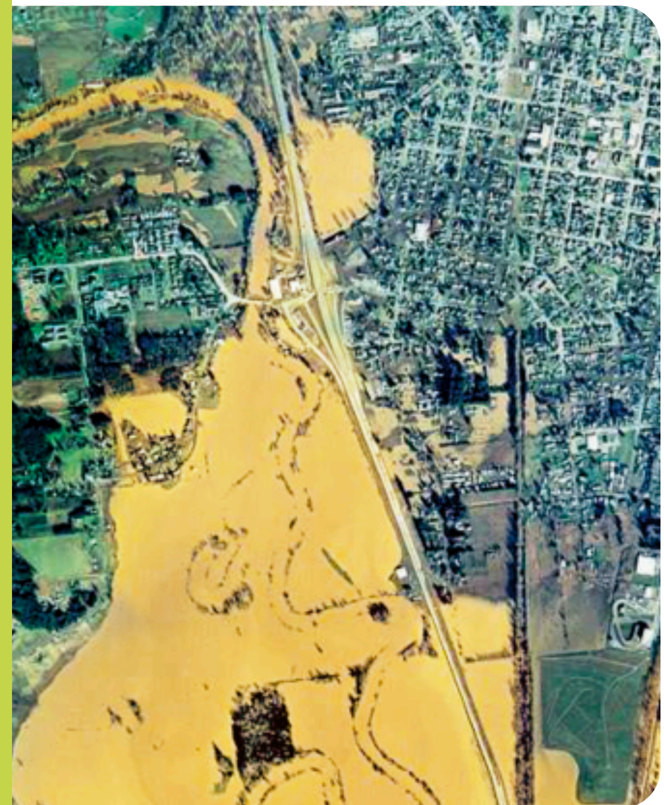
FLOOD PROTECTION AND ECOSYSTEM SERVICES IN THE CHEHALIS RIVER BASIN

May 2010



Prepared by

EARTH ECONOMICS

for the

CHEHALIS RIVER BASIN FLOOD AUTHORITY

FLOOD PROTECTION AND ECOSYSTEM SERVICES IN THE CHEHALIS RIVER BASIN

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Executive Summary

The Chehalis Basin experienced catastrophic flooding in 2007 and 2009. In response, the Chehalis River Basin Flood Authority was created to take action to protect public safety and assets, prevent flood damage and reduce flood hazards.

The purpose of this study is to inform the Flood Authority's decision-making process and ensure maximum return on future flood protection investments. *Flood protection* in this study is defined as flood damage prevention and hazard reduction.

This report identifies and estimates the economic value of natural systems in the Chehalis River Basin. One benefit these natural systems provide is flood protection. An asset value of these benefits is also provided, allowing traditional flood project cost/benefit analysis to include ecosystem services.

This study also identifies and maps some of the residents who benefit from flood protection in the Chehalis Basin. The study examines modeling systems, proposes flood protection criteria, provides recommendations, and suggests next steps.

The Connection between Flooding and Ecosystem Services

Floods are generated by the quantity, location, and duration of rainwater, and by factors such as tides, terrain slope, vegetation, soil, floodplain characteristics, floodway shape and constrictions, temperature, rain on snow melt, and how water moves spatially across the landscape. *Flood damage* occurs if people, houses, businesses, farms, and other assets are harmed by inundation.

Floods are not always bad; some flooding benefits people by providing increased fertility to agricultural soils or by renewing valuable natural systems such as those influencing salmon migration. Excessive flooding, however, or locating people and economic structures in the path of floodwaters, threatens people's lives and livelihoods. There is no question that flood protection is a necessity. Understanding how flood protection is provided within the Chehalis Basin is vital for making good private and public investment decisions.

Flood protection is a benefit provided to people by natural capital, built capital and social capital. Examples of natural capital are forests, rivers, lakes, wetlands, and permeable soils. Large trees, for instance, break up heavy rainfall. Organic soils and established root systems assist in absorbing water, while permeable soils allow surface water to soak in and recharge groundwater resources. Built capital includes man-made structures, such as dams and levees, which retain and divert water to avoid flood damage to protected areas. Social capital encompasses actions that govern people's behavior, such as early warning systems, rules requiring raised structures or better land use planning to move or keep people and assets out of danger's way. Both natural and built structures can be overwhelmed by excessive floodwaters.

Ecosystem services are benefits that natural systems provide to people. Flood protection is an ecosystem service. Watersheds provide a suite of ecosystem services. This report examines the ecosystem services that the Chehalis River Basin provides: water flow and filtration, water supply, gas and climate regulation, food, timber, fish and medicines, soil erosion control and soil formation, control of pests and diseases, waste processing, biodiversity and habitat, and pollination. It also provides aesthetic, recreation, tourism, cultural, scientific and educational values.

These ecosystem services, if healthy, have substantial economic value and are often provided by nature for free and in perpetuity. If these services were unvalued, they would easily be impaired, neglected or destroyed. Consider, for example, the Cedar River Watershed where the trees and soils filter Seattle's water. Without the forest doing the job, Seattle would have had to pay over $250 million for a water filtration plant. Most U.S. cities have made that investment.

When ecosystem services are lost, people pay. If natural flood protection, salmon productivity, storm water conveyance or drinking water services are lost, then tax districts are formed, and storm water systems, levees, hatcheries and filtration plants must be built. Real costs are incurred to replace services that were previously free. These replacement services are often less efficient than the natural services they replace. In addition, one expensive infrastructure may damage another. Such is the case of costly urban watershed storm water systems that actually increase peak flows and flooding, requiring further flood protection expenditures. In the past, polluted stormwater and levees that narrow floodways have done damage to salmon populations.

Funding Flood Protection

The rural/urban distribution of floods and ecosystem services is important. Floods and ecosystem services have distribution and equity elements. While rural areas such as the Chehalis River Basin are the net providers of ecosystem services, it is large urban areas that are the net consumers of these ecosystem services. Because the provisioning of ecosystem services remains unmapped and unvalued, there are few existing financial mechanisms to compensate rural regions for the benefits they provide to urban regions.

Modeling and mapping can help ensure that investments succeed. Reliable scenario planning can help guide flood protection investments. The most helpful would be those that are based on flood modeling and include the effects of proposed projects, such as widening the floodway, building levees, elevating housing, constructing dams, and restoring riparian functions. This modeling should provide maps of expected flood areas with different flood protection and rainfall scenarios.

Flood protection modeling approaches (the models are not yet complete) are provided in this study, using data from the Chehalis Basin (likely the most extensive use of Chehalis Basin data in any modeling effort to date). Outputs include preliminary maps generated from Chehalis Basin Geographic Information System (GIS) data for flood source and flood protection provisioning. This report introduces a computer aided analysis system, ARtificial Intelligence for Ecosystem Services (ARIES) which, once complete, could be used to provide scenario analysis of proposed flood protection projects. ARIES requires further development of hydrological modeling and scenario software. As this system is developed, more robust outputs will be developed.

Understanding flooding and ecosystem services leads to fair, efficient and effective funding mechanisms. Mapping and valuing the provisioning, beneficiaries and harms to ecosystem services establishes the requirements for getting the economics "right" and for opening new funding mechanisms for flood or watershed authorities. For example, there are state and federal impacts of flooding in the Chehalis Basin. It is in the interest of the State and Federal governments to help fund flood protection in both the short and long run. In addition, the Chehalis Basin is a net carbon sink; a carbon compensation scheme would bring funding into the Chehalis Basin. Larger timber and more soil carbon increasing water retention would also contribute to flood protection. Other countries provide a small payment to rural landowners to promote longer timber rotations. This has resulted in greater flood protection. *Consideration of Ecosystem services can help solve some of the budgetary and equity issues in rural river basins.*

For this study, initial modeling and mapping of flood beneficiaries and flood protection were completed. Additionally, conceptual modeling and mapping of flood sources (causes) were performed, and carbon sequestration for the Chehalis Basin was modeled and mapped. These models and maps were based on GIS data from the Chehalis Basin.

Economics and Scale

Flood protection provided by natural systems and social actions can be evaluated with economic analysis and should be included in all flood protection project economic analysis. If only built structures are considered to be flood protection assets, then the flood protection value of natural systems may be overlooked and lost, necessitating even greater investment in built structures. Recognizing the benefits of natural systems and their "asset value" allows them to be compared "apples to apples" with built assets and incorporated into traditional cost/benefit flood analysis. It also allows for the inclusion of other often overlooked ecosystem services, for instance salmon restoration and water quality, in the economic analysis used to evaluate flood protection projects.

It is crucial to get the scale of flood protection right. A basin-wide watershed scale focus is a relatively new and superior approach to flood protection. Until recently, flood protection jurisdictions have been created within the limited boundary of where flooding occurs and not at a scale of which includeswhere flood protection is provisioned. For example, six Washington State flood districts in King County were all limited to portions of the lowest elevations of the watersheds where historic flooding occurred. This meant that investments in flood protection were limited to levees in the lower watershed, omitting the surrounding landscape that contributed both flood protection and floodwaters to the flood zone. Realizing that flood districts that are restricted to the area of flooding simply could not provide adequate or cost effective flood protection, King County recently merged the six flood districts into a countywide district. This enables comprehensive flood prevention investment throughout a watershed. The Chehalis River Basin Flood Authority has avoided this "scale" error by setting the jurisdiction at a basin scale.

