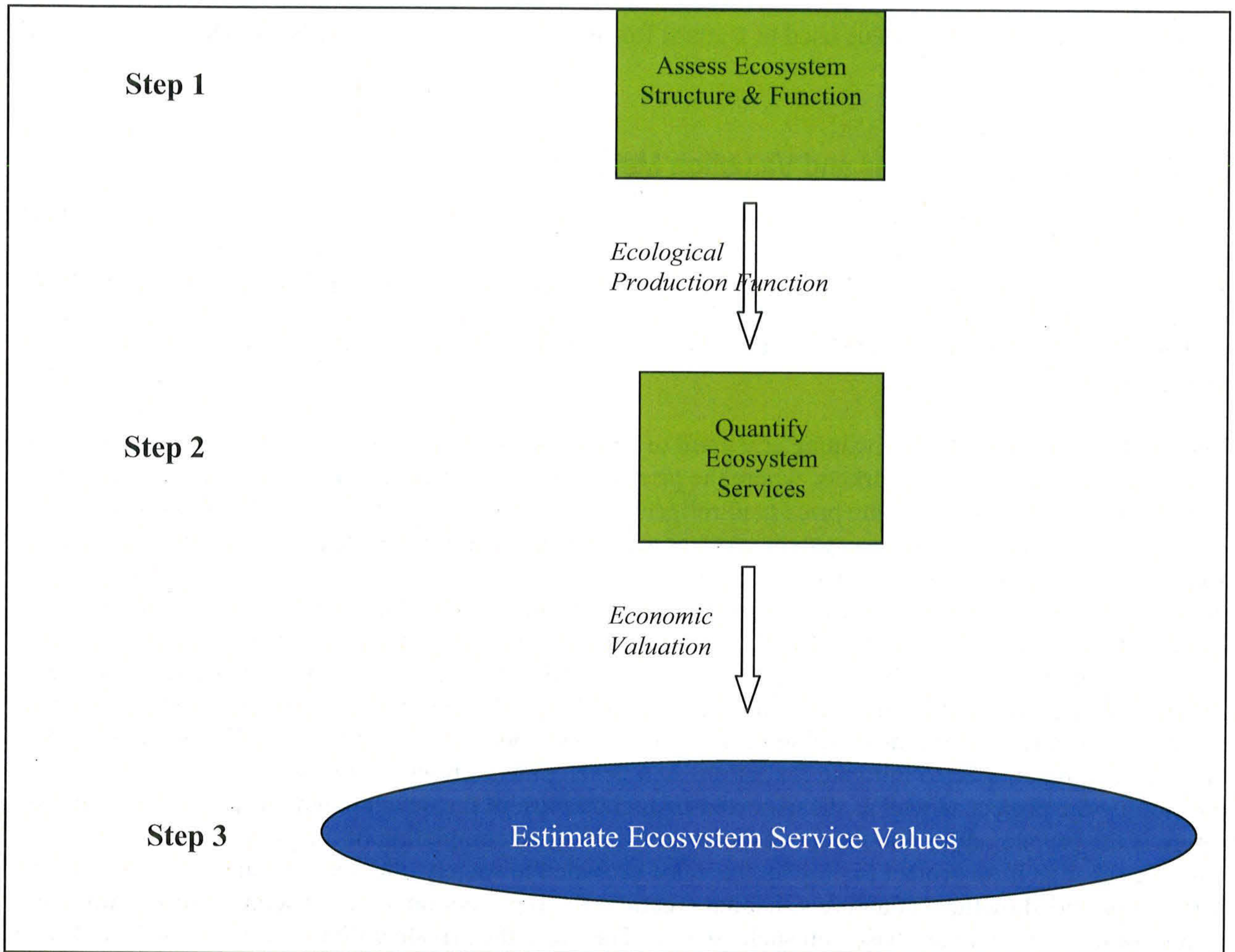

Figure B-1 Steps in Ecosystem Service Valuation

B.1.2.1 Ecosystem Function and Service Estimation

Ecosystem structure and function were evaluated in the Natural Resource Conditions technical memorandum, and were further evaluated in this analysis to estimate ecosystem service flows. Quantitative analysis of service flows was feasible for some services, such as air purification, flood regulation, and climate regulation (carbon sequestration), based on existing models and data. Quantification of other services, such as water purification, was not feasible as the function of water regulation is very site-specific and there is no known, available water purification data for WHI or similar wetlands on the Columbia River. Estimation of the economic value is thus less certain for water purification. The function of habitat provision is quantifiable based on acreage of habitat on WHI, but existing data is not adequate to quantify the associated function of biodiversity maintenance in terms of species populations (e.g. how much does WHI shallow water habitat enhance salmon populations) or biodiversity in the region (e.g. does WHI grassland habitat affect the number of bird species in the region). Therefore, to estimate the value of habitat and biodiversity, the analysis focuses on species benefits provided per acre of habitat, rather than values directly based on populations of specific species (e.g. there is not a calculation based on value per individual of a species and the number of individuals of that species that exist due to WHI habitat). The methodology used in this analysis instead focuses on estimates of value that include the co-extensive, and rather inseparable benefits of habitats and associated species. Results represent the total value of species and their natural habitats. This methodology is consistent with estimates of value used in Natural Resource Damage Assessments (NRDA) and other frameworks.

B.1.2.2 Economic Values and Valuation Methods

Various economic valuation methods used to value ecosystem service benefits are described below. They include market value, as well as non-market valuation techniques such as replacement costs, avoided costs, travel costs, contingent valuation, and hedonic pricing. Additionally, the benefits transfer method is described, which provides guidelines for transferring estimates found in one study to another context, such as WHI. The section concludes with an overview of the types of economic values that ecosystem services provide.

The most prevalent method of valuing any good or service is to use the market price. Commercial goods typically have well-defined markets, where the price of a good is dependent on the demand for the good and the amount supplied, and the price paid reflects the consumer value for that good (absent market distortions). However, many ecosystem services are not traded, and therefore do not have a monetary value determined in the marketplace. For those ecosystem services that do have market values, such as carbon (via purchase and sale of carbon offsets) and wetlands (via development of wetland mitigation banks), those market values are provided. The market price for an ecosystem service, seldom represents the total economic value of the ecosystem service. Generally the market price of an ecosystem service represents the private value and not the public value of the service provided. Therefore a market price should be considered a minimum value for an ecosystem service. For example the willingness to pay for an acre of wetland, used to mitigate for actions of a development project, is tied closely to the cost of developing the project as well as the expected financial return of the development project. The expected return is the private return that the developer would earn upon completion of the project. While these variables change from project to project, the value provided to society, the public value, for the ecosystem services provided by the wetland (e.g. habitat creation, flood protection, nutrient sequestration, nitrogen sequestration) will not vary based on such factors. Therefore the private willingness to pay is an indicator but not a measure of total societal value.

Non-market valuation methods used to derive use values include replacement costs, avoidance costs, travel cost, and contingent valuation. The replacement cost and avoidance cost methods are related techniques which value non-market goods and services based on the costs of equivalent replacement resources (such as engineering water purification) or the costs of impacts avoided (such as flood damage) due to the resource. An example of replacement costs methods would be to consider a forest that provides water purification services to a downstream community. Using the replacement costs method to value the forest sets a minimum ecosystem service value of the forest equal to the costs of providing the same water purification services through such means as building a water treatment facility or constructed wetlands.

The travel cost method is most commonly used to estimate the value of outdoor recreation such as boating, hunting, fishing, and wildlife viewing. This method uses the cost of recreational activities as a proxy for the minimum value of the experience. In other words, the cost of gas, lodging, food, user fees, and other expenditures for a fishing trip or other recreational outing constitutes the "price" of the experience for the recreationist, and therefore the experience, and therefore the ecosystem service, must be at least valued at that price.

Contingent valuation utilizes surveys to elicit people's willingness-to-pay to preserve use of (or the existence of) a resource, or alternatively willingness-to-accept compensation to forfeit the use or existence of a resource. This method is used to estimate non-use values, as these values are typically not possible to estimate through other methods.

Another technique, the hedonic property value method, analyzes property values based on a variety of characteristics including environmental attributes. The approach considers all properties within an area, and employs regression analysis to isolate the degree of price difference that is attributable to individual property characteristics such as environmental amenities. This technique has been used extensively to estimate the value of open space for residential areas based on the extent that property values increase in locations near green infrastructure and open space.

A final, but very important method for use in this study is the benefits transfer technique. This technique was developed for decision-makers who do not have the time or the resources to conduct a comprehensive non-market valuation study. The benefits transfer method is a widely accepted method that estimates economic value by transferring available information from studies already completed in another location and/or context. Benefit transfer can only be as accurate as the initial study, and several criteria must be met to ensure the suitability of transferring a value from one context to another. Often, many caveats are associated with applying benefits-transfer methodology in a formal analysis.

The ecosystem services provided on WHI require different valuation techniques based on the types of benefits or values they provide. One important distinction is between use benefits that are generally associated with people's use of ecosystem services, and non-use (or passive use) benefits that do not require present use and, instead, are derived through the knowledge that the services exist and are protected. Within the use and nonuse benefit categories, there are further subcategories. Subcategories of use benefits include direct, indirect, and option values, while non-use benefits include existence and bequest values. These values are described in **Table B-1**.

Table B-1 Categories of Use and Non-Use Values

Value Type	Source	Example
Use Value		
Direct Use Value (Provisioning and Cultural Services)	Derived from the consumptive and/or non-consumptive direct uses of ecosystem services	Timber harvesting Fishing Water sports Bird-watching
Indirect Use Value (Provisioning, Regulating, and Supporting Services)	Ecosystem services used as intermediate inputs for production of final goods and services to humans[a]	Water purification Flood prevention Pollination Waste assimilation
Option Value (Cultural Services)	Derived from the preservation of the option for future use of ecosystem services	Retaining the future option to either build a dam or continue preserving the resource
Non-Use Value		
Non-Use Bequest Value (Cultural Service)	Derived from the knowledge that a future generation will be able to enjoy the benefits of a natural resource.	Endangered Species Protection Prevention of Irreversible Change
Non-Use Existence Value (Cultural Services)	Derived from the knowledge that a natural resource exists, separate from any use of the resource.	Endangered Species Protection Natural Area Protection

[a] As defined in the Millennium Ecosystem Assessment (2005).

B.1.2.3 General Determinants of Value

The magnitude of ecosystem service values provided by a given natural area depend on a number of factors. Several of these factors are discussed below, including location of the natural area, the relative abundance or rarity of the resources in the natural area, and also the temporal and cultural context. These are important considerations when applying results from one study to the WHI context through benefits transfer methods.

Location

The level of ecosystem service provided by a resource and its associated value differs by location. First, the level of service provided by the same resource can differ based on location-specific structural and physical attributes. Second, the value of the ecosystem service also typically differs by location, depending on the human activity and population in the area. Take for example, the service of soil retention or erosion control. Riparian vegetation will retain more soil in areas with steep slopes than in areas with gentle slopes. Likewise, the economic value of this erosion control service will depend on location. On river banks with housing or other economic assets, the retention and stabilization of soil may be highly valued. In other areas, erosion control may have very little economic significance.

As another example, the water purification service of a wetland can have very different values depending on the location of the wetland. If a wetland captures polluted runoff and improves the quality of water entering a river that is often used for recreation or drinking water, then the water purification service of the wetland may have significant economic value. This potentially high value stems from the enhanced opportunity to provide water regulation functions due to concentrated pollutants in the runoff, and from the nearby presence of a water body in which water quality has particular economic value. In contrast, a wetland located in a natural area that is not exposed to polluted runoff (and thus will not remove the same level of pollutants) and is not adjacent to a water body of economic concern, would have lower water purification value.

Abundance

Similar to most economic goods and services, the value of an ecosystem service usually depends on its abundance. If a good or service is very abundant, the value of each unit is typically less than the value would be if the good or service is relatively scarce. This idea of scarcity is related to the concept of *marginal* value of a good or service, or the value of one more unit, compared to the *average* value. Typically, the more we have of a good or service, the less we value each additional unit. Consider the value of water use in the home. The value of the first few gallons used for drinking and basic cleaning activities is very high, while the marginal value of the last gallon consumed for watering the lawn or washing the car has much lower value. This pattern of declining marginal value is often applicable for both use and non-use values. For example, the recreation use value of a particular natural area is lower if there are many substitute natural areas nearby. Likewise, people tend to hold higher non-use existence values for conservation of endangered species than conservation of species that are not threatened.

Temporal and Cultural Context

Economic value is estimated based on the preferences of individuals, with total societal value being the aggregation of individual values. As individual preferences and willingness to trade one good or service for another can change through time and also can vary by culture, value is defined relative to a particular time and place. For example, in earlier centuries, American attitudes and perceptions of natural habitat and wildlife species were quite different than they are now. This is a reflection not only of the change in abundance of habitat, but also a changing perception and awareness by the public of the benefits of these natural systems. In addition to the temporal context, cultural differences also play a role in the value placed by individuals on different ecological goods and services. For example, due to the cultural value of salmon in the Pacific Northwest, the existence value of salmon (separate from any fishing or viewing use) is likely higher for a resident of the Pacific Northwest than for a resident of other areas of the country.

B.2 CULTURAL SERVICES (HABITAT & SPECIES)

Wildlife habitat provides species with shelter, food, and protection from predators. Many fish and wildlife species rely on WHI as a migration corridor and as an area for nesting, breeding, foraging, and rearing young. In addition to their ecological value, wildlife habitats also have economic value. People value habitat both for its own sake, and also for its value in sustaining biodiversity and producing wildlife. The importance to people of wildlife habitat and associated species is evident in the local, state, and federal regulations protecting species and habitat; the voluntary contributions of individuals to organizations that restore and conserve habitats; and the time and expenditures invested by people to visit wildlife habitat areas to recreate. This section first describes the wildlife habitats and associated species on WHI (**Section B-2.1**), then discusses the values from the economic literature and other sources describing these habitats and associated species (**Section B-2.2**), and concludes by providing estimate of the economic value of habitat and species on WHI (**Section B-2.3**).

B.2.1 Wildlife Habitats and Species on WHI

Habitat types associated with WHI include terrestrial and aquatic (wetland) habitats on the island as well as aquatic riverine habitats in the adjacent Columbia River. WHI habitats cover approximately 787 acres, while the shallow water habitat surrounding the island is 240 acres (defined as areas up to -21 feet to +9.5 feet NAVD88 vertical datum). The environmental foundation study for WHI has identified seven habitat types: shallow water habitat (SWH), upper beach (UBC), riparian fringe (RIP), forest/woodland (FW), wetland (WET), grassland/herbaceous (GRA), and shrubland (SHR). RIP is classified as a habitat type even though the vegetation communities which comprise it are also habitat types. RIP is defined as the zone within 150-feet of the Columbia River or a wetland, and is the area that predominantly provides riparian function and influences adjacent aquatic habitat.

The acreage in each habitat type is presented in **Table B-2**. Nearly half (414 acres) of WHI habitat is FW (of which 158 acres is located within the riparian fringe). The RIP is the second most abundant area, with 260 acres. The RIP is predominantly FW (60 percent), with some GRA (26 percent) and SHR (11 percent). SWH is also an extensive habitat type, with 240 acres of this habitat surrounding the shorelines of WHI.