Ecosystem Services in the Chehalis Basin are valued in the tens of billions of dollars. This report estimates the dollar value of 12 ecosystem services provided in the Chehalis River Basin Watershed. As is common in dealing with estimating the value of many economic assets, from companies to houses, these ecosystem services are valued using an appraisal methodology. Rather than choose an arbitrary mean or single number, the full range from lowest to highest values are presented so that readers can understand the range of uncertainty. The values and range are large, totaling $1.3 to $11.6 billion/year in benefits. The lower value represents typically older studies, while the higher value represents more recent studies. Wide ranges in value are part of the nature of economic assets. Washington Mutual Bank, for example, was valued at $306 billion in January, 2008 and sold for $1.6 billion in October, 2008. Natural assets often have more stability in value than most economic assets (i.e. drinking water prices are relatively stable). Of the 23 ecosystem services identified as present in the Chehalis River Basin, 12 were valued. Thus, the valuations, both low and high, likely underestimate the total ecosystem service value that the basin provides. The value of ecosystem services is rising as they become increasingly scarce and the costs of their replacement go up; yet another important reason to include ecosystem services in flood analysis.

The Chehalis River Basin Flood Authority is the first flood authority to request a basin-wide flood and ecosystem service analysis to help inform flood protection investment decisions. This brings in the opportunity for more successful and cost effective flood protection. The Chehalis River Basin Flood Authority has the potential to be a national leader in flood protection, a leader from which other jurisdictions can learn.

Conclusions and Recommendations

This study makes the following conclusions:

1. Natural, built and social infrastructure provide flood protection In the Chehalis Basin.
2. In addition to flood protection, Chehalis River Basin ecosystems provide 22 other economically valuable goods and services, including water supply, food, and habitat.
3. A partial valuation of 12 Chehalis Basin ecosystem services shows a range of economic benefits between $1.3 and $11.6 billion in value to citizens every year.
4. The present value of the annual flow of these benefits (analogous to an asset value) is, at a 2.7% discount rate, between $43 billion and $400 billion for the Chehalis Basin. These benefits are provided to people living inside and outside of the River Basin.
5. The best investments for achieving flood protection are likely a combination of natural capital, such as floodplains, selective built capital, such as dams and levees, and social capital, such as early warning systems and training.
6. Some Chehalis Basin beneficiaries of flood protection were provisionally identified and mapped in Lewis and Grays Harbor. Thurston County and beneficiaries down the I-5 corridor were not mapped.

7. Project selection criteria should be adopted. This report suggests a suite of flood project criteria.
8. By understanding the set of ecosystem services provided, where flood protection is provisioned, who and where the beneficiaries are (some outside the watershed), and various flood scenarios, funding mechanisms for the Flood Authority or District can be developed.
9. An integrated approach to ecosystem services can reveal options for funding mechanisms with other ecosystem services, such as carbon sequestration, that complement flood protection.
10. Additional studies using more complete data, modeling, mapping, and hydrology could provide further information for identifying, prioritizing, and selecting flood protection projects.

Suggested next steps include the following:

Develop further modeling and mapping capacity. The basin-wide general investigation and characterization led by the U.S. Army Corps of Engineers, and hydrological studies, should be coupled with further development of flooding, ecosystem service, and scenario tools. The ARIES tools for identifying, mapping, and valuing flood protection, identifying beneficiaries of flood protection, and prioritizing flood protection project options and scenarios are still in development, but lay out a framework for better flood protection planning. Maps of ecosystem services can include:

a. **Provisioning maps** to show where flood protection and other ecosystem services and goods are produced;
b. **Beneficiary maps** to show who is benefiting from existing ecosystem services;
c. **Flood source maps** to show how flooding is created, and where provisioning of flood protection and other ecosystem services are being impaired, such as a bridge that might restrict the floodway causing increased flooding upstream, or a steep and unstable slope that could slide to block river flows;
d. **Critical Path maps** to show how the service of flood protection (which can include moving people out of the floodway) is transferred to beneficiaries, and to identify critical areas for flood protection and ecosystem service provisioning.

Develop scenario analysis. Create scenario analysis with modeling to help choose and prioritize project proposals against established criteria. These analyses might include:

a. Scenarios of different flood levels and rainfall patterns across the watershed;
b. Scenarios of single flood protection projects and combinations of projects.

Develop project prioritization and reporting methodology. Prioritize flood projects based on clear criteria, best science, public safety and a complete economic analysis of flood protection value of natural and built capital. Ensure robust reporting capability to keep stakeholders and the community informed of project status, location and performance.

Develop funding mechanisms. Examine improved cross-disciplinary funding mechanisms for flood protection and other ecosystem services to ensure the sustainability of flood protection projects and outcomes.

a. **Develop innovative funding sources.** Create complementary funding sources. Flood protection construction costs have generally been funded by federal and local agencies and through local taxes and fees. There are other funding mechanisms, such as a watershed investment district or carbon trading regime, which could provide complementary funding mechanisms (funding from outside the watershed) to supplement these traditional approaches.

b. **Seek cross-jurisdictional partnerships.** Develop funding mechanisms with a wide consideration of a combination of complementary federal, state and local funding mechanisms.

Improve Comprehensive Planning. Continue to advance land use planning, building standards and warning and evacuation systems in the Basin. These are likely some of the most effective ways of providing flood protection and creating a more efficient and prosperous economy. Examining ecosystem services within the watershed, in light of economic development planning, would also be a logical next step.

Flood protection, for some decades, will likely be one of the largest investments (over one hundred million dollars) in the Chehalis River Basin. Understanding the hydrology and science of the Basin is key to successful flood protection investments and to fully account for public safety. Understanding the economic value of built and natural capital is critical to providing an accurate economic analysis of flood protection proposals. Selecting and prioritizing projects requires the determination of selection criteria, understanding of the impediments to flood protection and identification of the location of beneficiaries. It also requires the modeling of flood protection provisioning. Tools for examining flood scenarios to test their overall economic costs and benefits, as well as the distribution of benefits, could greatly assist decision-makers. In addition, a solid governance structure for project selection, funding, sequencing, and implementation will help decision-makers secure flood protection success. This study assists with a number of these key components.

Introduction

*In this section we define the **objectives** of the study and outline what we have done to meet those objectives. Further, we provide an overview of the layout of this report.*

Objectives of the Study

The objective of this study is to provide useful information to the Chehalis River Basin Authority which enhances the Authority's ability to make effective flood protection investments. To meet that objective we have:

- Integrated land use management goals such as farming, salmon recovery, recreation, and water quality, into a comprehensive flood protection approach;
- Identified ecosystem services within the basin, and highlighted the importance of these services to sustained economic development;
- Assigned value to these ecosystem services within an economic framework of built and natural flood protection assets for long-term flood protection;
- Utilized the latest modeling and mapping tools from a National Science Foundation Grant (ARIES) for initial mapping of the flood protection provisions within the basin;
- Suggested an economic methodology for basin-wide flood protection;
- Provided an economic justification for funding flood protection, along with funding mechanisms;
- Proposed criteria for prioritizing projects;
- Concluded the results of this study, outlining the importance of a basin-wide approach to flood protection that takes into account the full suite of benefits within the basin.

How to Use this Report

It is our intention to present the findings of this report in a method that is logical, where each section leads naturally to the one that follows. Readers are encouraged to read the document in the order presented as we have tried to define terms and concepts prior to using them in examples. Recognizing that not all readers of this report will have the opportunity to read it in its entirety, there are occasions when we have repeated a concept or definition to ensure that the meaning of a particular section will not be confusing when taken out of context. We offer our apologies to readers of the full report for this redundancy.

An overview of the flow of this report as defined by primary subject headings follows:

- **The Chehalis River Basin** defines the subject of the study in terms of geography, economics and demographics.

- **The Importance of Flood Protection** defines the problem, looking closely at the impacts of flooding in terms of dollar and other costs.
- **Integrating Development Goals** introduces the theory that flood protection goals and other development goals can complement one another in compelling ways.
- **Key Concepts** defines fundamental elements and definitions necessary for an understanding of an ecological economics approach.
- **Economics and Ecosystem Value in the Chehalis Basin** goes deeper than the previous section into describing how an ecological economic approach applies to the study of the Chehalis Basin.
- **Valuation of the Chehalis Watershed** puts ecological economics into action, determining dollar values based on concepts developed in the previous two sections.
- **Earth Economics Ecosystem Service Valuation Analysis** summarizes the data used to arrive at the base dollar values.
- **Modeling Flood Protection** introduces a new and sophisticated modeling tool being developed to help decision makers, and provides preliminary maps generated from one of these tools.
- **Management Implications** summarizes several of the critical issues raised in this report.
- **Conclusions**, **Suggested Flood Project Criteria**, and **Next Steps** are intended to help the reader of this report to both synthesize the information presented, and understand how to use it.

The Chehalis River Basin

*As readers of this report may not be intimately familiar with the Chehalis Basin, we describe in this section the **geography** of the region, including a description of regional **land use** patterns, and we provide an overview of the region's demographics, looking at the **economy** and **employment** historically, in the present, and the future.*

Geography and Land Use

The Chehalis Basin is the second largest in Washington State, spanning 2,600 square miles and covering parts of six counties in Southwest Washington. As of the 2000 Census, the total population in the basin was 141,000 (Chehalis River Basin Flood Authority, 2009). The largest cities are Hoquiam, Aberdeen, Centralia, and Chehalis. The Chehalis Basin extends from the Olympic Mountains in the North to the Willapa Hills and Cowlitz River Basin along the South; and from the Deschutes River in the East towards Grays Harbor, where the Chehalis River meets the Pacific Ocean.

Much of the watershed is covered by forest and shrub – only 4% of land has been developed for urban and industrial uses while 87% of the land remains as designated forest. Of the nearly 1.1 million acres of non-riparian forest cover in the Chehalis Basin, 480,000 acres are early succession forests (trunks 0-4.9 inches in diameter). Over 230,000 acres of forestland are pole (5-9.9 inches). 290,000 acres are mid-succession (10-19.9 inches) and 78,000 acres, primarily at the northern end of the watershed, are late succession/old growth forests (20 inches and greater). Other land uses include rivers and lakes (2%) and agriculture (7%). Much of the forested land is operated by commercial timber companies, which supply local jobs and produce economic gains to the basin and the state. The Capitol State Forest, parts of the Mt. Baker-Snoqualmie National Forest and the Olympic National Forest are also within the basin boundaries (Chehalis Basin Partnership, 2002).

Though the bulk of natural value in the Chehalis Basin is provided by forestland, the Grays Harbor Estuary also provides a great deal of economic and ecological value. Historically, the estuary housed vast eelgrass beds. Roughly 70% of the estuary is still intact, with most of the loss resulting from damage caused by land conversion (Chehalis Basin Partnership, 2004). Today, according to recent studies, eelgrasses provide annual nutrient cycling services worth over $20,000 an acre (Costanza et al., 1997). Additionally, eelgrass beds provide nurseries for crab, shellfish and finfish. Other vegetation types provide value. These include riparian areas supporting salmon spawning grounds, agricultural lands providing crops, and wetlands providing flood protection, to name a few.

The Chehalis Basin spans multiple jurisdictions. By county, the majority of the land is within Grays Harbor County (50%), Lewis County (28%), and Thurston County (12%), with smaller portions in Mason County (7%), Pacific County (3%), and Jefferson County (.07%). The Chehalis Indian Reservation is also within the basin, located near the mouth of the Black River.

There are three distinct ecoregions in the basin: the Cascade region, which includes the Olympic Mountains, the Puget Lowland region, and the Coast Range region (Grays Harbor County, 2004).

The basin has two Watershed Resource Inventory Areas (WRIAs). These are districts authorized under the Water Resources Act of 1971, Revised Code of Washington (RCW) 90.54. These areas are WRIA 22 - Lower Chehalis, and WRIA 23 - Upper Chehalis. The basin contains over 30 sub-basins.

Economy and Employment

A great deal of demographic information is collected by the US Census, while employment information by industry or occupation is often captured by agencies at the state level, such as the Washington Workforce Training and Education Coordinating Board (WTB) or the Washington State Employment Security Department. These entities do not break all of their information down by county. Instead, they divide the state into 12 Workforce Development Area Regions. Grays Harbor, Lewis, Mason, Pacific, and Thurston Counties are grouped together in **Region 2: Pacific Mountain**. This data includes roughly 99% of the Chehalis Basin. However, Region 2 also includes Olympia, which is outside the Chehalis Basin and houses a large government sector.

The data shows high rates of employment in the forest products industry (33 times the national average) and fishing and seafood processing (16 times the national average) (Sommers et al., 2008). Of the seven counties that are part of the Chehalis Basin, all except Thurston County fall into the lowest category of average annual per capita income (as measured by the Washington Regional Economic Analysis Project) of $30,000 or below (WREAP Website). In part, these income statistics reflect the area's historical reliance on natural resource-based employment, such as forestry and fishing, as opposed to higher paying industries like technology or manufacturing, though new economic development within the basin has included some manufacturing and sustainable energy technology (DOLETA Website). And according to the WTB's 2008 report, "Industry Cluster Analysis for Washington State Workforce Development Areas", the Pacific Mountain Region is expected to see growth in new job markets including ambulatory health care, construction (including architectural and engineering services, and marine construction) and business support services.

While growing industries may potentially impact the economic future of the Chehalis Basin, the current economy in this region is still largely dependent upon industries based in the natural environment such as forestry, fishing, and retail and manufacturing of products for recreational and professional activities that take place outdoors. According to the Washington State Workforce Training and Education Coordinating Board, of the clusters for which data were available in the region, the most important industries at this time are:

1. Forest Products
2. Fishing, Seafood Processing & Shipbuilding
3. Travel Trailer and Camper Manufacturing
4. State & Local Government – Non-education
5. Other Accommodations

6. Sporting Goods Manufacturing
7. Agriculture and Forestry Support
8. Animal Production – except Cattle & Poultry
9. Business Support Services
10. Cattle Ranching and Farming
11. Other State and Local Government Enterprises
12. Other Ambulatory Health Care Services
13. Other New Construction

The Pacific Mountain region, including the Chehalis Basin, produced over $1 billion in taxable sales in 2005. The recent recession demonstrated that some types of natural resource-based employment may be more stable than manufacturing and industry. While all four counties in the Pacific Mountain region experienced higher unemployment than the state average in November 2009 (Vleming, 2009), goods producing sectors, such as manufacturing and construction, reported the biggest job losses (Vleming, 2009).

The future of a healthy Chehalis River Basin economy will require innovative and effective management of natural systems, and working and wild lands, as well as economic diversification into developing fields such as renewable energy. Core to this development strategy is flood protection because, as floods in recent years have shown, the costs of unmitigated flood damage are devastating to the local and regional economy.

The Importance of Flood Protection

*This section considers the importance of **flood protection** as a mechanism for **preventing damage**, and **reducing hazards** which affect people, the economy and the environment, and makes the assertion that an integrated, basin-wide approach is necessary to clearly see the advantages of different flood protection investments. We look in detail at the **costs of flooding**, including **transportation costs** caused by delays and ruined infrastructure, and **private property costs**. We summarize actual spending on the 2007 flood, which exceeded $200 million by Washington State and amounted to nearly $94 million by Lewis County.*

Flood protection is defined here as flood damage prevention and hazard reduction. Flood protection is central to public safety, economic development, and ecological health. Flooding caused immense damage to personal property, agricultural land, local businesses, and transportation systems in 2007 and 2009. Past approaches to flood control have at times created other problems by damaging fish habitat, shifting flooding to communities down or upstream, and by changing soil quality.

Floods can be enormously hazardous, threatening human safety and causing extensive economic damage, but it cannot be overlooked that they can also provide benefits such as fertile soil and habitat restoration. An integrated, basin-wide approach is necessary to understand and evaluate the advantages of different flood protection investments.

Impact of Floods on People

Public Safety. Floods can kill people, as past floods in the Chehalis Basin have tragically demonstrated. Flood protection saves lives.

Personal Trauma. Flood protection helps people avoid the hardship, personal distress, and long-term economic impoverishment often linked to flooding.

Psychological Harm. Flood protection can avoid the increased alcoholism, domestic violence, high school drop-out rates, and suicide rates that have been associated with large floods.

Communities. Flood protection helps communities be more stable, retaining greater cohesion, and job capacity, and it reduces emigration and crime.

Quality of Life. Protection from catastrophic floods is a requirement for people and communities to maintain a high quality of life.

Impact of Floods on the Economy

Transportation. Flood protection protects roads, railways, and highways, ensuring that financial benefits from transportation continue both locally and regionally.

Private Property. Flood protection guards homes, businesses, and larger industries and reduces insurance costs and government flood damage payments.

Public Infrastructure. Public services, such as clean drinking water and power, are retained with flood protection, avoiding costly repairs due to flooding.

Agriculture. Farms can benefit from both flooding and carefully applied flood protection. Some lands can receive floodwater and sediment, while other should be protected.

Water Quality and Overflow. Flood protection can prevent release of pollutants, chemicals, and garbage, protecting drinking wells, rivers and streams, and, finally, the ocean.

Wastewater. Flood protection retains sewage systems and treatment plants, preventing untreated sewage, which threatens public health, from flowing into waterways, homes and buildings.

Impact of Floods on the Environment

Landslides. Slope stability is highly dependent on soil saturation, types and structures, as well as vegetative cover and other factors. A single massive rain event can cause as much land sliding and erosion in 24 hours as 100 years of more moderate weather. Land use directly impacts slope and soil stability.

Erosion. Erosion is a natural process. Higher elevation materials move downstream with increased rainfall and flooding. Excess debris and sediments can clog waterways and cause new flow channels to form. Mudslides typically occur as a result of soil saturation after heavy rainfall and flood events.

Wildlife and Salmon. Seasonal and moderate flooding, as well as sufficient water in low-flow periods, are important factors for the life-cycles of many animals.