Table B-2 West Hayden Island Habitat Acreage

Habitat	Acres
Shallow Water	240
Upper Beach	28
Wetland	59
Forest/woodland	415
Grassland/herbaceous (Dredge Material Storage Area)	227 (101)
Shrubland ((acres outside of Riparian Fringe)	76
TOTAL (not including duplicative Riparian Fringe area)	1,045

1. This criteria was used to capture unclassified or covers not used in forming habitats such as developed area, roads, facility.
* Includes acreage of this vegetation community found in Riparian Fringe

At least 39 species of resident and anadromous fish, including 20 native species, have been documented in the lower Willamette River.[5] Most of these species, if not all, have a reasonable chance of occurring in

[5] Farr, Ruth A. and David L. Ward. 1993. Fishes of the Lower Willamette River, Near Portland Oregon. Oregon Department of Fish and Wildlife, Research and Development.

the WHI area. Many migratory birds nesting on or near WHI also forage in the open water and nearshore habitats. These include piscivorous bird species such as bald eagle, osprey, double-crested cormorant, great blue heron, belted kingfisher, common and hooded mergansers, and other waterfowl. WHI riparian fringe, upper beach, and shallow water habitats and their associated vegetation communities are suitable for passerines and aquatic-associated birds. Cliff swallows, various waterbirds, and shorebirds such as spotted sandpiper utilize the beach/intertidal area for nesting and foraging.

Mammals including mink and river otter use the riparian and upper beach as foraging corridors as well as shallow water habitats, and are known to rear young along the shorelines well. Northern red-legged frogs and Pacific tree frogs occur on WHI, and long-toed salamanders are expected to be present, although comprehensive amphibian surveys have not been conducted. The nearshore habitats, low water velocity areas, shoreline embayments, and ponds (particularly those that contain vegetative or woody structure) are important breeding and foraging areas for these amphibian species. Western painted turtles and northwestern pond turtles use the lower Columbia River corridor, in particular bottomland habitat, seasonal wetlands, and slow flow, low energy habitats such as ponds and sloughs. Table B-3 provides an overview of species-habitat associations on WHI. The table is not intended to be comprehensive since many other species may use the island for various seasons and lengths of time.

Table B-3 Species-Habitat Associations on WHI

Species	HABITAT TYPE USE						
	SHW	UBC	RIP	WET	FOR	SHR	GRA
FISH							
White crappie, black crappie, smallmouth bass, largemouth bass, bluegill, pumpkinseed, yellow perch, Northern pikeminnow, peamouth, largescale sucker, walleye Oregon chub, green sturgeon, white sturgeon, lamprey, coho, chum, Columbia River bull trout, cutthroat trout	X	X	X	X			
Listed: Snake River (SR) sockeye, SR Spring/Summer Chinook, SR Fall chinook, SR steelhead, Upper Columbia River (UCR) Steelhead , UCR Spring Chinook, Lower Columbia River (LCR) steelhead, LCR Chinook, Columbia River chum, Middle Columbia River steelhead, Upper Willamette River (UWR) Steelhead, UWR Chinook	X	X	X				
MAMMALS							
Raccoon, coyote, mole, brush rabbit			X	X	X	X	X
Listed: Columbia White-tailed deer						X	X
BIRDS							
Resident birds: dark-eyed junco, song sparrow, American robin, black-capped chickadee, and red-breasted nuthatch, warbler sp., tricolored blackbird, olive-sided flycatcher, little willow flycatcher; Overwintering: fox sparrow, white throated sparrow; Nesting and Foraging: pileated woodpecker, black-capped chickadee, swallow sp.;			X	X	X	X	X
Raptors, Hawks and Owls: osprey, northern harrier, bald eagle, hawks (up to 6 species), owls (up to 6 species)			X	X	X	X	X
Waterfowl: mallard, sea ducks, brant, wood duck, cinnamon teal, canvasback, Canada goose, Ross's goose, double-breasted cormorant	X	X		X			
Loons, grebes, herons, egrets and bitterns	X	X	X				
Listed: Aleutian Canada goose (potential use), bald eagle				X		X	X
AMPHIBIANS AND REPTILES							
Oregon Spotted frog, Northern Red-legged frog, Northwestern pond turtle, painted turtle, Pacific chorus frog, long-toed salamander, garter snakes	X	X	X	X	X		
INVERTEBRATES							
Lepidoptera (butterfly) sp., Heterocera (moth sp.), cabbage white, satyr angelwing, painted			X	X	X	X	

Species	HABITAT TYPE USE						
	SHW	UBC	RIP	WET	FOR	SHR	GRA
lady, mylitta crescent, spring azure							
BENTHIC COMMUNITY							
Nematode, oligochetes, bivalves, stone fly, caddis fly, mayfly, isopods, amphipods	X	X					
MACROINVERTEBRATES							
Mayflies, dragonflies, damselflies, Daphnia, scud, water beetles, water boatman, midges, fairy shrimp, water striders	X		X	X	X		
PLANTS							
Listed: Howellia, Willamette daisy, Bradshaw's lomatium, golden paintbrush, Kincaid's lupine, Nelson's checkermallow			X	X	X	X	X

Sources: Port of Portland 1995 (based on probable use/potential use drawing from Puget Island sub-population), ODFW species distribution descriptions

B.2.2 Economic Value of Habitat and Species

People value habitat for multiple reasons, including the benefit they derive from the habitat area itself (habitat value) and the value of the species associated with the habitat (species value). Benefits are derived through direction interaction with habitat and species resources (use values), but can also be derived separate from any interaction with the resource (non-use). Adding use and non-use values together provides an estimate of total economic value of a resource.

Use values stem from use of the habitat (e.g. hiking, walking, viewing) or use of the wildlife (e.g. fishing, wildlife viewing, hunting). Recreation is only one component of species and habitat use values (education, scientific, and aesthetic values are also use values), but it is recognized as a substantial component of use values and has been the most widely studied. Due to the availability of literature on recreation use, it is the primary use value provided in this study.

Many individuals also value habitats and species separate from any use. Non-use values include the benefits people derive solely from the knowledge that habits exist (existence value), both for the habitat itself and for its provision of species' needs. Existence values are generally higher for rare habitats or species, (such as those classified as Threatened or Endangered) due to their relative scarcity, than for abundant species or habitats. Additionally, existence values are also higher for iconic species, such as the bald eagle or salmon, as well as for ecosystems that have received public attention and been the focus of public education, such as old-growth forest. A second type of non-use value is the benefit people derive from the existence of a species or habitat for future generations. The bequest value is less studied in the literature, and as such, it is not examined in the WHI context. The non-use value (including both existence and bequest value) of habitat is generally measured in people's willingness-to-pay to protect habitat. Often this value is elicited or asked directly though household surveys. The non-use value elicited from a particular individual may be related to a habitat's ability to provide for a specific species such as Coho salmon or the general function of the habitat itself.

To value WHI habitat and biodiversity, this study focused on the use and non-use values associated with WHI habitat types. As noted in **Section B-1**, it is unknown to what degree WHI habitat increases the population of a particular species or the biodiversity of the region. Therefore, there is too much uncertainty to apply estimates of value to WHI based on species population enhancements or regional increased biodiversity. A few studies of the use and non-use values of population increases are presented here for context, but are not used to estimate the economic value of WHI habitats.

In addition examining the use and non-use values of habitat from the literature, this study examines the replacement cost of habitat based on habitat restoration costs, as well as the market value of habitats for which mitigation banks exist (wetlands). The market value and replacement cost valuation techniques are not true measures of the economic habitat, but do indicate at least the minimum level that organizations are willing to pay for habitat restoration and preservation. After examining the data from each of these three methods, the value of habitat and associated biodiversity on WHI is estimated (see **Section B-2.3**). In order to compare studies, all figures have been converted into 2010 dollars using the Consumer Price Index.[6]

As the available literature varies by habitat type, the analysis is able to quantify benefits associated with wetlands, forest, and shallow water habitat with very little quantification feasible for the remaining habitat types. This does not indicate that these habitats have less value, but that they are not yet studied to the same extent. The section provides a review of the available economic literature and alternative indicators of value, and finds that the habitat value for wetlands and stream restoration in particular are consistent across the economic literature and alternative indicators (mitigation market value and habitat replacement costs). **As summarized in Section B-2.3, the total habitat value associated with wetlands, forest, shallow water habitat, and upper beach habitat is estimate to range from $550,000 to $4.5 million.**

B.2.2.1 Values from the Literature

Use Value

The use values of terrestrial habitat on WHI are limited as the beaches are the only authorized use areas for the public, and most of the area is isolated from commercial and residential areas. The lack of access and facilities limits the recreational value of the island, while the limited visibility of terrestrial habitat areas from off the island also limits the aesthetic value of the island. Aesthetic values of natural habitat areas can be quite substantial, and are often measured based on increases in residential property values. However, the relative inaccessibility of WHI and its separation from roads and residential areas limits the impact of WHI natural areas on aesthetics values. In particular, impacts to property values are expected to be minor as numerous studies have found that most impacts are concentrated within a one-half mile to at most one mile of an open space area.[7] There may be aesthetic values of WHI habitats to boaters on the Columbia River who view the island; this aesthetic value may be enhanced because of the surrounding industrial area, or it may be diminished.

Regarding recreation use values, the only direct use of terrestrial habitats is beach use. As presented in **Table B-4**, the per-person per day value of beach use is estimated at $45 per day. It is not known how many boaters access WHI beaches annually. However, if we assume that it is in the range of approximately 250 to 1,000 people annually (assuming 10 to 40 people visit WHI beaches weekly from May through October), then **the annual value of beach recreation on WHI may reasonably be expected to be in the range of $11,000 to $45,000.** In addition to the value of recreation on beaches, there may be indirect recreation value of WHI terrestrial habitats. This indirect value is associated with any recreation benefits derived from wildlife viewing or hunting of species at other natural areas that utilize WHI habitats. For example, a migratory bird that relies on WHI habitat for part of the year may be viewed or hunted elsewhere in Washington or Oregon. Since the wildlife viewer/hunter indirectly benefits from WHI habitat utilized by the migratory bird, some portion of their use value is attributable to WHI. While the proportion of per day recreation value at other natural areas that is attributable to WHI habitat is unknown, it is likely to be small and is not estimated in this study. The per day value of beach

6 CPI Inflation Calculator, Bureau of Labor Statistics, accessed at http://www.bls.gov/data/inflation_calculator.htm

7 Crompton, John, 2005, "The impacts of parks on property values: empirical evidence from the past two decades in the United States", *Managing Leisure*, (10): 203-218.

recreation and wildlife hunting and viewing presented in **Table B-4** are based on 40 studies of the net value of recreational activities in Oregon and Washington compiled by Loomis, et al.[8]

In terms of aquatic use values, WHI has 240 acres of shallow water habitat for fish and other aquatic species. While not quantifiable for this study, WHI habitat contributes to the provision of these species that benefit both recreational and commercial fishermen. Recreational angling in particular is a popular activity in the Columbia River, with average per day use value estimated at $48 (based on daily fishing values in Washington and Oregon from Loomis. Habitat that improves fish populations can have substantial recreation value. For example, one study has estimated that an increase in salmon catch rate of one fish in Oregon or Washington, yields an angler between $31 and $136 in economic benefits.[9]

Table B-4 Use Value by Recreation Activity

	Use Value per Person per Day	Annual Value from WHI
Going to the Beach	$45	$11,000 - $45,000
Hunting	$41	Not Quantified
Wildlife Viewing	$40	Not Quantified
Fishing	$48	Not Quantified

Source: Loomis, 2005

The recreational value of each additional fish caught is significantly higher than the commercial value of each fish. While the contribution of WHI shallow water habitats to the commercial fishery is expected to be quite small, the market value of commercial fish is useful as it represents the economic value of each fish species as a consumer commodity, whether for anglers or for fishermen. The market price presented in **Table B-5** is the ex-vessel price, which is the price paid to the net harvester or tender.[10] In 2009, over 28 million pounds of salmon were purchased from ports within Oregon and Washington.[11] The average ex-vessel price per pound by species is presented in **Table B-5** with the total pounds caught in 2009. Assuming an average fish is approximately 15 pounds, the per-fish value ranges from $2 to $26, with four out of six species falling in the range of $10 to $20 per fish. As stated above, these values are not applied to WHI as it is not known how WHI habitat affects populations and associated catch rates. Therefore, the function of WHI habitat as it relates to increasing fish consumption (provisioning service) is not estimates in this study.

8 Loomis, John, 2005, 'Updated Outdoor Recreation Use Values on National Forest and Other Public Lands,' General Technical Report PNW-GTR-658.

9 Freeman III, A. Myrick, 1995, "The Benefits of Water Quality Improvements for Marine Recreation: A Review of the Empirical Evidence, Marine Resource Economics, Vol.. 10, pp. 385-406.

10 Independent Economic Analysis Board, 2005, 'Economic Effects from Columbia River Basin Anadromous Salmonid Fish Production,' Document IEAB 2005-1.

11 Pacific Fisheries Information Network, 2010, 'ODF All Species Report: 2009 Commercial Landed Catch: Metric-tons, Revenue, and Price-per-pound,' and 'WDFW all Species Report: 2009 Commercial Landed Catch: Metric-tons, Revenue, and Price-per-pound,' accessed online at http://pacfin.psmfc.org/pacfin_pub/woc.php.

Table B-5 The Ex-vessel Catch in Oregon and Washington, 2009

Species	Total Catch (pounds)	Average Catch Price ($ per pound)	Value of 15 Pound Fish	Total Value of Catch
Chinook	572	$1.76	$26.40	$1,008
Coho	5,310,076	$1.25	$18.75	$6,632,285
Pink	17,083,621	$0.14	$2.10	$2,306,289
Sockeye	71,432	$1.29	$19.35	$92,111
Steelhead	367,743	$0.97	$14.55	$355,056
Chum	5,891,193	$0.72	$10.80	$4,241,659
Total	**28,724,636**			**$13,628,407**

Source: PacFIN, 2010

Non-Use Values

Previous studies have estimated the value of habitat, separate from any recreational or commercial use, through a review of current literature. Based on a comprehensive review of existing literature, Batker, et al 2008 examined the value of Puget Sound habitat as it relates to providing breeding and migration habitat for species.[12] This study finds that values can vary dramatically for a given habitat type. For example, **the existence value of wetland habitat ranges from $60 to $13,500 per acre, while the existence value of riparian forest habitat ranges from $290 to $540 per acre.** In another study, the value of salmon habitat is valued per stream mile, and indicates that for coho salmon habitat alone, **shallow water habitat is valued at approximately $1,800 to $10,000 per year.**

The value of salmon habitat to Oregonians is further revealed in a 2003 study of five rural Oregon and Washington communities (Bell et al., 2003). This study included a survey to elicit residents' willingness-to-pay for Coho habitat enhancement through a hypothetical tax increase. For each community, a high and low enhancement program was outlined specific to the Coho needs in the area. Depending on household income and enhancement program, the mean household willingness-to-pay for Coho enhancement in the three Oregon communities (Coos Bay, Tillamook Bay, and Yaquina Bay) ranged from $24 to $120 per year. The size of the restoration projects is not provided in the study, so the values are not converted to a per-acre or per stream mile basis. Additionally, this value may capture use values by residents as well, so may not be directly comparable to other estimates of non-use value.

Table B-6 Value of WHI Wildlife Habitat Per Acre Per Year by Habitat Type

Habitat Type	Low	High	Source
Riparian Forest	$290	$538	Batker et al., 2008
Wetland	$63	$13,480	Batker et al., 2008
Coho Salmon Habitat (Value per stream mile)	$1,821	$9,650	Knowler, et al., 2003

Although not easily applicable to WHI, species existence values provide another indication of the value to individuals of habitat conservation. In a 2009 study by Richardson and Loomis, the total economic value

[12] Batker D, Swedeen P, Costanza R, et al. 2008. A new view of the Puget Sound economy: the economic value of nature's services in the Puget Sound basin. Seattle, WA: *Earth Economics*.

of threatened and endangered species was estimated through a meta-analysis of over 30 studies estimating household willingness-to-pay per year for species conservation. The results measure total economic value of species conservation, including the associated use and non-use values. Findings from this study indicate that the average American household values bald eagle conservation at $42 annually, and salmon and steelhead conservation at $87 annually. These estimates represent the average economic value per household in the United States to conserve these species. If Oregonians and Washingtonians value species conservation similarly to the national average, then the 4.1 million households in Oregon and Washington[13] value bald eagle conservation at approximately $170.4 million annually and salmon/steelhead conservation at approximately $355.3 million annually. These are likely conservative estimates of value as Oregonians typically have a closer cultural connection to conservation of these species than residents of most other states.

B.2.2.2 Replacement Cost of Habitat

A minimum measure of society's willingness-to-pay (or value) for habitat is the cost expended by organizations to create, restore, or enhance habitat areas. Non-profit organizations such as The Nature Conservancy and the Lower Columbia River Estuary Partnership as well as government agencies are undertaking numerous restoration projects in the lower Columbia River area. Despite the number of projects, few organizations are prepared to share project costs, so information is limited. This is partly due to the fact that many organizations (public and private) receive matching funds for restoration projects, and these matching funds are often not accounted for in that organization's cost accounting for the project.[14] Furthermore, restoration projects are often conducted using volunteer or reduced rate labor and donated land. Due to these difficulties, the estimates of habitat restoration and enhancement projects presented in this study area are limited to 1) generalized constructed wetland costs, and 2) estimates from the Oregon Department of Fish and Wildlife (ODFW) for specific aquatic restoration projects.

The cost of each restoration or habitat creation project depends on site specific factors. For example, a constructed wetland may require excavation and earthwork, intense vegetation restoration, outlet structures, fencing, pilings, and pumps, while a different constructed wetland may only require stream reconnection. Thus the costs of the two projects will vary substantially. Additionally, many restoration projects include several habitat types, so the cost of wetland versus shallow water restoration is often not feasible to isolate. Based on these site and project-specific factors, the costs of the example restoration projects are not expected to represent the actual cost of replacing WHI habitat. Rather they are an indication of society's willingness to pay for aquatic habitats. As discussed below, constructed wetland restoration costs vary significantly based on the type of wetland and other factors, with expenditures typically ranging from $60,000 to $175,000 per acre. Stream restoration costs per kilometer of stream also indicate high value for shallow water fish habitat, as average restoration cost being expended per mile is $250,000.

Constructed Wetlands

The costs of constructing a wetland include land purchase, site investigation, design, materials, labor cost. The cost of a constructed wetlands project depends greatly on the type of wetland being constructed, with costs ranging from approximately $4,000 per acre to nearly $500,000 per acre depending on the existing conditions, slope, water currents, and plant requirements.[15] The cost of constructed wetlands conducted

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13 U.S. Census Bureau, 2008, 'Selected social characteristics in the United States 2006-2008, Oregon, Washington, accessed at www.census.gov.

14 Hass, Evan, Lower Columbia River Estuary Partnership. Personal communication with ENTRIX staff.

15 Brookhaven National Laboratory, 2001, 'Peconic River Remedial Alternatives: Wetlands Restoration/Constructed Wetlands Technology Fact Sheet,' accessed online at http://www.bnl.gov/erd/Peconic/factsheets.html.

throughout the county have been compiled by the EPA and other organizations. [16] **Table B-7** summarizes costs of constructed wetlands compiled by the EPA while **Table B-8** summarizes costs compiled in a 1998 study of mitigation projects undertaken across the United States.[17]

The EPA published a report summarizing the costs of 9 constructed wetland projects. The costs of these projects (converted to 2010 dollars) are summarized in **Table B-7**. As shown in the table, a free water surface wetland may cost less than 20 percent of the cost of a subsurface flow wetland (also referred to as a vegetated submerged bed). A free water surface wetlands contains aquatic plants rooted in a soil layer with water running through the plant leaves. The free water surface wetland most resembles a naturally occurring wetland. A subsurface flow wetland does not resemble a natural wetland in that they do not have standing water, but are instead designed with a bed of rock or soil planted with aquatic plants. The weighted average cost per acre of free water surface wetlands is estimated at approximately $38,000, while the weighted average cost of subsurface flow wetlands is estimated as $198,000. The presented projects analyzed indicate that the per acre cost of projects decreases as the size of the project increased.

Table B-8 presents average costs for specific wetland types constructed across the United States for wetland mitigation, with costs typically ranging from $60,000 to approximately $175,000 per acre. WHI includes several types of wetlands, including emergent and forested wetlands, which the data indicates have been constructed within this range of costs. Construction costs include the initial costs required to establish a wetland area, to make these up-front costs consistent with the annual values presented elsewhere in the study, construction costs were converted to annual values using a 5 percent discount rate and a 50 year time-horizon. **On an annualized basis, the cost to replace a wetland similar to WHI wetlands is estimated at approximately $3,000 to $10,000 per acre per year (based on a five percent discount rate).** This annual value is based on the range of per acre construction costs of $60,000 to $175,000 per acre.

16 Imus, William , 2003, 'Wetland and River Restoration Costs, Yesterday and Today,' Presented at the 2003 Headwaters to Ocean Conference, available online at http://coastalconference.org/h20_2003/pdf/C-Sessions/F3C/Imus_H2O%20Conference.Session%203C.pdf. Natural Systems International, 2010, 'Constructed Wetlands,' accessed at http://www.natsys-inc.com/resources/about-constructed-wetlands/. US Environmental Protection Agency, 1999, 'Wetlands Fact Sheet,' as reported in B.F. Environmental 'Structural BMP Criteria,' accessed at http://www.bfenvironmental.com/pdfs/ConstrWetlands.pdf. Miller, Brian, Brian MacGowan, Richard Reaves, Perdue University, Forestry and Natural Resources, 2003, 'Are Constructed Wetlands a Viable Option for Your Waste Management System?' FNR-202-W. Phillips, Veronika, 1997, 'Restoratoin and Reclamation Review,' Vol. 2, Nov. 4. and Hawkins Julie, 2008, 'Constructed Treatment Wetlands,' USDA-NRCS, accessed at http://www.sera17.ext.vt.edu/Documents/BMP_Constructed_Treatment_Wetlands.pdf.

17 King, Dennis, 1998, 'The Dollar Value of Wetlands: Trap Set, Bait Taken, Don't Swallow,' National Wetlands Newsletter vol.20, no.4.

Table B-7 Comparable Costs of Nine Constructed Wetland Projects (2010$)

Location	Area (acres)	Cost ($ per acre)
Free Water Surface Wetlands		
Arcata, CA	7.4	$55,971
Gustine, CA	24.2	$67,330
Ouray, CO	2.2	$71,446
W.J.C. MS	49.9	$18,877
Weighted Average Cost per Acre		**$37,562**
Subsurface Flow Wetland		
Carville, LA	8.4	$288,855
Mandeville, LA	84.5	$176,584
Mesquite, NV	22.5	$180,150
Sorrento, LA	2.8	$686,909
Ten Stones, VT	0.4	$491,998
Weighted Average Cost per Acre		**$198,384**

Source: EPA, 1999
Note: All figures converted to 2010 dollars using the CPI.

Table B-8 Wetland Mitigation Project Costs

Wetland Type	Restoration Cost ($ per acre)
Louis Berger and Associates*	
Emergent	$59,221
Scrub/Shrub	$168,334
Openwater-Shrub/forest	$176,573
Emergent Scrub/shrub	$476,743
Emergent-forested	$319,734
Riverine emergent	$112,447
King and Bohlen**	
Aquatic bed	$61,018
complex	$128,816
Freshwater mixed	$70,510
Freshwater forested	$168,139
Freshwater emergent	$113,901
Freshwater tidal	$105,765

Source King, 1998

*Louis Berger and Associates Inc., 1997, 'Costs for Wetland Creation and Restoration Projects in the Glaciated Northeast,' A Report to the EPA as reported in King, 1998.

**King, Dennis and Curtis Bohlen, 1994, 'Making Sense of Wetland Restoration Costs,' University of Maryland, Center for Environmental Science as reported in King, 1998.

Oregon Stream Restoration Projects

Five fish habitat restoration projects in Oregon designed to benefit fish cost are summarized below. The five projects vary in size from 300 feet to 2.5 miles of stream length; while the project costs vary between $12,000 and $619,000 (see **Table B-9** below). The per stream mile restoration values are significantly less than the per acre constructed wetland values due to the higher cost to transform a habitat into a wetland versus to restore and repair riparian and wetland habitat areas. On average across the five projects, the cost per stream mile for restoration is approximately $250,000. **On an annualized basis, the cost of restoring a mile of fish habitat is approximately $14,000 per year (based on a five percent discount rate and a 50-year time horizon).**

The largest and most costly stream restoration project reported by ODFW is the Boulder Creek and Middle Fork Restoration Project. This project restored fish habitat, stream channel morphology, and adjoining riparian community along approximately 2.5 miles of stream on the Middle Fork of the John Day River watershed. The intent behind this project is to repair steelhead, Chinook salmon, and bull trout spawning and rearing ground previously impaired by human use.

The remaining four restoration projects target habitat for redband trout, brown trout, bull trout, mountain white fish, Chinook salmon, and steelhead. One project, the Low Creek Channel and Wetlands Restoration Project also aims to benefit bald eagles and the little willow flycatcher. Watershed projects were conducted in the upper Deschutes River (La Pine, Camp Polk Meadow), Coquille River (Lowe Creek), and the Willamette River (Bylund). These restoration projects are all on streams and rivers smaller than the Columbia River, but provide an indication of the value of fish habitat in Oregon.

Table B-9 Habitat Restoration Costs

Project Name	Total Cost	Stream Length (miles)	Cost per Mile
Boulder Creek and Middle Fork Restoration Project	$619,029	2.5	$247,612
Camp Polk Meadow Preserve Channel Restoration	$184,995	1.2	$154,163
Bylund/Oregon State Parks Salmon Habitat Improvement	$263,875	1.2	$219,896
La Pine State Recreational Area Fish Habitat and Bank Protection	$11,872	0 .1	$189,952
Lowe Creek Channel and Wetlands Restoration	$436,569	1	$436,569
Average			$249,638

B.2.2.3 Market Value of Habitat/Wetland Mitigation Banks

Market values for habitat are starting to appear through mitigation banking. Mitigation banks within the local area are restricted in number and in the Pacific Northwest are generally limited to wetland habitats.[18] Wetland mitigation banks (banks) offer restored, established, or enhanced wetland credits for the purpose of providing compensation for unavoidable impacts to wetlands. Banks are created by government,

[18] Communication and research on habitat restoration project costs or mitigation bank costs through the Lower Columbia River Estuary Partnership, the Willamette Partnership, the Columbia River Estuary Study Taskforce, the Columbia Land Trust, Ducks Unlimited, Wildlands Inc., etc. did not produce estimates of total cost and acreage that could be used in estimating the replacement cost or market value of habitat on WHI.

corporate, nonprofit, or other organizations under a formal agreement with a governing agency. The credits are specific to a certain geographic area known as the bank's service area. The value of credits represents the market value for wetlands, and reflects the cost of construction and monitoring. It is important to note that per acre values for wetland mitigation credits do not necessarily represent the total economic value of wetlands, as the private cost of construction and monitoring may not match the total social benefit of ecosystem services provided by wetlands.

Wetland mitigation credits within the Willamette Valley range from $50,000 to $175,000 per acre, with the average cost of $60,000 per acre (Willamette Partnership, 2006). The significant variation in costs reflects the diverse land values across the valley. A planned mitigation bank near WHI is the Columbia River Wetland Mitigation Bank at the Port of Vancouver. The bank includes 154 acres of wetlands with credits expected to range from $175,000 to $200,000 dollars per acre.[19] Annualizing this value (at a five percent discount rate over 50 years), indicates that **the mitigation value of wetlands on WHI may be in the range of $10,000 to $11,000 per acre on an annualized basis.**

B.2.3 Estimate of WHI Habitat Value

Three types of valuation methods are presented above, including the economic value of habitat from the literature, the cost of habitat replacement or restoration actions (which reflects the willingness to pay for habitat), and the market value of habitat mitigation credits. The annual per acre value found from these three methods are summarized in **Table B-10.** Based on these values, and the acreage of these habitat types found on WHI, the value of these habitat types are estimated. It is important to note that no applicable values were found in the literature for grassland/herbaceous or shrubland habitat. These habitats have economic value, but have not yet been as extensively studied, and therefore values are not estimated for these habitats.

Table B-10 thus presents the approximate value of habitat and biodiversity for WHI forest, wetland and shallow water habitat/upper beach. The values for WHI shallow water / upper beach habitat are based on the value of coho Salmon habitat and the cost of stream restoration efforts, combined with an estimated 9.4 kilometers of shoreline habitat on WHI. The value of riparian forest on WHI (applied to all forest acreage on WHI), is based on the average existence value from studies throughout the United States. The value of WHI wetlands is based on the cost of restoration/replacement and the mitigation value, with falls within the range of existence value. Finally, the only use value of WHI habitat that is included provides an estimated value of public recreation on WHI beaches (the only habitat currently authorized for public use).

As presented in Table B-10, the economic value of these habitat types on WHI is estimated at approximately $550,000 to $4.5 million annually. While the ranges are quite broad, particularly for shallow water/upper beach habitat, the values represent an indication of the potential economic benefit of WHI habitats based on the value of similar habitat types studied throughout the United States. The economic values presented in **Table B-10** represents only the forest, wetland, beach and shallow water habitat on WHI due to data limitations, and is thus expected to underestimate the total value of cultural services provided by habitat on WHI.

[19] Woodward, Victor, Columbia River Wetland Mitigation Bank Sponsor. April 20, 2010. Personal Communication with ENTRIX staff.

Table B-10 Annual Economic Value of Habitat on WHI

	Estimated Value / Acre									
	Existence Value		Restoration / Replacement		Mitigation Market		Applied Value to WHI		Total WHI Value	
Habitat	Low	High	Low	High	Low	High	Low	High	Low	High
Riparian Forest	$290	$538					$300	$500	$124,000	$207,000
Wetland	$63	$13,480	$3,000	$10,000	$10,000	$11,000	$3,000	$11,000	$177,000	$649,000
Shallow Water / Upper Beach	$1,131	$5,996	$8,000	$24,000			$1,000	$15,000	$240,000	$3,600,000
Beach (Recreation Only)									$11,000	$45,000
Total Habitat Value									**$552,000**	**$4,501,000**

B.3 AIR PURIFICATION SERVICE

Trees and other vegetation improve ambient air quality by removing air pollutants. Specifically, vegetation absorbs and intercepts such potentially harmful pollutants as nitrogen dioxide, particulate matter, carbon monoxide, and sulfur dioxide.[20] These pollutants are removed by vegetation through gaseous uptake, as well as through physical deposition of particulates on vegetation surfaces. The air purification services of vegetation that reduce ambient air concentrations of pollutants has economic value because of 1) improved health and reduced incidents or severity of respiratory illness such as asthma, bronchitis, lung disease, and respiratory infections,[21] and 2) improved aesthetics through increased visibility. This section first describes the current state of air quality in Portland (**Section B-3.1**), estimate the air purification services performed by WHI vegetation (**Section B-3.2**), and estimates the economic value of this air purification based on existing literature (**Section B-3.3**).

B.3.1 Air Quality in Portland

Air quality in Portland is monitored by the Oregon Department of Environmental Quality (DEQ) through the Air Quality Program.[22] Four air quality monitoring stations are located in the following areas of the Portland Metropolitan Area (Portland): Southeast, Downtown, Sauvie Island, and North Portland. The DEQ air quality monitoring system is based on the Environmental Protection Agency's (EPA) Air Quality Index (AQI). The AQI is an index that reports air quality on a daily basis for ground-level ozone, particulate pollution, carbon monoxide, and sulfur dioxide. These pollutants are regulated under the Clean Air Act and the EPA has developed national air quality standards for each to protect public health. The AQI is divided into six levels of concern: good, moderate, unhealthy for sensitive groups, unhealthy, very unhealthy, and hazardous.