Shellfish and Fish. Contamination from extensive flooding can damage shellfish areas and wild fisheries, reducing harvests and employment.

Healthy Ecological Effects. Some natural systems require flooding for cleansing, gravel migration and more. Flood protection does not mean the elimination of flooding.

Integrated flood management should be custom designed for the basin, integrated with the economic development visions of counties and cities, and supportive of other goals, such as improving agriculture and restoring salmon populations. Sustainable and effective flood protection begins with drawing the boundaries of jurisdictions, such as flood districts, correctly. Flood jurisdictions have often been created at the wrong scale to adequately address flooding. Boundaries are based on the areas of flooding--usually the lower portions of the watershed--not on the entire river basin, which encompasses the true scale of flood generation and protection.

The Cost of Flooding in the Chehalis River Basin

Major Chehalis River Basin flood events have occurred in 1972, 1975, 1986, 1990, 1996, 2007, and 2009. In the past 30 years, 16 events have been declared federal disasters in Lewis County, 13 caused by, or related to, flooding. Storms, in 2007 and 2009, required closure of Washington State's primary commerce corridor, Interstate 5, and a major railroad corridor. Damages extended far beyond the basin, disrupting delivery of medical supplies, food, hazardous materials and fuel in Western Washington and down the west coast. The collective cost to the public, of severe flooding in the Chehalis River Basin, was in the millions of dollars each day (Cowlitz Wahkiakum Council of Governments 2009; WSDOT, 2008).

Costs from a storm that floods the Chehalis River may include agricultural losses, property damage, losses to local homeowners and businesses, damage to public infrastructure, and water pollution from storm runoff and sedimentation. In recent years, the severity of flood damage, and consequently, the cost, has risen. Predictions that storm frequency and intensity may be increasing with climate change must be seriously considered, and cost-effective mitigation strategies developed. If the flood events of the past few years are any indication of what may become a regular occurrence, the Chehalis Basin needs a dramatic improvement in flood protection.

The 2007 storm, for example, brought hurricane-force winds and heavy rains throughout the Pacific Northwest. Lewis County received a record 20 inches of rain in 48 hours, and the flooding "buried some towns under 10 feet of water and caused tens of millions of dollars in property damage" (Mayo, 2009). There were 730 landslides across the Chehalis River Basin, according to aerial surveys by the DNR (Mayo, 2009). Gauges along the Chehalis River, in place since 1939, measured a peak flow of more than twice any previous measurements (Mayo and Bernton, 2008). Thurston and Grays Harbor Counties were also severely affected. Farms, houses, gas stations and other facilities were flooded in Thurston County. Highway 101 and State Road 12 were submerged cutting off the major roads to Grays Harbor. Many residents throughout the watershed were cut off by flooded roads and lost electrical power. Thurston, Lewis, Grays Harbor and Pacific Counties were declared disaster areas.

Damage from this storm was particularly costly due to recent development in the floodplain: over half of Lewis County's commercial lands, and up to 32% of the industrial lands, are located within the footprint of the last two major floods in the area (Cowlitz Wahkiakum Council of Governments, 2009) Development has increased impervious surfaces resulting in decreased area for water infiltration/absorption.

Final flood damage estimates in Lewis County total in the hundreds of millions. The Federal Emergency Management Agency, or FEMA, estimates at least $166 million in private and public damages[1]. Costs included damage suffered by residents, businesses, public institutions, property, farmland, the I-5 closure, contamination of local water supply, and infrastructure repair costs.

1 Lewis County Health Department, February 10, 2008; Long Term Recovery Project, a coalition of Lewis County churches.

Many costs were born by businesses and landowners. Much of the repair was paid for with government funds at the local, state, and federal levels.

As Table 1 demonstrates, over $200 million in federal funding was allocated to Washington State following the 2007 disaster. Governor Christine Gregoire proposed state spending of $77.5 million dollars in flood recovery as part of the 2008 budget (Governor Chris Gregoire Policy Brief, 2007). In addition to state spending, there was substantial local spending and contributions from private parties. Table 1 is followed by a detailed description of the costs, by category.

Table 1. Federal Funds spent on 2007 Flooding of the Chehalis River

Source	*Total WA State Funds Allocated*	*Total Lewis Co. Funds Allocated*	*% Lewis Co. Funds Allocated*
IHP Totals (HA + ONA)	$20,814,604	$12,196,554	58.7%
SBA Disaster Loans	$35,637,700	$23,314,900	65.4%
Public Assistance Obligated	$38,390,984	$11,025,140	28.7%
Federal Highway Admin.	$62,811,814	$6,832,107	10.9%
National Flood Insurance	$50,602,832	$40,338,076	79.7%
Total	**$208,257,934**	**$93,729,878**	**44.9%**

Source: Economic Development Administration, 2009. Lewis County 2007 Flood Disaster Recovery Strategy, January 2009

Transportation Delay Costs

Flooding has increasingly impacted access to major highways and regional roads. I-5 was closed for one day in 1990, four days in 1996, four days in 2007, and two days in 2009. Army Corps estimated at that time in 2004 that the total cost for a one day closure along I-5 would be 3.4 million dollars. They also estimated that a 100-year flood would close the section of I-5 in Lewis County for roughly 4.5 days (WSDOT 2008). However, recent closures have been both more frequent and more costly than estimated. Road closures for up to 4 days have already occurred twice in the past 13 years, indicating either an increase in 100-year flood frequency, or an underestimate of the susceptibility of I-5 to flooding. More current estimated costs per day of closure have been triple the 2004 estimate. According to the Washington Department of Transportation (WSDOT), the total cost of four days of freight delay along I-5 in 2007, including lost state tax revenue, jobs, and personal income, was $47 million (Cowlitz Wahkiakum Council of Governments, 2009). The most recent WSDOT report estimated that the economic impact of closure along I-5 was closer to $12 million per day, and $6 million per day for I-90 (WSDOT, 2008).

The most significant costs to the state come from major freight delays along regional shipping corridors such as I-5, as well as major east/west throughways. However, many additional expenses are incurred by private operating companies from logistical and scheduling costs, and indirect market costs. Costs in detour fuel and driver wages can range from $500 - $850 per truck per day (WSDOT, 2008). Assembly lines may be shut down if vital inputs are delayed. Smaller roads have also been closed, causing additional losses in foregone wages and lost productivity. During the winter of 2007-2008, coastal communities in Washington faced the closure of 65 local roadways (WSDOT, 2008).

Transportation Infrastructure Repair Costs

The cost of freight and passenger traffic delays is only part of transportation flood costs. Storms can cause enormous damage to roads and infrastructure. Indeed, the Lewis County 2007 Flood Disaster Strategy Report found restriction of road access to be the most significant and costly infrastructure damage (Cowlitz Wahkiakum Council of Governments, 2009). Road damage in 2007 included $4.5 million worth to I-5 and SR 6 and an additional $1.5 million to other Lewis County roads including SR 7 and US 12 (Cowlitz Wahkiakum Council of Governments, 2009). The storm damaged many logging roads (Mayo, 2009) as well as rail and air infrastructure. Damage to the Curtis Industrial Park rail line, railroad bridges, and neighboring culverts in between the Port of Chehalis and Pe Ell cost $1.5 million to repair. Levee failure resulted in flooding at the Chehalis-Centralia airport causing damages totaling $346,000 (Cowlitz Wahkiakum Council of Governments, 2009).

Private Property Costs

The damage caused by flooding of private property was enormous. While erosion, debris, and sedimentation contributed the most to agricultural damage, road blockage and water damage caused a greater share of the problems for businesses, public agencies, and residences in the floodplain.

Prior to the flooding in December 2007, many businesses in the Chehalis Watershed were unaware of the potential risk and were ill prepared for severe flooding. One resident described the flood as a “freak event,” despite the area’s frequent flood history (Green et al., 2008). Only about half of the businesses had made emergency flooding plans. Less than half of all businesses had flood insurance, despite being flooded previously (Green et al., 2008). More than 200 businesses were flooded in December 2007. This included two large shopping centers, strip-mall retailers, locally-owned businesses, farms, and retail chains (Green et al., 2008). Many businesses who did not suffer flood damage were profoundly affected as well; road closures preventing customer access (Green et al., 2008). Negative indirect effects were also high. Businesses, both inundated and not inundated, reported still lower than average sales two and a half months after the waters subsided (Green et al., 2008). Only 25% of flooded businesses considered themselves recovered after two and a half months, while 38% expected to recover within a year (Green et al., 2008).

The Institute for Global and Community Resilience at the Huxley College of the Environment, Western Washington University, carried out an analysis of business impacts in the aftermath of the December 2007 flood. Findings showed that most businesses experiencing an average of 3 ft. of flooding were forced to close during that period. Many reported depressed revenue long after the flood, due in part to lost inventory, road closures and repairs, lack of disposable income and dislocation of many residents. Of those flooded businesses surveyed, an average total loss of 38% of gross annual sales was experienced as of mid-February, 2008 (Cowlitz Wahkiakum Council of Governments 2009). In total, business costs from the 2007 flood were estimated to be $45 million (Cowlitz Wahkiakum Council of Governments 2009).