In 2008, Portland had 309 days of good air quality, 51 days of moderate air quality, and 6 days of air quality rated as "unhealthy for sensitive groups". Since 2002, the number of good air quality days has generally fallen, from 317 days in 2002 to 309 in 2008 (see **Table B-11**). The trend for the number of days that air quality has been considered unhealthy has risen, from three days in 2002 to six days in 2008.

20 Nowak, David J. Daniel E. Crane, Jack C. Stevens, 2006, 'Air pollution removal by urban trees and shrubs in the United States,' Urban Forestry and Urban Greening, 115-123.

21 Air Quality Standards accessed at www.airnow.gov.

22 Oregon Department of Environmental Quality, 'Air Quality in the Portland Region,' accessed 3/19/2010 at http://www.deq.state.or.us/aq/northwest/index.htm.

Good air quality poses little to no health risk to all population groups. Moderate air quality may cause moderate respiratory issues for individuals who are unusually sensitive to ozone or particulate pollution. "Unhealthy for sensitive groups" air quality is not expected to adversely affect the general public but does increase risk for pollution-related health concerns in people who are active outdoors, people with heart or lung disease, older adults, and children. Unhealthy air quality may cause the general population to suffer air quality-related health effects.

Table B-11 Air Quality Index Levels for Portland 2002 to 2008

	2008	2007	2006	2005	2004	2003	2002
Good	309	308	313	310	304	314	317
Moderate	51	49	45	55	59	50	45
Unhealthy for Sensitive Groups	6	7	5	0	2	1	3
Unhealthy	0	1	1	0	1	0	0

Source: Oregon Department of Environmental Quality, 'Oregon Air Quality Report Data Summaries 2002-2008', accessed online at http://www.deq.state.or.us/aq/forms/annrpt.htm.

B.3.2 Quantifying Air Quality Purification on WHI

Estimates of air quality benefits from vegetation were drawn from US Forest Service (USFS) modeling of pollution removal in Portland using the Urban Forest Effects (UFORE) model. These data were extrapolated to estimate air quality benefits of WHI vegetation. Based on a local inventory of trees and shrubs as well as local data on meteorological conditions and pollution concentration levels, the UFORE model estimates the air pollution removed by trees and shrubs in Portland. The lead developer of this model, Dr. David Nowak at the USFS Northern Research Station, provided estimates of air pollution removal by all trees and shrubs in Portland as well as the air pollution removal per square meter of canopy.[23]

Nowak's estimates are based on air pollution concentration and canopy cover levels in the City of Portland in 2000. **Table B-12** presents the data that Nowak and his colleagues provided for air pollution removal by Portland trees and shrubs. Data provided by Nowak are for five pollutants known to adversely affect health and/or visibility (carbon monoxide –CO, nitrogen dioxide –NO_2, ozone –O_3, PM_{10}, and sulfur dioxide –SO_2). The data for both monthly and annual pollutant removal for each pollutant in metric tons (approximately 2,200 pounds) are presented below in **Table B-12**, while the average pollutant removed in grams per square meter of tree or shrub canopy are presented in **Table B-13**. It was assumed in this analysis that the average air pollutant removal per square meter of tree canopy from the year 2000 (as provided in **Table B-13**) is a good indicator of future pollution absorption (e.g. that future pollution removal per canopy area will not vary significantly).

Table B-12 Removal of Selected Air Pollutants by All Trees/Shrubs in Portland

	Pollutant Removal (Metric Tons)				
Month	CO	NO_2	O_3	PM10	SO_2
January	0.2		1.9	8.6	
February	0.2		2.7	11.3	0.7
March	2.7		16.4	18.6	2.9
April	6.3		50.3	27.3	5.0

[23] Nowak, Dr. David, Research Forester in Urban Forests, Human Health, and Environmental Quality Unit at the US Forest Service Northern Research Station. Personal communication with ENTRIX, Inc.

Table B-12 Removal of Selected Air Pollutants by All Trees/Shrubs in Portland

May	4.5	13.4	57.5	22.9	6.9
June	5.6	17.6	57.9	25.5	13.2
July	5.8	15.5	59.0	32.2	9.0
August	7.3	20.1	59.2	30.2	13.0
September	6.6	16.7	31.2	29.5	10.0
October	4.1		12.9	26.8	60.2
November	0.3		1.8	13.9	1.2
December	0.2		1.1	12.2	1.0
Annual Pollutant Removal in City	43.8	83.2	351.9	258.9	123.1

Source: Nowak, personal communication 2009 and 2010.

Table B-13 Annual Removal of Selected Pollutants in Portland Per Square Meter of Canopy

Pollutant	Grams / Square Meter of Canopy / Year
CO	0.5
NO_2	0.9
O_3	3.6
PM_{10}	2.6
SO_2	0.7

Source: Nowak, personal communication 2009 and 2010.

The estimates of air quality improvement by vegetation are based on canopy cover specific to urban forests in Portland. In order to apply these estimates to WHI habitats, the air purification services provided by forest with canopy cover must be adjusted for other types of habitat on WHI. To do this, the leaf area index (LAI) is used as presented by Asner.[24] LAI is the number of layers of leaves within an area of vegetation cover, and affects pollution removal rates. It is assumed that LAI indicates the relative capacity of vegetation classes to remove air pollutants. The Asner study analyzed existing studies of LAIs around the world and estimated average LAI for various habitat types. Asner's results for selected habitats are presented in **Table B-14**.

Table B-14 The Leaf Area Index for Selected Habitats

Habitat Type	LAI
Wetland	6.3
Shrubland	2.1
Forest	5.1
Grassland	1.7

Source: Asner et al., 2003.

[24] Asner, Gregory P., Jonathan M.O. Scurloc, and Jeffrey A. Hicket, 2003 'Global synthesis of leaf area index observations: implications for ecological and remote sensing studies,' Global Ecology and Biology, 12, 191-205.

Using the above sources of data estimating the pollutant removed by Portland vegetation and the LAI, the total removal of pollutants by WHI habitat type is estimated. These estimates are presented in **Table B-15**. Wetland habitat on WHI is assumed to have an equivalent air purification capability to forestland on WHI (despite Asner's estimate that globally, LAI for wetlands exceeds that for forestland). This is based on aerial photography images that indicate that vegetation density on WHI wetlands does not exceed vegetation density in forest/woodland areas. The other habitat types are indexed to forest to determine their relative pollutant removal capacity. This data is applied to Nowak's estimates of annual pollutant removal by acre to determine the total pollutant removal by type on WHI.

Table B-15 Pollutant removal by Habitat type

			Removal of Pollutants by WHI Habitat (metric tons per acre per year) [b]				
Habitat Type	WHI Acres	Service Level Compared to Forest Canopy	CO	NO_2	O_3	PM_{10}	SO_2
Shallow Water	240	-					
Upper Beach	83	-					
Wetland	59	6.3	0.12	0.21	0.86	0.62	0.17
Shrubland	76	2.1	0.06	0.11	0.46	0.33	0.09
Forest	414	5.1	0.84	1.51	6.03	4.36	1.17
Grassland	152	1.7	0.10	0.18	0.74	0.53	0.14
Inland/upland	6	-					
Total pollutant removal	1,030		1.1	2.0	8.1	5.8	1.6

[a] Source: Basedon Anser et al., 2003.

[b] Source: Based on Nowak 2009 and 2010 and ENTRIX estimates.

B.3.3 Economic Value of WHI Air Quality Improvement

People value air quality improvements for a multitude of reasons, with the two primary reasons being health and visibility benefits. The health benefit of improved air quality has been widely studied, but few studies are available on the economic value of this benefit. Since the value of that benefit is not directly captured in the marketplace, the economic value of air quality improvements is often elicited through peoples' willingness-to-pay for air quality improvement. This value can be derived different ways. One method to estimate households' willingness-to-pay to eliminate air quality pollutants uses the hedonic valuation method, which contrasts home prices in areas of relatively good and bad air quality (see the discussion on Delucchi et al., 2001 below). A second way to estimate the economic value of air quality improvements is through a per ton value of the benefit of reducing air quality pollutants based on avoided health costs (see discussion on OMB, 2003 below).

A 2001 meta-analysis of the available literature derived the annual household willingness to pay to reduce total suspended particulates (TSP, which includePM_{10}, NO_x, SO_x, and VOC) through a national evaluation of home prices and air quality.[25] This study estimated that the total willingness-to-pay nationally to eliminate TSP ranged from \$74 billion to \$121 billion in 1990 (2010\$). On an individual basis, willingness to pay, or value of TSP reduction, is estimated at approximately \$74 to \$124 annually (see **Table B-16**). Of this value, visibility effects range from 15 percent to 35 percent of total TSP reduction

[25] Delucchi, Mark A., James J. Murphy, and Donald R. McCubbin, 2002, 'The health and visibility cost of air pollution: a comparison of estimation methods,' Journal of Environmental Management, 64.

willingness-to pay, while health effects range from 50 percent to 70 percent. These values indicate the value to households of air quality improvements, but do not indicate the value per unit of pollution reduction.

Table B-16 Willingness-to-Pay to Eliminate TSP Pollution, Health and Visibility Effects, Billions of dollars

	TSP Pollution Reduction WTP		Health Effect		Visibility Effect	
	Low WTP	High WTP	50%	70%	15%	35%
PM_{10}	$41	$75	$20	$53	$6	$26
NO_x	$16	$31	$8	$22	$2	$11
S_{ox}	$17	$16	$8	$11	$3	$6
VOC	$1	$2	$1	$1	$0	$1
All Pollutants	**$74**	**$124**	**$37**	**$87**	**$11**	**$43**

Note: Figures are in billions of 1991 dollars
Source: Delucchi et al., 2001

To conduct cost benefit analyses of air quality regulatory programs, the Whit House Office of Management and Budget[26] (2003) has estimated the economic benefit of reducing one ton of NO_2, O_3, or SO_2. These values are per ton values rather than total elimination values, so these figures are not directly comparable with the figures in **Table B-16**. The economic benefit is measured as the avoided health-care cost, which is the cost of pollution-related healthcare that would have been incurred if not for the air quality improvement. These figures are presented in **Table B-17**. In 2010 dollars, the annual value per ton of pollution depends on the type of pollution being reduced, with values ranging from $734 (low estimate) for O_3 to $9,546 (only estimate) for SO_2.

In a 2006 study, Dr. Nowak provided the quantity and resulting economic benefit of air pollution reduction by city. The study provided estimates of total economic benefit of air pollutant removal by type (see **Table B-17**) based on various previous studies. The estimates represent the national median economic cost of pollution. Thus, the value represents both the visibility and health-care benefit of removing one ton of each pollutant from the air.

Table B-17 Economic Value of Reduced Air Pollution by Type in Avoided Health-Care Costs

	$ / Ton of pollution removal (in 2010 dollars)			
	Office of Management and Budget, 2003			Nowak et al., 2006
Pollutant	Low	High	Average	
CO (carbon monoxide)				$1,403
NO_2	$1,346	$6,731	$4,039	$9,875
O_3 (ozone)	$734	$3,304	$2,019	$9,875
PM_{10} (fine particulate)				$6,593
SO_2 (sulfur dioxide)	$9,546	$9,546	$9,546	$2,418

Using the relative removal of pollutants determined through the LAI and Nowak's estimate of pollutant removal by type, the economic value of air quality related ecosystem services on WHI can be estimated.

26 The Office of Management and Budget assists the President of the United States in overseeing the preparation of the federal budget and supervise administration of executive federal agencies.

Due to the large variation in value per ton of air pollution reduction in the literature, two estimates of air quality benefits from WHI are provided: one based on OMB estimates of values and one based on the estimates of value presented in Dr. Nowak's study. Since the OMB value represents only the avoided health care cost for three pollutants, it is expected to represent a lower bound estimate of the total economic value of air-quality related ecosystem services on WHI (see **Table B-18**). **Based on OMB values, the economic benefit of air quality related ecosystem services currently provided by WHI is estimated at approximately $40,000 annually. The second estimate, based on values from Nowak et al., (2006), is an estimate of the total externality cost (health and visibility) for all five pollutants, and is $142,000 annually.** This is the estimated range of air purification services currently provided on WHI.

Table B-18 Estimated Economic Value of Air Quality Related Ecosystem Services on WHI

	Value of Pollutants by Habitat ($ per acre per year)					
Habitat Type	CO	NO_2	O_3	PM_{10}	SO_2	Total
Lower Bound Estimate [a]		$8,163	$16,326		$15,007	$39,497
Upper Bound Estimate [b]	$1,575	$19,959	$79,838	$38,497	$3,801	$142,095

[a] Source: OMB, 2003 and ENTRIX derivation.

[b] Source: Personal Communication with Dr. David Nowak, 2010 and ENTRIX derivation.

B.4 CLIMATE REGULATION SERVICE

The human release of carbon dioxide and other greenhouse gases (GHG) has been directly linked to climate change by many scientific studies and is consequently a major environmental concern. Climate regulation services on WHI are related to carbon sequestration by WHI vegetation. Carbon sequestration refers to both the removal of CO_2 from the atmosphere and the prevention of CO_2 from entering the atmosphere. The carbon sequestration services provided by WHI come from terrestrial sequestration, which removes CO_2 from the atmosphere and stores it for long periods in vegetation or soil.

What follows is a description of carbon sequestration protocols (**Section B-4.1**), estimates of the amount of carbon sequestered on WHI (**Section B-4.2**), and a description of three measures for valuing the sequestered carbon (**Section B-4.3**). The section concludes with an estimate of the range of values for carbon sequestration on WHI.

B.4.1 Sequestration and Carbon Storage on WHI

Protocols have been developed for calculating carbon credits from sequestration and reduced emissions. The protocols guarantee that an offset offered in a market transaction translates to one ton of carbon sequestered and stored. Thus the market value placed on the carbon offsets is backed by the certainty of that offset. One of the most widely accepted of these is the World Resources Institute GHG Protocol (GHGPI, 2009). This protocol establishes clear procedures to guide analysis and reporting of GHG emissions. Another widely referenced protocol is the California Climate Action Registry (CCAR) Urban Forest Project Reporting Protocol (CUFR), which provides standards and guidance for reporting GHG emissions and reductions for all trees owned, controlled, or managed by the reporting entity.

Current sequestration on WHI would not qualify for sequestration credits under these market protocols, as it does not meet several requirements. For example, current sequestration would not meet the additionality requirement, which requires that the sequestration project result in carbon storage that is *in addition to* the baseline that would occur without the project. Protocols also typically require instituted mechanisms for long-term carbon security, annual monitoring, and other requirements. Thus, existing WHI habitat carbon sequestration/storage is not expected to be eligible under the voluntary or mandatory carbon markets. However, the sequestration services provided by WHI do provide economic value, as they store carbon that prevents additional greenhouse gas formation.

B.4.2 Carbon Sequestration Estimates

To estimate the amount of carbon sequestered by plants from the atmosphere into the plant matter and the soil requires assumptions regarding soil type, below ground biomass, soil organic matter saturation, and the size, species, and age of vegetation. Given these many variables, the actual amount of carbon sequestration can vary widely.

The age of vegetation affects the amount of carbon uptake in the above ground and below ground plant matter, which then affects the carbon uptake in the soil. This study indicates that over time a great deal of sequestration in biomass can occur below the soil and should be taken into account. A study was performed looking at the *Abies amabilis* forests in the Washington Cascades Mountain range to look at this difference.[27] For comparison, the amount of net primary production was examined for trees ranging from 23 to 180 years old in grams per meter squared per year. It was found that the 23 year old trees had about 27 percent of the biomass above ground and 73 percent below ground, whereas the 180 year old trees had only 18 percent of net primary production above ground.