Agriculture Costs

In 2007, flooding and landslides led to a great deal of erosion. As water ran over eroded areas, silt and wood debris was carried downstream, particularly near Pe Ell. According to the Lewis County Conservation District, 4,776 acres of agricultural land in the county were affected by the flooding, with a total cleanup cost of $2,388,000 (Cowlitz Wahkiakum Council of Governments 2009).[2] Fencing was damaged (42.8 miles) according to the USDA, with the total cost of repair likely between $797,223 and $1,025,001. The USDA also estimated that reseeding costs for 1,886 acres ranged between $188,600 and $490,360.[3]

The Lewis County Health Department counted a total of 1,600 commercial livestock, including 400 dairy cows, which perished in the flood.[4] Other livestock lost included cattle, horses, sheep, goats, pigs and llamas.

Equipment from cars to tractors was flooded and destroyed. As much as $5 million of farm equipment was damaged. Some farmers were unable to suitably prepare their fields for the next spring planting, and others had to clear significant debris off of fields and out of flooded barns and buildings (Washington State OFM 2008).

Shellfish Costs

Shellfish harvests were reduced due to flooding. Flood waters may wash animal waste and human sewage into the rivers. Ingesting shellfish from such areas can cause serious gastrointestinal illnesses. Sedimentation and impacts to upstream sewerage treatment plants can also damage shellfish and fisheries. During 2007 flooding, twenty-two shellfish areas were closed for up to two weeks, until mid-December. These closures affected 242 commercial harvesters (Washington State OFM 2008).

Water/Power Utility Costs

During flooding in 2007, 75,500 people lost power and 16,100 water customers were affected (Governor Chris Gregoire Policy Brief 2007). One example of how flooding can have long-lasting impacts on residents and taxpayers is the damage the 2007 storm caused to the Boistfort Valley Water Corporation. Boistfort Valley Water has two treatment plants – one located on Stillman Creek and the other on the Chehalis River in the upper Chehalis Basin.

The Stillman Creek plant, near Little Mill Creek, was damaged during flooding in 1990, and suffered damage again during the 2007 flood. Major landslides along Little Mill Creek, Stillman Creek, and heavy debris that overflowed from the Chehalis River caused damages amounting to an estimated $750,000 for Boistfort Valley Water (K. Voyles, personal communication, August 2009). The area's

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2 Citing 27 Lewis County Conservation District. Unpublished document, April 7, 2008 (Interview with Bob Armine, District Manager, April 8, 2008).

3 Citations within Lewis County 2007 Flood Disaster Recovery Strategy.

4 Citations within Lewis County 2007 Flood Disaster Recovery Strategy.

3,000 customers who depend on the creek for water went three months without potable tap water. The Boistfort Valley Water Corporation also lost income from residents who were forced to move away after damage to their homes and foreclosures. Though the USDA recommends increasing monthly base rates by $2 per year, because of the flooding, the monthly base rate for Boistfort Valley Water consumers was raised from $50 to $56 per month (K. Voyles, personal communication, August 2009). Until the causes of this damage are fully addressed, Boistfort Valley Water will remain at risk to flood damage.

Roads, sewage treatment facilities, drinking water systems, schools, and government buildings are all critical community investments which can be destroyed by flood damage. Levees and dams can also be severely damaged by floods, and may require expensive repairs.

Social Costs

The full social costs of the 2007 and 2009 floods cannot be measured. However, following the 2007 flood, it was estimated that 12,000 people would have benefited from crisis counseling. It was estimated that the flood would result in an 8 percent increase in alcohol and substance abuse over 9 months. In addition, many residents were forced into temporary living conditions (Washington State OFM 2008).

Integrating Development Goals

In this section we propose that flood protection, salmon restoration, water quantity and quality, agriculture, recreation, economic development and the quality of life within the Chehalis River Basin are ***interrelated****. We explain why any flood protection solution must be integrated with development, community and environmental goals.*

The Chehalis River Basin provides a high quality of life for residents. The basin supports a well-balanced economy including farming, fishing, industry, energy generation, ports, retail outlets, services, schools, many small businesses and government agencies. The Basin also contains abundant natural resources, which are increasingly scarce in many parts of the world. When investigating flood protection it is critical to favor solutions that do not harm these natural resources. Flood protection planning must also consider tribal rights, endangered species lists, drinking water quality, et cetera. Further, great consideration should be given to solutions that enhance these precious resources.

Construction of a levee, for example, may confine the floodway, and while protecting one area from flooding, may increase flooding in other areas. Thus, while the overall benefits may outweigh the costs, the distribution of costs and benefits may not be equal. Fully examining the natural and built infrastructure can decrease the overall costs and increase the overall benefits.

Following are scenarios that demonstrate the importance of an integrated flood protection approach:

Chinook salmon and bull trout are federally listed endangered species. There is a clear legal and social mandate to restore these populations to health. Improving watershed health in areas important for salmon is a critical goal, recognized and manifested in the Chehalis River Basin Partnership. Flood hazard mitigation actions can benefit or harm salmon populations. In many urbanized watersheds, levees occupy and narrow the transition zone for salmon, where the young adjust from fresh to salt water. This can create swift currents that sweep young fish directly from fresh to salt water, resulting in high mortality rates. On the other hand, setting levees back (widening the floodway) coupled with restoration investments such as off-channel sloughs, can create greater salmon habitat while at the same time provide greater flood protection, restore salmon populations and reduce levee maintenance costs.

Farming, forestry, shellfish and fishing have always been core to the Chehalis River Basin economy. With the recession, unemployment, rising oil prices, and climate change, there is a rising interest in locally grown food, and the Chehalis Basin provides food well beyond its boundaries. Farming and flood protection efforts need not always be in conflict. Indeed, farming originated in flood prone valleys and deltas, and most Northwest crop rotations are compatible with winter flooding. Flooding, water quality, and nutrient flows all have significant impacts on shellfish, and some fisheries as well. Thus, flood protection has a considerable impact even in marine waters.

Dairy cows, beef cattle, sheep, horses, and poultry can be killed and critical farm equipment lost in floods. It is vital that flood protection decisions be supportive of the agricultural community and agricultural development goals. Elevated platforms, called "Critter Pads", for example, can be installed to provide higher elevation refuge for livestock during a flood event.

Tribes within the basin have sovereign rights that must be respected and supported. Sacred areas or burial grounds need to be protected. The Chehalis Tribe has been a consistent and vigilant advocate for a healthy Chehalis Watershed, which has benefited tribal members and everyone else living within the Watershed. The Tribe has often led in creating policy which supports healthier riparian and upland watershed habitat.

By taking a comprehensive basin-wide approach to flood protection, inclusive of communities affected by flooding, and areas that provide flood protection, the Chehalis River Basin Flood Authority is set at the right scale to integrate flood protection with development and conservation goals across jurisdictions, industries, ecosystems and communities.

This paper has proceeded with the assumption that flood protection is integrated with development, community and environmental goals. To further advance an understanding of an integrated flood protection approach, some key concepts are provided in the following section.

Key Concepts

*In this section we consider the idea that economic analysis which includes ecosystem services is important to flood protection. Investments in flood protection have always been based on a cost/benefit analysis to determine whether flood protection options provide a positive rate of return on investment. Here, we explain fundamental elements of **ecological economics**, key to understanding and embracing an innovative, integrated approach to flood protection. We look at **built capital**, **natural capital and social capital** and how they complement one another, and we introduce a number of additional Key Concepts that appear in greater detail further into this document.*

Flood protection, salmon restoration, water quantity and quality, agriculture, recreation, economic development and the quality of life within the Chehalis River Basin are interconnected. Investments in each area must be carried out with an understanding of the full costs and benefits, as well as the distribution of these benefits and costs.

Ecological Economics

Flood protection is provided by natural systems, built infrastructure and social decisions. However, flood management has often focused almost exclusively on built infrastructure. This is because the economic analysis of flood protection measures the economic value of built structures that provide flood protection. The economic value of natural systems such as forest cover, which provides flood protection, and social actions such as improved planning, have generally not been included in flood protection economic analysis.

This is an important consideration for the Chehalis River Basin Flood Authority, because built structures such as levees require maintenance by local flood jurisdictions and inevitably depreciate. Natural systems have a greater capacity for self-maintenance, and changing land use patterns can avoid future flood damage. Assigning value to natural systems is a new and widely accepted field in economics. Economic methods for estimating social benefits were beyond the scope of this report.