The soil also contains carbon in the form of organic matter, so when estimating sequestration it is important to determine the actual amount of organic matter and soil type. One article states that a cubic foot of silt-loam soil weighs roughly 85 pounds, and that the top 8 inches of soil is a good depth for estimation of the amount sequestered.[28] Organic matter is about 58 percent carbon; thus, for every one percent organic matter in soil, there are about 0.3 pounds of carbon per square foot. Soil in a garden can have 7.7 percent organic matter content and therefore contain 2.5 pounds of carbon per square foot. Consequently, it is important to determine the actual amount of organic matter and soil type when calculating sequestration for a specific area.

Finally, the type of vegetation on the soil can have a large effect on the amount of carbon stored. Relevant information on carbon stores in Oregon was identified for forests only. The COLE Development Group of the Forest Service has estimated the carbon storage of specific forest tree species within Oregon.[29] The values relevant to WHI are included in **Table B-19**. These values represent the total carbon storage including vegetation and soil by forest species. These figures are based on sample sites within the state and include varying forest quality and age. Assuming an average lifespan of 130 years (the estimated average lifespan of Cottonwood)[30], the annual carbon sequestration would average 0.6 metric tons per acre of cottonwood forest. This figure is consistent with the revegetation forest restoration scenario presented in the restoration module. The figures presented for grasslands are based on two studies. A 1997 study of carbon sequestration in coastal California grasslands found the average value of carbon stored by grasslands studied to be 10 metric tons per acre.[31] A 2000 World Resources Institute study of worldwide grassland sequestration by latitude found an average of 36 metric tons per

27 Schlesinger, William H., 1997, *Biogeochemistry: An Analysis of Global Change*. Academic Press, San Diego, California.

28 Meadows, Donella H., 2000, The Brothers Foley Develop A Sense of Humus. The Global Citizen, http://www.sage.wisc.edu/newsarchive/meadows2.html

29 The U.S. Forest Service, 2010, 'COLE 1605(b) Report for Oregon,' accessed online at http://www.fs.fed.us/ne/durham/4104/.

30 Bowes, G. G.; Spurr, D. T. 1996. Control of aspen poplar, balsam poplar, prickly rose and western snowberry with metsulfuron-methyl and 2,4-D. Canadian Journal of Plant Science. 76(4): 885-889. [27519]Willamette Partnership, 2006, 'Understanding Supply and Demand for Environmental Off-Set Credits in the Willamette River Basin' accessed online at http://willamettepartnership.org/publications/MarketplacePubs/UnderstandingSupplyandDemandforEnvironmentalOff-setCredits....pdf.

31 Hungate, Bruce, Elisabeth Holland, Robert Jackson, Stuart Chapin III, Harold Mooney, and Christopher Fields, 1997, 'The fate of carbon in grasslands under carbon dioxide enrichment,' NATURE, vol. 388.

acre over the mid-latitude.[32] The average grassland carbon store of the two studies is 23 metric tons per acre. These figures are annualized over the 40-year grassland saturation period (as presented in the restoration module) to get an annual value of 0.6 metric tons of carbon sequestered by an acre of grasslands. This figure is also consistent with the annual carbon sequestration rates presented in the restoration module. Based on the annual carbon sequestration of approximately 0.6 tons per acre per year and approximately 540 acres of grassland and forest/woodland on WHI, there are an estimated 325 tons of carbon sequestered annually. This is a very small amount of sequestration compared to carbon emissions in the Portland metro region. For example, according to the Union of Concerned Scientists[33], the average American generates approximately 20 tons of carbon dioxide emissions annually, or 5.45 tons of carbon per year. This implies that the carbon sequestration on WHI is approximately equivalent to the emissions of 60 residents of the City of Portland.

Table B-19 Forest Carbon Storage by Tree Species

Ecosystem	Soil Carbon Store (tons / acre)	Vegetation Carbon Store (tons / acre)	Total Carbon Stock (tons / acre)	Source
Forestland				
Oregon Cottonwood Forest	37	33	70	COLE, 2010
Oregon Ash	37	58	95	COLE, 2011
Oregon Cottonwood/Willow	37	31	68	COLE, 2012
Average Oregon Cottonwood/Ash/Willow Forest Store			78	
Average Annual Oregon Cottonwood/Ash/Willow Forest Sequestration			0.6	
Grassland				
Grassland			10	Hungate et al., 1997
Grassland			36	Matthews et al., 2000
Average of Grassland Carbon Store			23	
Average Annual Grassland Carbon Sequestration			0.6	

Source: COLE, 2010

B.4.3 Value of Carbon Sequestration

Carbon sequestration is expected to reduce the effect of global climate change and thereby contribute to human well-being through reducing economic damages associated with the earth's temperature rising. Recognizing the inherent uncertainty in estimates of the total social and economic costs of climate change, this analysis presents not only estimates of this economic value, but also two proxies for economic value. The two proxy measures suggest minimum values for greenhouse gas reduction benefit, while the avoided damage costs represent economists' best estimate of the total economic cost of climate change per unit of greenhouse gas.

- Market Value (Demonstrates the private cost and benefit of developing and acquiring carbon credits)
- Replacement Value (Indicates the private cost of developing a sequestration project to replace sequestration on WHI)

[32] Matthews, Emily, Richard Payne, Mark Rohweder, and Siobhan Murray, 2000, 'Pilot Analysis of Global Ecosystems,' published by the World Resources Institute, available online at http://www.wri.org/publication/pilot-analysis-global-ecosystems-forest-ecosystems.

[33] Union of Concerned Scientists, 2006, "What's Your Carbon Footprint?", accessed online at http://www.ucsusa.org/publications/greentips/whats-your-carb.html.

- Avoided damage costs (Estimates the true economic benefit of sequestration in terms of avoided future cost of climate change.)

The market value, replacement cost, and social values of carbon sequestration are not additive.

B.4.3.1 Market Value of Carbon Sequestration

Generally, markets can be either voluntary or regulated such as those markets managed under a cap and trade system. Activities throughout North America are developing both voluntary markets, the most prominent of which is the Chicago Climate Exchange, and cap and trade markets, like the Regional Greenhouse Gas Initiative (in the Northeast U.S.) and the Western Climate Initiative in Western North America. Generally, a regulated cap and trade market would see credit prices that are higher than a voluntary market like the CCX. The market price of a carbon offset, particularly on a regulated market, represents the private benefit of carbon sequestration which is less than the total social and economic benefit of carbon sequestration. For example the offset price represents a minimum value that a business is willing to pay for the opportunity created by buying the offset, e.g. for a business to increase emissions and expand production above current levels.

The Waxman-Markey bill is legislation designed to place a cap on GHG emissions requiring businesses with high emissions to meet certain targets between now and 2050. These regulated industries would need to acquire permits for emissions after the program is launched. If a company reduces emission beyond requirements resulting in more offset permits than needed, it can sell excess permits to other companies or bank them for future use. On the other hand, if a company does not reduce emissions to the required level resulting in not enough permits, that company can buy offset permits or borrow future emission credits from itself with interest. Non-regulated entities are also able to buy and sell permits, adding liquidity to the market. Under this scenario, the USEPA projects the market value of a permit to emit one metric ton of carbon dioxide (or its equivalent) will be worth $11 to $15 (2005 dollars) in 2012 and between $22 to $28 by 2025[34] as more permits are auctioned off vs. allocated free of charge to emitters and as emission reduction goals increase.

Though the EPA predicts a steep growth in carbon values due to regulation, the current voluntary market value of 2010 carbon offsets on the CCX is around $0.10 per metric ton. This value has decreased substantially since its peak in 2008 of $7.4 for one ton of the current year vintage of carbon offsets (see **Figure B-2**). The steep decrease in price is related to recession-induced uncertainty. The recession has caused a slowdown in manufacturing, which curtails GHG emissions thereby reducing demand for GHG offsets and leading to a decrease in the price of GHG offsets.[35] Note that WHI habitat is not currently eligible as a CCX offset project since there is not a well-monitored project in place to sequester carbon. Thus, these figures are presented for comparison purposes to estimate the value of WHI carbon sequestration and not as a potential market for current WHI carbon sequestration.

[34] Sheppard, Kate, Everything you always wanted to know about the Waxman-Markey Energy / Climate Bill – In Bullet Points, Grist, June 3, 2009, accessed online at http://www.grist.org/article/2009-06-03-waxman-markey-bill-breakdown/.

[35] Hickey, Macro, 2008, 'Chicago Climate Exchange (CCX),' accessed at http://www.scribd.com/doc/17556877/Chicago-Climate-Exchange-CCX-Research-Paper.

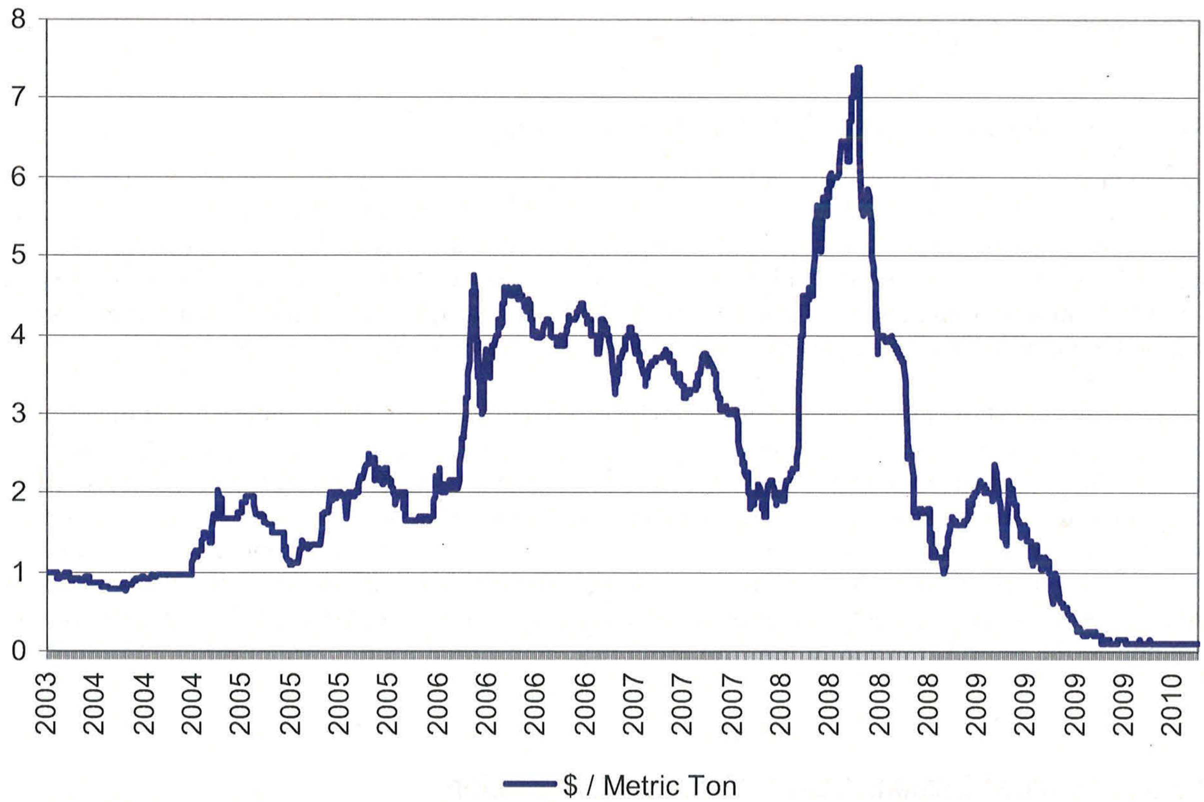

Figure B-2 History of Current Year Vintage Carbon Sequestration Prices Per Ton on the CCX[36]

The European Climate Exchange (ECX) is a cap and trade market for GHG emission offsets within Europe. The price of ECX offsets has faced uncertainty in the past. In 2006, an oversupply of free permits allocated to emitters by European governments weakened the price of offsets, which eventually dropped to almost zero. In the severe economic downturn beginning in 2008, the price of offset permits again plummeted. Industry curtailed production as a result of the downturn causing a reduction of GHG emission by industry. The reduction in emissions led to a decrease in demand which inevitably led to a decrease in the price of offsets.[37] The ECX market is currently at $14.49 per metric ton, which is a decrease from its trading value of over $25 per metric ton in early 2008.[38]

The Regional Greenhouse Gas Initiative (RGGI) is a mandatory market-based cap and trade system to reduce CO_2 emission from the power sector within ten Northeastern and Mid-Atlantic States. RGGI has a 10 percent reduction in greenhouse gas emissions 2018.[39] The market opened with an auction in 2008 where the offset credits were sold at $3.07 per ton. The offset price was expected to start low, as the greenhouse gas emission cap is being set at the previous years' pollution level.[40] The March 10, 2010 auction held for greenhouse gas emission offset credits resulted in current market prices of $2.07 and

36 Chicago Climate Exchange website accessed April 22, 2010,: http://www.chicagoclimatex.com/market/data/summary.jsf

37 Kanter, James, 2009, 'Pressure Grows on E.U. to Intervene in Carbon Market,' The New York Times, accessed online at http://greeninc.blogs.nytimes.com/2009/02/27/pressure-grows-on-eu-to-intervene-in-carbon-market/.

38 The European Climate Exchange, accessed at www.ecx.eu.

39 Regional Greenhouse Gas Initiative, 2010, accessed online at http://www.rggi.org/home.

40 Sustainablebusiness.com, September 30, 2008, 'REGGI Reports on First Auction,' accessed online at http://www.sustainablebusiness.com/index.cfm/go/news.display/id/16848.

future prices at $1.86 per ton.[41] The mandatory nature of the REGGI market should result in higher prices than the voluntary CCX market.

B.4.3.2 Replacement Cost of Carbon Sequestration

A second proxy measure of the value carbon sequestration is the cost to develop sequestration projects. This cost represents the marginal replacement cost of carbon sequestration. The marginal cost of one ton of carbon sequestration depends on the total amount of carbon being sequestered. For example, in a program designed to sequester 300 million tons of carbon annually, the marginal cost of sequestering one ton of carbon ranges from $25 to $75. In a program designed to sequester 500 million tons of carbon annually, the marginal cost of sequestering one metric ton of carbon ranges from $30 to $90.[42]

The replacement cost of carbon sequestration can be estimated thorough the voluntary offset of carbon emissions by individuals as well. The price of this offset is set by the agency offering the offset and represents the cost of sequestering or reducing one ton of carbon. Sequestration projects generally rely on reforestation to produce carbon sequestration offsets. Reduction offsets are project that reduce carbon emissions such as renewable energy. Offset agencies often offer multiple offset options or a mix of both sequestration and reduction projects within one carbon offset making it difficult to delineate between the price of sequestration and reduction offsets. Carbon offsets range in price from $9 to $26 per metric ton depending on the projects associated with the offset (e.g. geothermal energy, wind energy, replanting of a forest).[43]

B.4.3.3 Avoided Damage Cost of Carbon Sequestration

The third measure used to value carbon sequestration, which conceptually represents the best estimate of true economic value of reduced atmospheric carbon, is the savings of avoided damages related to global climate change. This cost considers benefits that accrue to society as a whole and is conceptually the appropriate value to use to estimate the true economic value of carbon sequestration on WHI.

The social value of carbon is much debated in the literature, which is why the proxy values presented by European regulated markets and replacement costs provide a useful reference point for carbon values. For example, Mendelsohn (2003) suggests the social value of carbon often reported in the literature as ranging from $7 to $20 per ton between 2010 and 2019 may actually be closer to $1 to $2 per ton. In a 2009 study, Tol estimated the social value of carbon through a meta-analysis of 232 published estimates.[44] The study presents the mean, median, and mode value of the published estimates as $149, $41, and $18 per metric ton of carbon, respectively. The results from meta-analysis indicate a higher mean, median, and mode value for the social value of carbon with $215, $124, and $58 per metric ton of carbon, respectively. This analysis uses the mean and median values from the published literature of $41 and $149 as a representative range of the economic value of reduced atmospheric carbon.