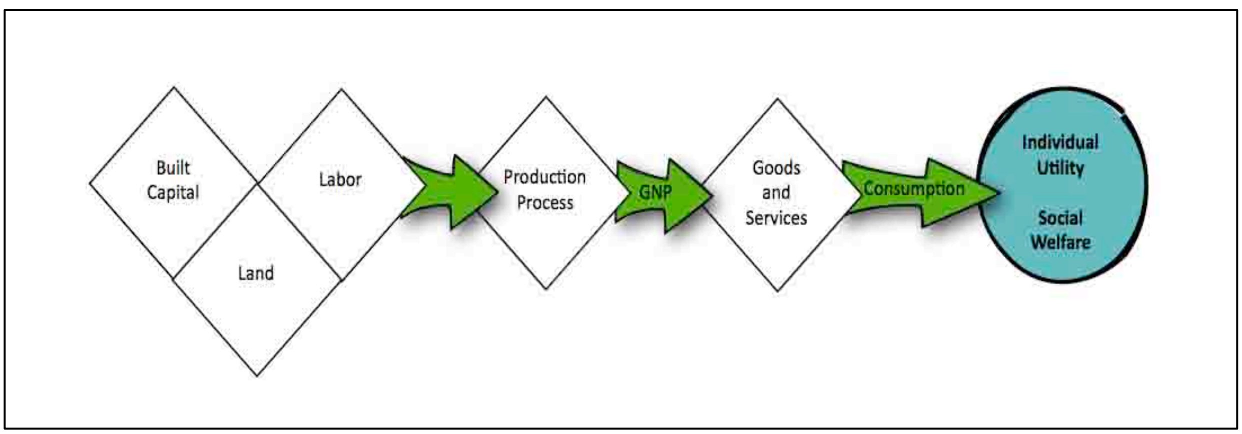
Our natural environment provides things we need to survive – breathable air, drinkable water, food for nourishment, security from flood and storm, and stable atmospheric conditions – to name a few. These are what we refer to as “ecosystem goods and services”. Natural systems are now seen as economic assets, providing economically valuable goods and services. If these valuable goods and services are lost, people sustain costs, like increased flooding. The service previously provided by natural systems for free, must be replaced by costly, built structures. In some cases, once lost, ecosystem goods and services cannot be recovered - a species gone extinct, for example.

Many economic measures were developed when natural capital was abundant and built capital scarce. With the goal of providing more manufactured goods and services, we developed a blind spot to the economic importance of natural systems. Built and financial capital, along with labor, are typically considered as the primary "factors of production" for economic development, and have long been considered to have value in flood analysis. Land and natural systems, on the other hand, were infrequently included in economic analysis.

Today, economics recognizes the many things important to human well-being beyond manufactured products. In fact, a great deal of research suggests that things like leisure time, equality, and healthy relationships are much more important to happiness than greater consumption (Easterlin, 1995; Easterlin, 1974; Graham, 2005).

This is important to the prioritization of flood protection projects because if only a sub-set of economically important benefits are considered in flood protection analysis, then other critically important natural systems or community values may be missed. Figure 1 provides a sketch of the economy without valuing natural systems.

Figure 1. Model of the Economy that Excludes Natural Capital



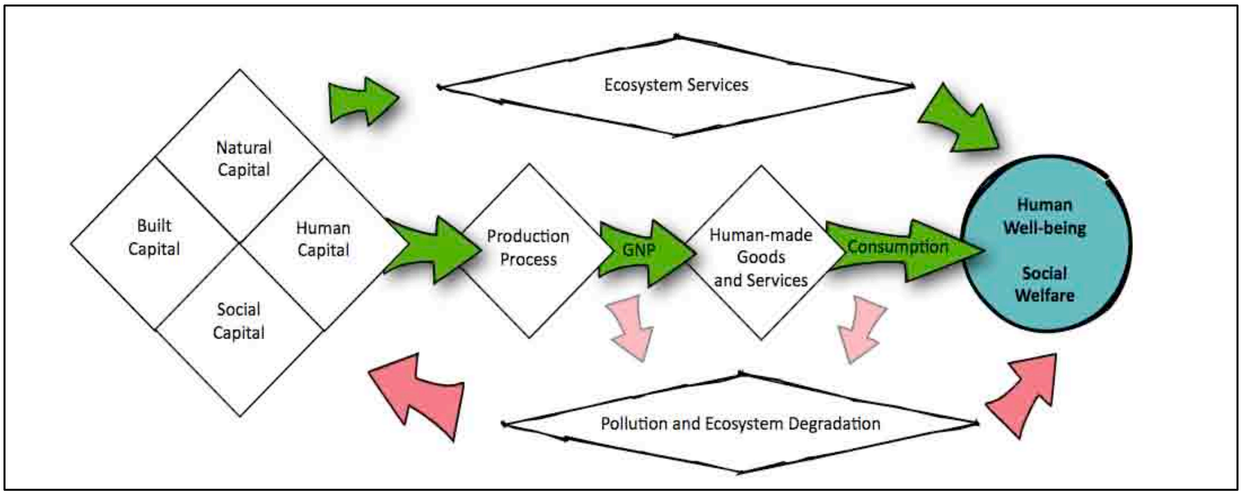
Adapted from Costanza et al. 1997a

As natural capital and the goods and services it provides have become scarcer, work in this area of economics has increased. In 2009, Elinor Ostrom, a founding member of the International Society for Ecological Economics, shared the Nobel Prize in Economics for her work on the economics of natural resources and the commons.[5]

5 http://nobelprize.org/nobel_prizes/economics/laureates/2009/index.html

Built capital has often been considered a substitute for natural capital. For example, a filtration plant can substitute for forests that filter water. However, built and natural capital, when used in combination, provide the best services to people. Water pipes, for example, cannot substitute for water. It takes both to provide water at the spigot. In addition, all built capital requires natural capital inputs of material and energy. Natural capital and built capital are productively used as complements rather than substitutes (Daly and Farley 2004).

Figure 2. Ecological Economic Model of the Economy



Adapted from Costanza et al. 1997a

Figure 2 shows how built, natural, human and social capital all contribute to successful production processes, goods and services, and human well-being. Ecosystem services provide direct economic benefits for human well-being, while pollution and ecosystem degradation cause damages.

Economics is important to flood protection because virtually all flood protection investments are based on economic cost/benefit analysis to determine if the flood protection investment will provide a positive economic return.

Ecosystem Goods and Services

Ecosystem goods and services are natural resources based on ecological functions. Natural systems, such as forests, wetlands and riparian habitat are like factories in a way; their particular structure and the flow of living and non-living materials through these systems generate goods, such as timber or salmon, and services, such as flood protection or recreational value. Just as an assembly line must be organized with the inputs fed in, natural systems require structure and inputs to produce goods and services.

Natural Resources

This is the entirety of goods and services derived from the geology, atmosphere, and terrestrial and aquatic natural systems. These may include everything from energy sources such as petroleum, coal and wind energy, to minerals like gravel or copper, as well as timber, salmon, and the clean, breathable air we need to live.

Natural and Ecological Functions

Natural systems, such as forests, wetlands, rivers, and marine waters have a vast number of functions that maintain them. These functions utilize and regulate the flow of water, nutrients and materials, as well as regulate the interactions between elements within these systems. Natural functions are dependent on natural infrastructure. For example, trees on slopes break up falling rainwater and facilitate greater infiltration and lower/slower peak flood flows, while those same slopes devoid of vegetation have faster run-off, greater erosion, less infiltration and higher/faster peak flood flows. Natural systems have lots of functions, right down to the mechanics of microbes. Many of these functions are not well understood, and, for many others, there are no apparent links to human well-being. The ecological functions produced by natural systems that *do* provide very clear benefits to people come in two forms: ecosystem goods and ecosystem services.

Ecosystem Goods

Goods are physical objects created as a result of a process. Ecosystem goods are typically tangible, items quantifiable in flow, volume, weight, or quantity. Examples are drinking water, timber, fish, crops and wildlife. Most goods are exclusive, which means that if one individual owns or uses a particular good, that individual can exclude others from owning or using the same good. For example, if one person eats an apple, another person cannot eat that same apple. Excludable goods can be traded and valued in markets. The quantity of water produced per second, or board feet of timber cut in a 40-year rotation can be measured by the physical quantity an ecosystem produces over time. The current production of goods can be easily valued by multiplying the quantity produced by the current market price.

The sustainable stream of goods provided by an ecosystem is a “flow of goods.” These goods can provide enormous economic return; for instance the Washington State Department of Natural

Resources (DNR) predicted over $222 million worth of timber sales and removals for 2009 (Washington State DNR, 2009). This revenue can be realized by a public agency such as the DNR, or by a private corporation. However, the collection and sales of ecosystem goods can affect the ability of the remaining ecosystem to provide other goods and services, such as flood protection, clean drinking water or recreation. In order to reach optimum economic efficiency, the value of timber revenue *and* flood protection, clean water, recreation, and other goods and services should be considered. Though timber harvest may be a privatized good, maximizing its value may lower the value of other public services and goods. By including the value of the entire suite of ecosystem goods and services, the economic relationships and tradeoffs can be better understood.

Ecosystem Services

Services, such as flood protection, are not measurable in physical quantity. Some services, such as human labor, can be valued (wages), measured (time or work accomplished) and traded in markets (labor market). Ecosystem services are defined as "the conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfill human life" (Daily et al., 1997). Unlike ecosystem goods, ecosystem services are not tangible items that you can hold. Ecosystem services are often difficult to value, measure and trade because they have no labor component. Flood protection, recreational value, aesthetic value, and water filtration are a few of the services that many ecosystems provide. Many services are not easily measured in terms of market value--many are fundamentally "public goods". Because of their physical nature, no one can privately own them, and they cannot be traded in markets, just as no one can own or trade natural flood protection (though built infrastructure that provides flood protection, like levees, *can* be owned). Ecosystem services are more difficult to value, yet they are very valuable and vital both for our quality of life and for economic production (Daily, 1997; Costanza et al., 1997).

Many ecosystem services are non-excludable. When one person enjoys a view of the sunset, it does not prevent another person from enjoying the sunset same, unless congestion develops. Similarly, all downstream residents benefit from the flood protection provided by forested land or dams upstream. Many ecosystem services, such as oxygen production, soil regulation, and storm protection are not, or cannot, be sold in markets. However, markets for some ecosystem services are possible and slowly growing; water temperature trading and carbon sequestration markets are examples.

Typically, in an ecosystem service market, beneficiaries of an ecosystem service pay those who offer to provide the ecosystem service. In Costa Rica, flood protection services, drinking water supply, and water quality were being lost as forests were cut down. San Jose, the capital, was experiencing floods, drinking water shortages, and silt laden water by the early 1990's because upland landowners had cleared 79% of original forest cover, primarily for cattle ranching, greatly decreasing the ability of forestland to provide ecosystem services (Tidwell, 2006). In 1996, the country adopted a new system using a gasoline tax, and slightly increased water fees to pay upland landowners for increasing forest cover and recovering the hydrological ecosystem services, giving them incentive to keep trees on their land. Forest cover rose from 21% to 42% forested in 12 years, flooding was greatly reduced, and San Jose's water supply became clean and sufficient. By understanding the provisioning of flood control and drinking water on the landscape, identifying beneficiaries, and setting up a payment mechanism, flood protection and drinking water were restored and both upland and downstream residents were better off.

The Link between Flood Protection and Ecosystem Services

Flood protection and other ecosystem services, such as salmon restoration, water quality, and climate stability are linked. This is a critical concept as we consider that flooding may become even more frequent in the coming years. If climate change predictions prove accurate, annual precipitation changes over the region, projected through 2050, range from a decrease (-7% or 2 inches less annually) to a significant increase (+13% or 4 inches more annually).

More importantly, projected precipitation increases are concentrated in winter, with decreases or smaller increases in summer. Because of this seasonal pattern, even as the projections show increases in annual precipitation, they also show decreases in water availability during summer months. During the winter, snowpack levels will decrease due to warmer temperatures, increasing rain on snow events, and winter flooding will further contribute to summer drought conditions. Costs will likely be incurred by agriculture, recreation, public utilities, and water management sectors (Parson, 2001).[6]

In light of these changes, it is all the more important to balance flood protection provided by a combination of engineered solutions (such as dams and levees) with naturally provided ecological services (such as water storage in wetlands, agricultural lands, and forests) as well as social infrastructure, (such as land use planning and early warning systems). Not only will this approach improve flood protection and prevent landslides, it will also provide other economic values. These include improved summer water quantity and quality, better agricultural soil quality, recovered wildlife populations, like salmon, waterfowl, and birds, and higher recreational and aesthetic values. All of this amounts to a higher quality of life for local residents.

A flood protection management regime that introduces both river naturalization and consideration of "green infrastructure" allows more floodplain for the river. It also reduces velocity, damage to existing levees, and it lowers maintenance costs for local jurisdictions. If land acquisition is required, it can be expensive initially, but has been shown to significantly reduce costs over a 30-year period (Swedeen and Pittman, 2007).

Funding Mechanisms

As government based funding mechanisms and markets for habitat, climate control (carbon), and water quality develop, both in the United States and internationally, the effectiveness of funding mechanisms to correct inefficiency and secure valuable ecosystem services is rapidly improving. , Still, a number of factors make ecosystem service markets more challenging than markets for goods. A flow of services, or "service flux", cannot be measured in the same terms – quantitative

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6 Also see figure: http://cses.washington.edu/cig/pnwc/ci.shtml#figure1

productivity over time - as goods. Quantifying the amount of flood protection provided by a given forest tract, and its value, is much more difficult and costly than calculating its potential for timber harvest. This is precisely why flood districts are governmental institutions and are not built around private markets.

Though the value of a public ecosystem service (flux) may be more difficult to measure, in many cases its value may significantly exceed the value of the flow of goods. For example, a study of Philippine mangroves showed that their services of storm protection and nursery functions produced several times the value of the alternative land use of shrimp aquaculture operations, which had displaced mangrove forests. Because 85% of commercial fish species are dependent on the mangroves for a period of time within their life cycle, the lost nursery and habitat services resulted in a significant economic loss to the greater public, far exceeding the economic gain in aquaculture production. While a single owner can capture the revenue from a shrimp aquaculture operation, a greater number of local people can benefit from wild capture fisheries and the storm protection provided by mangroves along the coastline (Boumans et al. 2004).

Economics and Ecosystem Value in the Chehalis Basin

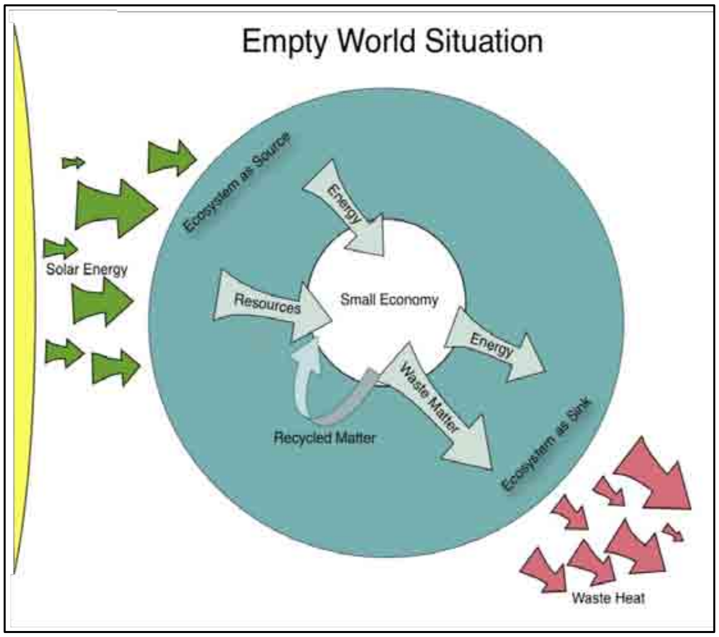
In this section we use an economic approach to look at how the Chehalis Watershed has gone from and ***empty world scenario*** *to a* ***full world scenario****. We point out the complications this natural evolution creates, and define the economic goals which must be met in order to be successful in a full world scenario. Next, we define the four types of capital, including* ***natural capital****,* ***human capital****,* ***social capital*** *and* ***built capital,*** *all of which are relevant to any discussion about meeting these economic goals. Finally, we focus on natural capital, looking at the* ***ecosystem structures*** *and* ***processes*** *that produce natural goods and services. We discuss, from a broad perspective, how these goods and services are valued both in the present and over time. We then narrow our perspective and look specifically at goods and services produced in the Chehalis Basin.*

Economics and Ecosystems

A century ago, the Chehalis Basin, filled with forests, waters, fish and other resources seemed virtually unlimited. There were few people, and the size of the economy, relative to the natural systems that supported it, was small. Figure 3 shows an "Empty" world economy, where human labor is limited while natural resources are unlimited. Figure 4 illustrates that as the economy expands, ecosystems are impacted by its increasing size and demands. In the last century, we have shifted from a seemingly empty world of unlimited and stable resources and natural systems to a full world scenario of limited natural resources where global systems like climate can be disrupted.

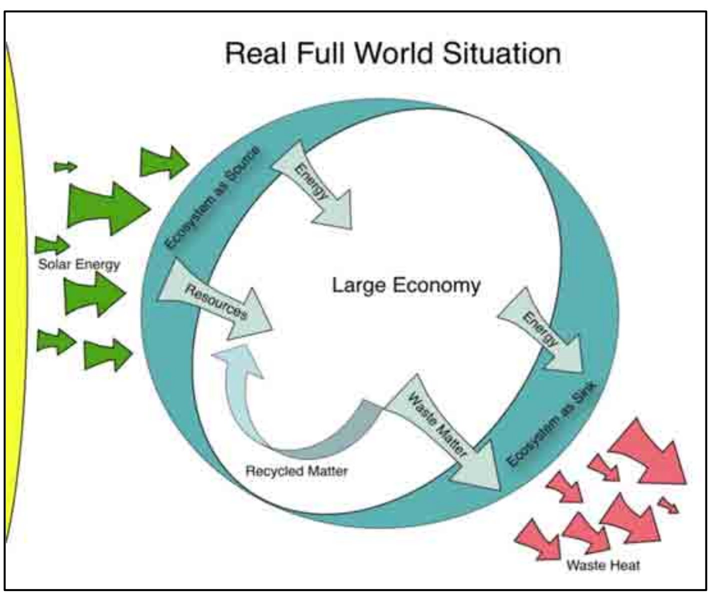
Ecosystem goods and services depend on ecosystem structure and processes. **Structural components** in ecosystems include trees, wetland plants, soil, topography and animals. **Ecosystem processes** include the flow of water, animal life cycles, photosynthesis, nutrient cycles and others. These structural components and ecosystem processes support **ecosystem functions** such as water catchment, soil accumulation, habitat creation, and buffers to flooding. Ecosystem functions generate benefits to people called **ecosystem goods and services**.