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41 REGGI, 2010, 'Auction Results,' accessed online at http://www.rggi.org/co2-auctions/results.

42 Stavisns, Robert and Kenneth Richards, 2005, 'The Cost of U.S. Forest-Based Carbon Sequestration,' Prepared for the Pew Center on Global Climate Change, accessed online at http://www.pewclimate.org/docUploads/Sequest_Final.pdf.

43 Carbonfund.org, terrapass.com, carbonoffsets.org, carbonfootprint.com, begreennow.com, and nativeenergy.com.

44 Tol, Richard, 2009, 'The economic effects of climate change,' Journal of Economic Perspectives, Vol. 23 No.2.

B.4.4 Value of Climate Regulation on WHI

Using the value of carbon storage per acre of WHI forestland and assuming an average lifespan of WHI forestland of 130 years[45], the annual value of carbon sequestration per acre of forestland on WHI is estimated at 0.6 metric tons per acre. The annual quantity of carbon sequestered by grasslands is also estimated at 0.6 metric tons per acre based on grassland carbon storage and 40 years until carbon saturation. This figure is also applied for shrubland. The roughly 101 acres of grasslands within the dredge material management area are conservatively not included in the estimates of grassland carbon sequestration as this area is sparsely vegetated (which reduces air quality benefits), and the appropriate LAI for this vegetation type is not known. The range of benefits of carbon sequestration on WHI is presented in **Table B-20**. **Based on the avoided damage to society the annual value of sequestering carbon on WHI ranges from approximately $13,000 to $48,000 based on an estimated 325 tons of carbon sequestered annually.**

Table B-20 The Economic Value of Carbon Sequestration on WHI

	Value of Carbon ($ / tons)	Annual value of forest carbon sequestration ($ per acre)	Annual value of forest carbon sequestration on WHI
Forestland			
Low avoided social damage / replacement cost	$41	$25	$10,000
High avoided social damage	$149	$89	$37,000
Grassland and Shrubland (excluding dredge material area)			
Low avoided social damage / replacement cost	$41	$23	$3,000
High avoided social damage	$149	$85	$11,000
Total Value			
Low avoided social damage / replacement cost		$48	$13,000
High avoided social damage		$174	$48,000

Figures may not sum due to rounding
a) Based on the mode social value of carbon ($58 per metric ton) estimated through a meta-analysis in Tol (2009)
b) Based on the mean social value of carbon ($215 per metric ton) estimated through a meta-analysis in Tol (2009)

B.5 WATER PURIFICATION SERVICE

As with air quality, improved water quality has economic value through its effect on human health and aesthetics, as well as through effects on the health of wildlife populations. Individuals benefit from improved water quality in the form of healthier water in which to recreate, reduced exposure to toxins in fish consumed, improved appearance of the water (aesthetic value), reduced costs of municipal water treatment, and the knowledge that local waters and aquatic ecosystems are being protected. Water quality in the Columbia River watershed is valued by individuals and society, as reflected in water quality regulations and water quality improvement efforts by federal, tribal, state, and local governments; non-profit organizations; and private industry.

[45] Bowes, G. G.; Spurr, D. T. 1996. Control of aspen poplar, balsam poplar, prickly rose and western snowberry with metsulfuron-methyl and 2,4-D. Canadian Journal of Plant Science. 76(4): 885-889. [27519]Willamette Partnership, 2006, 'Understanding Supply and Demand for Environmental Off-Set Credits in the Willamette River Basin' accessed online at http://willamettepartnership.org/publications/MarketplacePubs/UnderstandingSupplyandDemandforEnvironmentalOff-setCredits....pdf.

B.5.1 Columbia River Water Quality

Water quality in the Columbia River basin is regulated and/or monitored by a variety of state and federal agencies, including the U.S. Army Corps of Engineers (ACOE), Oregon DEQ, Washington Department of Ecology, and the U.S. Environmental Protection Agency (EPA). Regulated contaminants within the Lower Columbia River Basin include, among others, dioxin, polychlorinated biphenyls (PCBs), and dichlorodiphenyltrichloroethane (DDT). Dioxins, PCBs and DDT impair water quality and cause negative effects to human health and aquatic species such as insects and salmon.[46]

Total maximum daily loads (TMDL's) in the Columbia River have been established for TDG levels and dioxin discharges.[47] In addition, the *EPA 2006-2011 Strategic Plan* for the Columbia River Basin has targeted a ten percent reduction in mean concentration of pollutants of concern, as measured against median baseline concentrations derived from water column samples. Priority contaminants for reduction goals for the mainstem Columbia River are PCBs and DDT.[48] A fish advisory in effect for the lower Columbia River due to elevated PCB levels recommends that all persons should avoid eating the fatty parts of fish caught in this portion of the river.[49] Results from the 2002 EPA Columbia River Basin Fish Contaminant Survey show the presence of residues of 92 priority pollutants in fish, including PCBs, dioxins, furans, arsenic, mercury, and DDE, a breakdown product of DDT.[50]

Table B-21 shows the TMDLs and targeted reductions for regulated contaminants in the Lower Columbia River Basin.

Table B-21 Select Regulated Contaminants in the Lower Columbia River Basin

Pollutant	TMDL	Targeted Reduction[5]
Total Dissolved Gas[1]	Ambient Water Concentration: 110 percent of saturation Loading Capacity[3]: 75 mm Hg	--
	Ambient Water Concentration: 0.013 ppq Loading Capacity[3,4]: 5.04 mg/day	--
PCBs[2]	--	2.34 ppt
DDT[2]	--	1.26 ppt

[1] Sources: Oregon Department of Environmental Quality, Water Quality, Total Maximum Daily Loads (TMDLs) Program, http://www.deq.state.or.us/WQ/TMDLs/columbia.htm#dd (accessed February 26, 2010).

[2] U.S. Environmental Protection Agency, EPA Strategic Plan 2006-2011, Measuring Success of Sub-objective 4.3.9: Restore and protect the Columbia River Basin, http://yosemite.epa.gov/R10/EXTAFF.NSF/Reports/2006+Regional+Priorities+Columbia+River+Basin/$FILE/Baseline-columbia.pdf (accessed February 26, 2010).

[3] Loading capacity is the greatest amount of loading that a river can receive without violating water quality standards. A TMDL must not exceed the loading capacity of a waterbody.

[4] Loading capacity as determined at Columbia River at Vancouver.

[5] Based on a ten percent reduction from EPA measurements taken in the Multnomah Channel of the Mainstem Columbia. ppt = parts per trillionppq = parts per quadrillionmmHg = millimeters mercury mg = milligrams

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46 Lower Columbia River Estuary Partnership. "Toxics Monitoring: Assessing Contaminants in Water, Sediment, and Fish." http://www.lcrep.org/toxics-monitoring-assessing-contaminants-water-sediment-and-fish (accessed April 20, 2010).

47 Oregon Department of Environmental Quality, Water Quality, Total Maximum Daily Loads (TMDLs) Program, http://www.deq.state.or.us/WQ/TMDLs/columbia.htm#dd (accessed February 26, 2010).

48 U.S. Environmental Protection Agency, EPA Strategic Plan 2006-2011, Measuring Success of Sub-objective 4.3.9: Restore and protect the Columbia River Basin, http://yosemite.epa.gov/R10/EXTAFF.NSF/Reports/2006+Regional+Priorities+Columbia+River+Basin/$FILE/Baseline-columbia.pdf (accessed February 26, 2010).

49 Oregon Department of Human Services, Toxicology Consulting Services, Oregon Fish Consumption Guidelines, http://oregon.gov/DHS/ph/envtox/fishconsumption.shtml#Lower (accessed February 26, 2010).

50 U.S. Environmental Protection Agency. "Lower Columbia: from Bonneville to Pacific Ocean." http://yosemite.epa.gov/r10/ECOCOMM.NSF/Columbia/Lower+Columbia (accessed April 21, 2010).

Oregon DEQ administrative rules specify water quality criteria for state waters. The temperature standard for the State of Oregon is promulgated in OAR 340-041-0028, which sets the seven-day average maximum temperature of the lower Columbia River at 68°F (20°C). Temperatures above 68°F harm juvenile salmon and steelhead by stunting growth, increasing the incidence of disease, and favoring predators such as carp and bass.[51] OAR Division 41 rules also provide criteria for compound concentrations not to be exceeded in order to protect human health and aquatic life. Priority pollutants and carcinogens are identified, and maximum concentrations for consumption of fish and drinking water are defined. For example, DDT is categorized as both a priority pollutant and a carcinogen, and concentrations for the protection of human health are not to exceed 0.024 nanograms per liter for fish water and fish ingestion.[52] DEQ does not have criteria indicators for nitrogen and phosphorus.[53] However, numeric nutrient criteria are currently being developed by the State of Florida, and in the future DEQ may develop similar criteria in the future due to nutrient loads in the Columbia River and elsewhere.

Water bodies containing high concentrations of contaminants are included in EPA's Section 303(d) List of Impaired Waters.[54] Hayden Island, which is located between Columbia River Mile (RM) 102 and RM 106, is within an impaired segment of the Lower Columbia-Sandy watershed. State impairments between RM 98 and RM 142 include arsenic, DDT, PAH, and PCBs.

The Columbia River Basin Toxics Reduction Working Group consists of EPA, other federal agencies, states, tribes, and non-profit organizations which meet with the goal of preventing and reducing toxic concentrations and loads in the Columbia River. The Working Group developed a list of toxics of highest priority, as shown in **Table B-22** below. Tier I contaminants are of a higher priority than Tier II and Tier III.

Table B-22 Prioritization of Toxics in the Columbia River by the Columbia River Toxics Reduction Working Group

Tier I	Tier II	Tier III
DDT (and metabolites)	Polycyclic aromatic hydrocarbons (PAHs),	Organochlorides[2]
PCBs	Arsenic	Trace elements
Mercury (including methylmercury)	Dioxins/furans	Current use pesticides[2]
Polybrominated diphenyl ethers (PBDEs)	Lead	Pharmaceuticals and personal care products
	Organophosphate insecticides[1]	Other wastewater compounds[2]
	Copper	Hormones
	Estrogenic compounds[2]	Synthetic pyrethroids
		Phthalates

Source: Columbia River Toxics Reduction Workgroup. July 17, 2007. "Contaminants of Concern: Prioritization of Toxics in the Columbia River." http://yosemite.epa.gov/r10/ecocomm.nsf/Columbia/SORR-RSI/$FILE/S3-Contaminant-Concern.pdf (accessed April 9, 2010).

[1] Azinphos methyl, chlorpyrifos, diazinon.

[2] Bisphenol A, AHTN, natural and synthetic estrogens, Nonylphenol.

[3] Examples include alpha BHC, aldrin, dieldrin, chlordane.

[4] Examples include carbamates, triazine herbicides, fipronil.

[5] Plasticizers, detergents, surfactants.

[51] Columbia Riverkeeper. "Adopt-a-River: Water Quality Monitoring." http://www.columbiariverkeeper.org/index.php/adopt_river/water_quality_monitoring (accessed April 20, 2010).

[52] The full list of water quality criteria can be viewed on DEQ's Oregon Administrative Rules page under Division 41, Table 20: Water Quality Toxic Criteria Summary, http://www.deq.state.or.us/regulations/rules.htm.

[53] Sturdevant, Debra, Oregon Department of Environmental Quality. February 26, 2010. Personal communication with ENTRIX staff.

[54] U.S. Environmental Protection Agency. Total Maximum Daily Loads, Listed Water Information. http://iaspub.epa.gov/tmdl_waters10/waters_list.control?huc=17080001&wbname=COLUMBIA%20RIVER&wbtype=RIVER (accessed April 9, 2010).

B.5.2 Mechanisms of Water Purification

Water is purified as it passes through healthy ecosystems. Vegetation and woody debris slow the passage of water and allow time for biological and chemical processes to break down, detoxify, and remove pollutants from the water column. Organisms that play a role in water purification include in-stream insects, such as caddisflies and black flies, that filter particles from moving water, and periphyton – a mixture of detritus, algae, bacteria, and fungi found in aquatic environments – that is effective at removing heavy metals and reducing the toxicity of herbicides. Fauna ingest organic matter and thereby absorb or transform contaminants, and also assist in decomposition by disturbing and oxygenating sediments.

Bacteria and fungi break down pollutants through aerobic (with oxygen) and anaerobic (without oxygen) decomposition. In wetlands, these microbial processes are facilitated by high amounts of dissolved organic matter, fine-grained substrates, and complex sediment beds. Decomposition in wetlands is also affected by temperature, pH, and dissolved oxygen. Different microbial communities are found in varying amounts of dissolved oxygen, but most thrive with a pH of between 6 and 9 and warm temperatures up to approximately 95°F (35°C).[55]

In addition to animals and microbial communities, vegetation provides water purification services. Plant roots stabilize soil and prevent erosion into waterbodies, and trap sediment contained in runoff. Contaminants are also taken up by plant roots and sequestered or detoxified in plant tissue via a process termed phytoremediation. Phytoremdiation occurs when pollutants are absorbed into root tissue, accumulated in above-ground tissues, or transformed to a less toxic chemical. Certain plants have the ability to remove toxic heavy metals and radionuclides from water, including arsenic, cadmium, cesium, chromium, lead, mercury, strontium, technetium, tritium, and uranium. Organic pollutants, such as PCBs, PAHs, nitroaromatics (such as trinitrotoluene, or TNT), and linear halogenated hydrocarbons (such as trichloroethylene, or TCE) are mineralized by plants into non-toxic forms.[56]

In addition to the pollutant-mitigating activities of flora and fauna, fine-grained soils (e.g. silt and clays) commonly found in wetlands remove from the water column contaminants such as heavy metals, some pesticides, and organophosphates. In addition to binding pollutants to sediment, wetlands and riparian buffers improve water quality by trapping sediment during periods of heavy rainfall, keeping it from entering adjacent downstream resources. Wetlands and vegetated areas also absorb nutrients such as nitrogen and phosphorus, helping to prevent or minimize algal blooms and subsequent oxygen deficiencies downstream. [57]

Finally, localized hyporheic (subsurface water) flows may contribute to the quality of aquatic habitat around the island, including a localized reduction in water temperature. Such localized influences can enhance salmonid habitat.

B.5.3 Economic Value of Water Purification on WHI

As described above, vegetation is capable of removing toxic compounds from polluted water and soil. Contaminants processed through phytoremediation include many of the toxics described earlier in this section as being of highest concern in the Lower Columbia River. Plant species capable of remediating

[55] Sutula, Martha and Eric Stein. June 27, 2003. *Habitat Value of Natural and Constructed Wetlands Use to Treat Urban Runoff: A Literature Review*. Technical Report #388. Prepared for the California State Coastal Conservancy.

[56] Richard B. Meagher. 2000. "Phytoremediation of Toxic Elemental and Organic Pollutants." *Current Opinion in Plant Biology*. Vol. 3, pp. 153-162.

[57] Sutula, Martha and Eric Stein. June 27, 2003. *Habitat Value of Natural and Constructed Wetlands Use to Treat Urban Runoff: A Literature Review*. Technical Report #388. Prepared for the California State Coastal Conservancy.

toxics of concern in the Lower Columbia River are found on WHI. For example, black cottonwood (*Populus trichocarpa*), a type of poplar, accounts for a large proportion of WHI's vegetation. Poplars have been shown to remediate chlorinated solvents, PAHs, atrazine, DDT, and carbon tetrachloride through phytodegradation (break down of contaminants into simpler forms) phytovolatilization (uptake and transpiration of contaminants), and phytoextraction (concentration of contaminants in above-ground vegetative tissue).[58]

In addition to processing toxics, poplar species also absorb nutrients such as nitrogen at high rates. Rivers transport the vast majority of nutrients reaching coastal waters, the concentration of land-borne nutrients tends to be high near the mouths of rivers. These areas of mixed fresh and marine water, referred to as estuaries, tend to be relatively slow moving and biologically rich water bodies that are particularly susceptible to the effects of nutrient over-enrichment.[59] Nitrogen and phosphorus are further absorbed by the 58.9 acres of wetland habitat and other vegetative communities on WHI. However, the functioning of these habitats to purify water is likely limited as they do not serve as riparian buffers to developed areas with concentrated nutrient or pollution runoff, but instead filter runoff generated from natural rainfall. WHI habitats do filter Columbia River water and associated nutrients and pollutants as the water flows through island habitats, particularly wetlands. The level of water exchange between these wetland habitats and the relatively low concentration of many pollutants in this section of the Columbia River (compared, for example, to highly concentrated runoff) limits the total amount of pollutants removed.

Hyporheic flows can buffer water temperature fluctuations primarily at a local level and in smaller streams or smaller watersheds.[60,61,62,63] In an evaluation of the Clackamas River to model the potential contribution that hyporheic flows could have on thermal regulation, Burkholder (2007) demonstrated that gravel bars or other physical channel features can create anomalous temperature changes.[64] The Columbia River, however, is a far larger system in which the temperature regime has been influenced by very large scale inputs such as the reservoir system and large tributary inputs. Although there may be some benefits, this contribution has not been evaluated on WHI. The value of WHI in regards to water temperature may be in the potential for thermal refuges along shoreline areas or alcoves. Floodplain restoration strategies that include the development of alcoves or side channels can provide thermal refugia for aquatic organisms[65] and WHI provides candidate areas for this type of ecological service.

While the degree of Columbia River water temperature attenuation by WHI is unknown, the economic value of temperature reductions in floodplain waters can be quite high. An economic analysis quantified the cost to reduce water temperatures within the Willamette River floodplain under different restoration strategies over a 50-year period. The maximum temperature reduction achieved under the hyporheic cooling scenario was 1.99°C. The total cost to reduce water temperatures by this amount was $4.28

58 Hinman, Curtis. *Low Impact Development Technical Guidance Manual for Puget Sound*, Appcdix 6: Phytoremediation Plant List. Produced by the Puget Sound Action Team, Olympia, Washington and the Washington State University Pierce County Extension, Tacoma, Washington. http://www.superorg.net/archive/proposal/plant%20species%20phyto.pdf.

59 Clean Coastal Waters: Understanding and Reducing the Effects of Nutrient Pollution, National Academy Press, Copyright 2000; accessed at: Website (http://books.nap.edu/openbook.php?record_id=9812&page=R1)

60 Evans EC, and Petts GE. 1997. "Hyporheic temperature patterns within riffles." *Hydrological Processes* 42: 199-213.

61 Moore RD, Sutherland P, Gomi T, Dhakal A. 2005. "Thermal regime of a headwater stream within a clear-cut, coastal British Columbia, Canada." *Hydrological Processes* 19: 2591-2608.

62 Sliva L, Williams DD. 2005. "Exploration of riffle-scale interactions between abiotic variables and microbial assemblages in the hyporheic zone." *Canadian Journal of Fisheries and Aquatic Sciences* 62: 276-290.

63 Johnson SL. 2004. "Factors influencing stream temperatures in small streams: substrate effects and a shading experiment." *Canadian Journal of Fisheries and Aquatic Sciences* 61: 913-923. DOI: 10.1139/F04-040.

64 Burkholder , BK. 2007. "Influence of hyporheic flow and geomorphology on temperature of a large, gravel-bed river, Clackamas River, Oregon, USA." *Hydrological processes* 22: 941-953.

65 Bryenton AG. 2007. "Heat balance of alcoves on the Willamette River, Oregon." MS thesis. Oregon State University. 92p.

million, or $2.15 million per degree of cooling.[66] Given the significant cost of to attain artificial hyporheic cooling found in a connected watershed, WHI likely provides a small, yet real economic benefit in the form of naturally reduced lower Columbia River temperatures.

A meta-analysis of 39 studies indicates that the value of water purification by wetlands is estimated to average $644 per acre (2010 dollars), with a high value of $1,616 per acre and a low value of $148 per acre.[67] It is expected that there is bias towards studying water quality of wetlands that provide significant water quality benefits, so that some wetlands provide even lower water quality benefits than $148 per acre. As the benefits from the WHI wetlands are expected to be on the low end compared to many of other wetlands, a range of values between $148 and $644 per acre is utilized in this study to estimate the water quality benefits of WHI wetlands. **Based on these values, the water quality benefits of the 58.9 acres of WHI wetlands are estimated at between $9,000 and $38,000 annually.**

B.6 FLOOD REGULATION SERVICE

Flooding of the lower Columbia River has the potential to inflict substantial economic costs. These costs include direct economic costs related to damage of infrastructure and economic assets such as homes, businesses, industrial facilities, roads, bridges, utilities, and water and wastewater treatment facilities, and agricultural crops. Additionally, flood damage results in indirect economic costs from interrupted business operations, which reduces local income. The wetlands and riparian vegetation on WHI store and convey storm and floodwaters, thereby increasing water storage and conveyance capacity in the river channel and reducing flooding. The value of this water storage and conveyance capacity depends on the relative volume of water stored and conveyed, the frequency and magnitude of flood events in the local area, and the value of economic assets that may be impacted by flooding. This section describes the flood regime on the Columbia River, its regulation by the dams, and an estimate of the value of WHI for flood mitigation.

B.6.1 Flooding of the Columbia River

The Columbia River carries the sixth largest volume of runoff of North American rivers, with average year-round flows of 275,000 cfs.[68] Mainstem flow volumes vary markedly across seasons, with natural runoff and flood events peaking during May and June due to melting of the accumulated winter snowpack. The most severe flooding events occur during periods of intense snowmelt coupled by heavy rain. Streamflow naturally declines during late summer and remains at a lower level throughout the winter. While less frequent than late spring/early summer floods, fall and winter flooding can occur in the event of low-elevation snowmelt and heavy precipitation.[69]

Climate change has the potential to affect the Columbia River flood regime, as small changes in temperature can impact snow accumulation, snow melt, and tidal effects.[70] Since the 1940s, the Pacific Northwest has experienced an average temperature increase of 1° to 2°C, resulting in an increased proportion of precipitation falling as rain (as opposed to snow) during the winter and spring months. This in turn is expected to lead to a reduced snowpack and an earlier spring snowmelt-derived streamflow, a

[66] Seedang, Saichon; Fernald, Alexander G., Adams, Richard M.; and Landers, Dixon H. 2008. "Economic Analysis of Water Temperature Reduction Practices in a Large River Floodplain: An Exploration Study of the Willamette River, Oregon." River Research and Applications.

[67] Woodward, Richard and Yong-Suhk Wui, 2001, "The economic value of wetland services: a meta-analysis", *Ecological Economics:* 37(2):257-270.

[68] Federal Columbia River Power System. April 2001. "The Columbia River System Inside Story." http://www.bpa.gov/power/pg/columbia_river_inside_story.pdf

[69] Corps of Engineers. Northwestern Division. North Pacific Region. May 2003. *Columbia River Treaty Flood Control Operating Plan.*

[70] Corps of Engineers. Northwestern Division. North Pacific Region. May 2003. *Columbia River Treaty Flood Control Operating Plan.*

trend that has been observed since the 1940s. Reduced predictability of springtime snowmelt due to climate change limits the ability to accurately predict flood frequency and severity. [71]

B.6.2 Flood Control by Columbia River Dams

After the Columbia River flood of 1948 devastated communities in the basin, flood control for the region became a federal priority. Efforts by the Army Corps of Engineers (ACOE) and negotiation between the Canadian and United States governments led to the development of the Columbia River Treaty of 1961, which specifies the responsibilities of the two governments regarding hydroelectric power generation and flood control in the basin.[72] Today, flood control on the Columbia River is managed by ACOE through operation of the Columbia River dams, with 16.5 million acre-feet of floodwater storage in Grand Coulee, Albeni Falls, Libby, Hungry Horse, and Dworshak dams in the United States. Another 20.5 million acre-feet of flood water storage is allocated in the Columbia River Treaty dams in British Columbia.73 Levees throughout the basin provide additional flood control. Multnomah County Drainage District (MCDD) manages the levees and pumps in northeast Portland; Marine Drive east of the island is located on one of these levees.

This flood control system has been designed to retain water in the reservoirs during the spring snowmelt high-flow period (known as the reservoir refill period). During the low-flow period between October and March, water is released from the reservoirs (known as the reservoir evacuation period). Flood control for the lower Columbia is achieved by maintaining a controlled flow as measured at The Dalles, Oregon. Controlled flow is based on the forecasted volume of spring runoff at The Dalles and the amount of upstream storage space available for system flood control.

Generally, flooding in the lower Columbia River commences when streamflow at The Dalles reaches 450,000 cfs. At this rate, the river reaches an elevation of 17.8 feet NGVD (16 feet, Columbia River Datum) at Vancouver, Washington. Significant damage starts to occur when flows reacht 600,000 cfs as measured at The Dalles, which corresponds to a river elevation of 24 feet NGVD (22.2 feet, Columbia River Datum) at Vancouver, WA. It is infeasible for the ACOE to regulate major flooding events to 450,000 cfs; therefore, the ACOE regulates major floods to 600,000 cfs at The Dalles.[74]

Climate change may have implications for dam flood control operations. An earlier snowmelt (up to one month early under climate change scenarios compared to the 20th century climate, according to some models) would necessitate an earlier reservoir refill period.[75] Continuing present policies to evacuate winter inflows under the climate change scenario, where a greater proportion of annual inflows would occur during winter than currently observed, would result in a decrease in reservoir refill during the spring. In this way, less water would be available during the dry summer and autumn months to maintain instream flow targets and to generate hydropower. Thus, continuing the present flood control policies may carry high costs associated with reduced availability of water during low flow periods. If future climate change conditions result in modifications to flood control policies, then flooding frequency and

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[71] Iris T. Stewart, Cayan, Daniel R., and Dettinger, Michael D. 2004. "Changes toward Earlier Streamflow Timing across Western North America." *Journal of Climate*. Vol. 18: 1136-1154.

[72] United States of America and Canada. Signed January 17, 1961 and ratified September 16, 1964. *Treaty Relating to Cooperative Development of the Water Resources of the Columbia River Basin*. http://www.ccrh.org/comm/river/docs/cotreaty.htm

[73] Northwest Power and Conservation Council. "Columbia River History". http://www.nwcouncil.org/history/Floods.asp (accessed April 16, 2010).

[74] Corps of Engineers. Northwestern Division. North Pacific Region. May 2003. *Columbia River Treaty Flood Control Operating Plan.*

[75] Se-Yeun Lee, Hamlet, Alan F., Fitzgerald, Carolyn J., Burges, Stephen J., and Lettenmaier, Dennis P. "Optimized Flood Control in the Columbia River Basin for a Global Warming Scenario."

magnitude regulated by the dams may change, and thereby change the economic value of natural flood regulation.[76]

B.6.3 Flood Control Policies

Federal and state entities regulate development in the floodplain, as do local agencies. For example, Metro, the elected regional government for the Portland, Oregon metropolitan area, manages development within Clackamas, Multnomah, and Washington counties. Metro Code Title 3, Section 3.07.340, regulates development of areas within the FEMA 100-year floodplain and the area of inundation for the 1996 flood. This policy stipulates that all development in the flood plain shall be managed such that flood storage and conveyance capacity is not reduced and flood elevations are not raised. This requires that all fill placed at or below the design flood elevation in flood management areas must be offset by an equal amount of soil removal. This policy indicates that areas with potential for additional flood control through soil removal may thus have economic value for offsetting loss of flood control services elsewhere.

B.6.4 Value of Water Storage and Flood Conveyance on WHI

Maps 1 through 4 depict the level of water storage and flood conveyance on WHI at three flood stages measured at the Vancouver Gauge: 17.8 feet (when flood damage commences in the lower Columbia River), 24 feet (when significant flood damage commences in the lower Columbia River), 27.2 feet (flood elevation during the 1996 flood event), and 31 feet (flood elevation in the 1948 flood event). There is an economic benefit to the volume of water stored or conveyed on WHI that reduces the likelihood or degree that the Columbia River rises above 17.8 feet and causes flood damage.

To measure the water storage and conveyance potential on WHI, the elevations on WHI were assessed. Elevations vary from 11.3 NGVD to 55.5 NGVD, with average elevation on the island of 26.1 NGVD. A 100-year flood event occurs when water levels reach 27.4 to 28.9 feet NGVD at the Vancouver Gauge. Total flood water storage and conveyance capacity on WHI is measured as the difference between the average elevation and the flood elevation at the 100-year flood event (chosen as 28.9 feet). On average, then, in a 100-year flood 2.8 feet of flood waters can inundate WHI. Given that there are 790 acres of habitat on WHI (excluding shallow water habitat), the total volume of water that can be stored or conveyed on WHI at any given time during a 100-year flood event is estimated at 26,560 acre-feet.

To put this value in context, when the Columbia River reaches 24 feet NGVD at the Vancouver Gauge, the flow is 600,000 cubic feet per second (cfs) at The Dalles. This is equivalent to 1.2 million acre-feet of water flowing past The Dalles every hour; this volume would be even greater during a 100-year flood event. The 26,560 acre-feet water that can be stored at WHI at any given time is therefore very small relative to the total flow and volume of the Columbia River. *Note that these numbers are not directly comparable, as the 1.2 million acre-feet is a volume of water flowing in a one-hour period, while the 26,560 acre-feet is the volume of water that can inundate WHI during a higher flow period without an associated time period.*

Due to the low relative volume of water that can be stored or conveyed at WHI, the avoided cost associated with natural flood control at WHI is expected to be small. As noted above, the ACOE manages the Columbia River dams to control flooding in the lower Columbia River. Interviews with ACOE confirm that the flood storage capacity in WHI relative to the size of the river and the volume of flood waters in the Columbia River, and that operation of the dams would not differ based on changes in

[76] Jeffrey T. Payne, Wood, Andrew W., Hamlet, Alan F., Palmer, Richard N., and Lettenmaier, Dennis P. 2004. Mitigating the Effects of Climate Change on the Water Resources of the Columbia River Basin." *Climatic Change*. Vol. 62: 233-256.

flood water storage and conveyance on WHI.[77] Furthermore, during the February 1996 flood event (roughly equivalent to a 100-year flood event), water levels at the Vancouver Gauge reached 27.2 feet NAVD. As the seawalls on the Washington and Oregon banks of the river are higher than 30 feet, it is not expected that the volume of water stored or conveyed on WHI would measurably increase the risk of breaching of the seawalls during a similar future flood event. Therefore, no avoided costs associated with WHI flood regulation are estimated.

In addition to avoided costs of flood damage, the value of natural flood mitigation can be measured based on the replacement cost of this storage and conveyance based on recent projects that removed soil in the floodplain to comply with local floodplain development regulations. Unfortunately, interviews with ACOE, Metro, and the City of Portland indicated that information is not readily available regarding recent, current, or future projects filling soil in the floodplain that would require offset excavation projects.[78]

B.7 WHI ECOSYSTEM SERVICE VALUES WITH RESTORATION

As described in the restoration module, the three ecosystem services likely to be enhanced through restoration are biodiversity (habitat), climate regulation, and flood control.[79] Additional ecosystem services from water purification are also be expected through increased channel connectivity and wetland enhancement. Each of these services is addressed below.

- ***Climate Regulation*** The climate regulation benefits would be achieved through revegetation of the forested and grassland areas on WHI, with estimated total carbon sequestration benefits of approximately 132 to 434 metric tons per year. **Based on this level of additional sequestration, and a range of $41 to $149 per metric ton, the economic value of carbon storage is estimated to increase by $5,000 to $65,000 annually.**
- ***Flood Regulation*** As described above, the capacity for flood water storage on WHI is expected to minimally change the level of flood damage in surrounding areas. However, restoration that results in increased flood storage and off-channel connections may be valued for its potential to offset floodplain fill required by development projects. This value may be significant if sites available for fill are scarce, or if the cost of such excavation projects are high. Unfortunately, no regulatory agency contacted for this project was able to provide insight into the potential cost of such projects.
- ***Water Purification*** Several management actions are intended to enhance or increase wetland connectivity and function on WHI. In particular, Management Area 5 is expected to increase wetland acreage on WHI by approximately 40 acres. Additional water purification services would be provided by this increased channel connectivity and water filtration on WHI. The value of these services may be approximately measured based on the water benefit estimates per acre of wetland presented in **Section B-5.0** of approximately $148 to $644 per acre. **The 40 additional acres of wetlands on WHI created through management action 5 may therefore increase water quality benefits provided by WHI by approximately $6,000 to $26,000 per year**. Other Management Areas are expected to increase wetland connectivity and therefore will likely increase water regulation functions and associated water purification, but the acreage and increased level of function are not known.

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77 Buchholtz, Robert, United States Army Corps of Engineers. April 7, 2010. Personal communication with ENTRIX staff. Zabel, Brian, United States Army Corps of Engineers. April 13, 2010. Personal communication with ENTRIX staff.

78 O'Brian, Tim, METRO. April 14, 2010. Personal communication with ENTRIX staff. Morgan, Doug, City of Portland. April 15, 2010. Personal communication with ENTRIX staff. Buchholtz, Robert, United States Army Corps of Engineers. April 7, 2010. Personal communication with ENTRIX staff.

79 Parametrix, 2010, Draft West Hayden Island Ecosystem Service Restoration Concept Plan, prepared for the City of Portland.

- ***Cultural Services Associated with Habitat & Biodiversity*** Finally, the restoration scenario would primarily result in habitat enhancements that would increase biodiversity on WHI. Through management actions to reduce invasive species, reconnecting areas with the river, and revegetation, management actions are expected to increase shallow water habitat, enhance grasslands and wetlands, and ensure the longevity of forest/woodland areas. Improvements to habitat and biodiversity function will enhance several types of cultural services. First, through the act of restoration, the cultural service of scientific knowledge will rise as the site is monitored for response to restoration techniques.

As the quality of habitat improves, the non-use existence value of that habitat also improves. Based on the management actions proposed, it is estimated that a minimum of 40 acres of wetlands would be created (Management Area 5) and approximately 85 acres of shallow water habitat (approximately 50 percent of Management Area 1) will be converted from grassland/herbaceous habitat in the dredge spoil area. Additional habitat enhancements are expected from all other management actions. The social value of WHI wetland habitat is estimated to be valued at $3,000 to $11,000 annually, so an additional 40 acres may be valued at $120,000 to $440,000. Likewise, the economic value of existing 240 acres of shallow water habitat is estimated to be valued at approximately $240,000 to $3.6 million. An additional 85 acres would increase shallow water habitat by approximately 33 percent, so it is assumed that the value of this additional shallow water habitat would be approximately 33 percent of the current value, or $40,000 to $1.2 million. These habitat conversions would result in the reduction of other habitat types, but it is assumed that the habitat enhancements being conducted through other restoration actions would at the minimum offset the losses associated with habitat conversion.

Furthermore, if access is allowed on the site, there would be increased value of educational opportunities related to restoration actions. Finally, if recreation access is permitted, the preservation and enhancement of habitat and biodiversity, particularly maintenance of forest and beach areas and increased presence of wildlife, will enhance use values.

B.8 WHI ECOSYSTEM SERVICES AND VALUES WITH DEVELOPMENT

The type and size of development on WHI will determine the effects on ecosystem services. In general, it is expected that the ecosystem services that would be primarily impacted by development would be cultural services associated with habitat and biodiversity, as well as climate regulation, air purification, and water purification services. Due to floodplain regulations requiring the offset of fill associated with development, it is not expected that flood control services would be measurably affected. Potential effects to each of the other ecosystem services are addressed in turn below.

- Cultural Services: Each of the following cultural services may be affected by development.
  - Aesthetics: Development has the potential to both increase and decrease aesthetic values of WHI natural areas. The value of aesthetic services provided by WHI natural areas will increase to the extent that development increases visibility of remaining natural areas through increased human activity and access to the area. Currently, aesthetic values are limited due to the lack of access and visibility of WHI from roads, residential areas, and recreation sites. However, if development is in areas visible by current users such as boaters on the Columbia River or beach users, and if development is perceived as less attractive than natural areas, then aesthetic values will diminish with development.
  - Recreation: Recreation on WHI is currently limited to beach activities and boating/fishing in adjacent waters. Development of recreational access and facilities would greatly enhance the recreational value of WHI. As presented in Section B-2, per person use values associated with outdoor recreation in Oregon are quite high. Total ecosystem services associated with recreation

development would vary based on size, type, and quality of facilities; ease of access; and associated number of visitors.

- Option/Existence/Bequest Habitat & Biodiversity Values: Development that reduces habitat quantity and quality would reduce both non-use existence values and bequest values for future generations, but also option values associated with the future potential to use, restore, or enhance the habitat.

- Climate Regulation: If development changes the amount of vegetation or disturbs the ability of soils to retain carbon, then the carbon storage and sequestration potential on WHI will change. The economic cost of removing vegetation on WHI would depend on whether the stored carbon from the vegetation is emitted into the atmosphere, or if it remains sequestered in the soil or in forest products. As the tree species on WHI are not typically the species used in furniture or similar wood products, it is expected that they would be used more for products from the pulp and paper industry that would not result in long-term sequestration of the carbon. The economic cost of every ton of reduced carbon storage in natural systems that is not offset elsewhere is estimated at $41 to $149 per ton. Based on these values, for every acre of forest or grassland developed, the potential reduction in carbon sequestration is estimated at $23 to $89 annually.
- ***Air Purification*:** Similar to climate regulation services, if vegetation were reduced on WHI, the magnitude of air purification services would be reduced, resulting in less economic value. **The air purification value per acre varies from $71 to $259 for forest and wetland, $24 to $86 for grassland, and $29 to $107 for shrubland.** For every acre of these habitats developed, these figures indicate the associated reduction in air purification value.
- ***Water Purification*:** Water purification benefits are linked to the degree of connection and exchange of water from the Columbia River as well as the capture of runoff from areas on WHI. Development has the potential to affect water purification services through both mechanisms. Development of facilities on WHI would almost certainly require filling of low-lying areas on the island, which would reduce the connectivity to the river and potential water filtration of Columbia River water. Fill activities that affect wetland acreage may also limit water filtration potential, but mitigation requirements would require these to be offset elsewhere, resulting in an unknown net effect on water purification services. Development may enhance the function of water purification by wetlands on WHI if polluted runoff is created from developed areas, but this would not result in a net improvement in water quality in the Columbia River and thus would not represent a net economic benefit.

B.9 CONCLUSIONS

This technical memorandum has evaluated the primary ecosystem services believed to be provided by WHI: air purification, water purification, climate regulation, flood regulation, and cultural services associated with habitat and species biodiversity. To the extent feasible given the scope of the analysis, the evaluation included quantification and valuation of each ecosystem service currently provided on WHI. The analysis also briefly evaluates the expected change in the level of ecosystem services and associated economic value under potential restoration and development scenarios.

Total ecosystem service benefits quantified under current conditions are estimated to be valued from $613,000 to $4.7 million annually, as summarized in **Table B-23**. Findings from the analysis indicate that the primary economic benefits provided by WHI resources are cultural service values related to the provision of wildlife habitat and support of biodiversity. These cultural service values, which stem from both use and non-use benefits derived from natural habitat areas, account for approximately 89 percent to 95 percent of all current ecosystem services values estimated for WHI, as presented in **Table B-23**. Benefits from air purification, carbon storage, and water purification by WHI vegetation and sediments all contribute to the annual ecosystem service benefits of WHI. Flood regulation services may also provide an economic benefit, but it is not expected that the volume of water stored and conveyed on WHI measurably affects economic damages during flood events. As additional services may be provided by WHI that are not quantified in this analysis, including habitat and biodiversity services provided by grassland and shrubland habitats, pollination services, and others, the figures in **Table B-23** likely underestimate the total economic value of ecosystem services provided on WHI.

Table B-23 also summarizes the *change* in ecosystem services from current conditions under the restoration scenario and potential development. As described in **Section B-7,** the primary benefits from restoration are likely to be increased services from habitat and biodiversity, with some additional benefits accruing from climate regulation, water purification, as well as flood control and air purification. Quantified benefits (for habitat/biodiversity, climate regulation, and water purification) are estimated to range from a minimum of $6,000 to at least $26,000 based on proposed management actions.

Under development, as described in **Section B-8**, the effect on ecosystem services depends greatly on the type, size, and level of use of developed areas and facilities. Development that includes increased recreation access and opportunities would have the potential to increase recreation and aesthetic values of WHI natural areas, but development would also be expected to reduce the amount of vegetation and acreage of habitat, with associated loss of air and water purification, climate regulation, and biodiversity services unless fully mitigated. The net effect of these changes would thus depend on the level of increased access and recreation opportunities on WHI and the level of mitigation for habitat loss and associated ecosystem service impacts.

Table B-23 Summary of Quantified Ecosystem Services Values on WHI

			Change from Current Conditions			
	Current Conditions		Restoration		Development	
Ecosystem Service	Low	High	Low	High	Low	High
Cultural Services of Habitat & Biodiversity[1]	$552,000	$4,501,000 +	$160,000	$1,640,000 +	Decrease	Increase
Air Purification	$39,000	$142,000	Increase	Increase	Decrease	Depends on Mitigation
Climate Regulation	$13,000	$48,000	$5,000	$65,000	Decrease	Depends on Mitigation
Water Purification	$9,000	$38,000	$6,000	$26,000 +	Decrease	Depends on Mitigation
Flood Regulation	Positive	Positive	Increase	Increase	Likely No Change	Likely No Change
Total Quantified Services	**$613,000**	**$4,729,000 +**	**$171,000**	**$1,731,000 +**	**Decrease**	**Potential Increase**

[1] Cultural services associated with habitat and biodiversity include recreation, aesthetics, scientific knowledge, spiritual, and cultural values.

Maps

Scale = 1:30,000
1 inch = 2,500 feet

0 0.2 0.4 0.6 0.8 1 Miles
0 1 Kilometers

Water Level

Map 1: Flood Scenario

Flood Level : 17.8 ft (NGVD 29) / 16.26 ft (NAVD 88)

West Hayden Island
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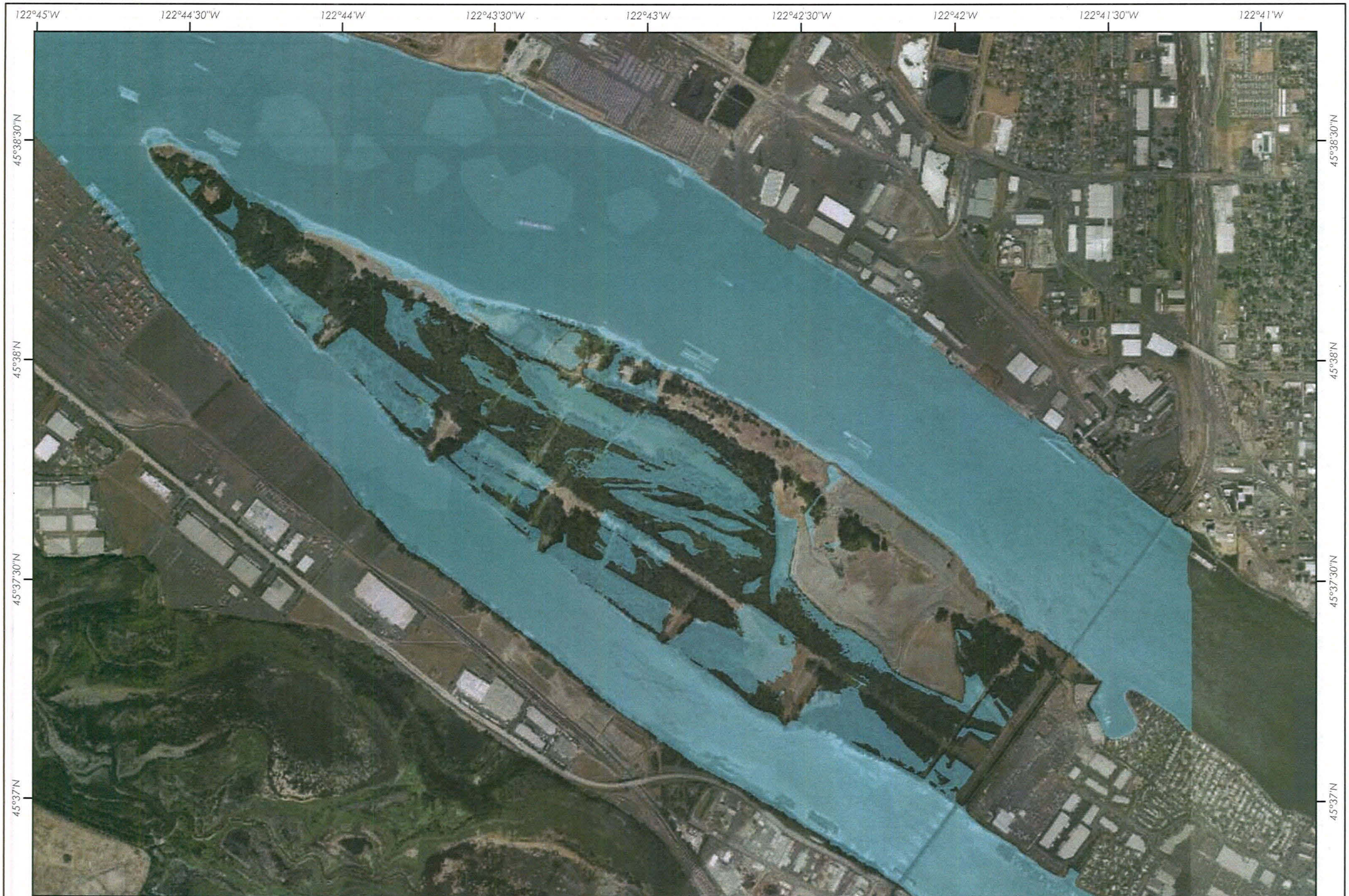
Map Projection: Mercator WGS84



Scale = 1:30,000
1 inch = 2,500 feet

0 0.2 0.4 0.6 0.8 1 Miles
0 1 Kilometers

Water Level

Map 2: Flood Scenario

Flood Level : 24.0 ft (NGVD 29) / 22.46 ft (NAVD 88)

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Scale = 1:30,000
1 inch = 2,500 feet

0 0.2 0.4 0.6 0.8 1 Miles
0 1 Kilometers

Water Level

Map 3: Flood Scenario

Flood Level : 27.2 ft (NGVD 29) / 25.66 ft (NAVD 88)

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Map Projection: Mercator WGS84

Scale = 1:30,000
1 inch = 2,500 feet

0 0.2 0.4 0.6 0.8 1 Miles
0 1 Kilometers

Water Level

Map 4: Flood Scenario

Flood Level : 31.0 ft (NGVD 29) / 29.46 ft (NAVD 88)

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Map Projection: Mercator WGS84