Figure 3. Empty World Perspective



Based on Goodland, Daly and El Serafy, 1992

Figure 4. Full World Perspective



Based on Goodland, Daly and El Serafy, 1992

Securing a sustainable and prosperous economy in a full-world requires meeting four economic goals. These goals are also important in examining and setting up criteria for designing a basin-wide approach to flood protection and selecting criteria for flood protection projects, they are:

Sustainable Scale. The first goal is to appreciate the physical limits of natural systems, which contain and sustain the economy, and determine the proper relationship of economies to those limits.

Fair Distribution. The second goal is to determine rights, and examine how benefits, including those from ecosystem services, are distributed among people. For example, the benefit of flood protection is provided within the boundaries of a watershed (provisioning area). The beneficiaries are those who live in flood prone areas, usually the watershed's lower floodplain, and those outside the watershed who benefit from infrastructure such as I-5 and railroads (benefit area). Other ecosystem services have different distributions for how they are provided and who receives their benefits. Oxygen production, for example, is a globally produced and globally distributed economic benefit. In general, private use of any natural resources may increase or decrease the provisioning of their benefits to the public.

Efficient Allocation. The third goal is to allocate where resources are best utilized in order to produce goods and services. Within our market system there exists a complex system of corporations under governmental regulations, which determines how most of our built goods and services are allocated and distributed. There is also an allocation of resources in natural systems, where minerals, nutrients, soils, water, energy and atmosphere produce natural goods and services, such as drinking water, food and timber. The physical nature of some products dictates where they are most efficiently produced

Good Governance. Finally, it is critically important to create and sustain institutions, which govern how goals 1-3 are achieved. All markets require regulation, oversight and enforcement, otherwise cheaters prosper. Governmental institutions must operate at the scale of the issue or problem they are meant to address.

Four Capitals

In order to meet these economic goals, we must redefine how we value capital so that it includes not only easily quantified private assets, but common assets as well. There are four kinds of capital to consider for economic progress and a high quality of life:

Natural Capital. The stock of minerals, energy, plants, animals and ecosystems found on earth. When taken as one whole system, natural capital provides the total biophysical context for the human economy. Nature provides resources as inputs, energy, and ecosystem functions that allow the continued production of natural resources, along with services that purify and recycle waste products. Human well-being depends on these resources and services.

Human Capital. The self-esteem, knowledge acquired through education, and interpersonal skills, such as communication, listening, cooperation, and individual motivation to be productive and socially responsible. Education and training are essential to economic progress, innovation and a high quality of life.

Social Capital. The inventory of organizations, institutions, laws, informal social networks, and relationships of trust that make up or provide for the productive organization of the economy. Without a functioning society, in which people respect each other and have some concern for the well-being of others, most economic activity would be impossible.

Built Capital. The infrastructure of technologies, machines, tools and transport that humans design, build and use for productive purposes. Coupled with our learned skills and capabilities, our built techno-infrastructure is what directly allows raw materials to be converted into goods and services, the typical products that we find in markets.

How Ecosystem Value is Provided and Protected

Natural capital assets are different from built capital assets in a few important ways. Natural capital may be irreplaceable, such as a species or the ozone layer, whereas a car is not irreplaceable. Natural capital can provide value over thousands of years, as a fishery or forest does. In addition, natural capital is self-maintaining, while all built capital must be maintained. These differences often increase the value of ecosystem goods and services, and also change the way that they should be valued over time. Just as with markets, value may change abruptly. For example, value may be relatively constant for a species up to the point at which the population nears extinction, when value skyrockets, only to vanish with extinction. Similarly, changes in natural systems, such as the climate, can have overarching economic effects, on flooding and flood damage, for example.

Different types of ecosystems support different types of infrastructure and processes. Eel grass areas in Grays Harbor, for example, contribute to water purification, food provisioning, habitat for fish and Dungeness crab, and nursery areas for juvenile crab and fish. Salt marshes, herbaceous wetlands, forested wetlands, coniferous forests, and deciduous forests all contain different infrastructure and maintain different ecosystem functions, producing varied goods and services including timber, fish and flood protection. In the Chehalis River Basin, natural and modified systems (including farming) provide goods and services essential to economic development. In most cases, built, natural and social capital, are required to provide benefits. Most of the flood protection within the Chehalis Basin is provided by natural capital, forests, soils, aquifers and water conveyance by rivers. Built capital, including levees and dams also provides flood protection. Early warning systems and effective land use planning are social capital flood protection systems.

The functions of natural systems vary widely in spatial boundaries both in their provisioning, and with regard to the beneficiaries. Oxygen migrates globally. The oxygen you are breathing may have been produced by trees above Centralia, or by plankton in the South Pacific. Salmon originate here, then range into the North Pacific, and return for spawning. Though rainwater may travel great distances, once it falls, it is confined to the watershed, unless piped out. Drinking water production is locally confined. Ecosystems provide benefits that extend globally (carbon sequestration) or locally (drinking water production).

Within each watershed, much of the provisioning of ecosystem goods and services relies on the existence of many of these processes working together over time, much like a human body. Human organs, such a heart, cannot function without the body, nor can the body function without a heart. The same is true for ecosystems. Interactions between the components make the whole greater than the sum of its individual parts – each of the physical and biological components of the watershed, if they existed separately, would not be capable of generating the same goods and services provided by the processes and functions of an intact watershed system (EPA, 2004). In addition, ecosystem services are systems of enormous complexity. Individual services influence and interact with each other, often in nonlinear ways (Limburg et al., 2002).

Ecosystem Value Over Time

Unlike a building, most healthy ecosystems are self-maintaining. Built capital, and everything produced in the human economy, depreciates in value over time, and requires capital investment and maintenance. Ecosystems, however, have the potential to appreciate in value over time -- potentially forever. A forest provides water control, flood protection, aesthetic and recreational values, slope stability, biodiversity and other services without maintenance costs.

Some cities, including Tacoma, Seattle, Portland, San Francisco, Vancouver, Canada and New York City, have already recognized this long-term economic advantage in the provisioning and filtration of drinking water. New York City demands more than one billion gallons of potable water a day. As development occurred in the upper watershed, the quality of this water began to decline. The city weighed the options – to build a water filtration plant for over $6 billion, with operating expenses of $300 million/year, or invest $1.5 billion in watershed restoration, allowing natural water filtration processes to meet drinking water standards. The City decided to invest in watershed restoration because it was less costly, provided a higher return on investment and is more resilient and more likely to meet water quality standards (Worldwatch Institute, 2005).

The Cities of Tacoma and Seattle have maintained forested watersheds that supply water at above drinking water standards and avoided hundreds of millions in filtration plant construction and operating costs. Tacoma and Seattle can boast of water that has no endocrine disruptors, or chemicals that mimic human hormones, because the water is tapped in the upper Green River watershed prior to contamination downstream. If we do not consider the economic value that natural systems provide, they may be lost at great cost.

Ecosystem Services and Value in the Chehalis Basin

The Millennium Ecosystem Assessment (MEA 2003) and many others classify ecosystem services into four broad categories, which describe their ecological role. These categories are provisioning services, regulating services, supporting services, and cultural services.

1. **Provisioning services** provide basic materials, mostly ecosystem service goods (De Groot et al., 2002; UNEP, 2005). Natural systems of the Chehalis River Basin provision a variety of goods: forests grow trees that can be used for lumber and paper; natural

systems provide berries and mushrooms for food and medicinal plants; floodplains provide fertile soil for crops, dairy farms and horses; rivers provide fresh water for drinking and fish for food. These are the most familiar services and also the easiest to quantify in monetary terms (Farber et al., 2006).

2. **Regulating services** are benefits obtained from the natural control of ecosystem processes including flood protection, the regulation of climate, atmosphere, water, and soil. Intact ecosystems also tend to keep disease organisms in check, while degraded systems propagate these organisms to the detriment of human health (UNEP, 2005).
3. **Supporting services** are the bases of ecosystem function. These include primary productivity, nutrient cycling and the fixing of CO2 by plants to produce food, the basis of the vast majority of all food webs on the planet.
4. **Cultural services** include all the ways that people interact with nature in socially meaningful modes, such as spiritual significance, enjoying natural places for recreation, and learning about the planet through science and education.

Each category holds more specific ecosystems services. These services are identified in table 2.

Table 2. Ecosystem Services

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

Based on Daly and Farley, 2004 and de Groot, 2005

Over the past three decades, several hundred studies have been conducted on the economic value of many, but not all, of these services. The valuation portion of this study utilizes likely the world's most comprehensive database of ecosystem service valuation studies. However, the information available today is still incomplete. Only some services have been valued across a wide variety of ecosystem types – for example we have a value for the pollination services provided on agricultural land, but not for pollination services on shrub land or pasture. There are drinking water values for forests, but not for snow pack, though snow pack is crucial to the provisioning of drinking water in much of Washington State, the US and the world.

Economic valuation of some ecosystem services can be very complex. Biodiversity includes a wide variety of plant and animal species with individual values, and values in combination. Aggregating biodiversity values is not a trivial issue, and has not come to a generally accepted resolution, so this study, like others, ignores values in combination. This means there is a systematic underestimate of the value of biodiversity.

Value varies based on location as well. Wetlands upstream of Centralia and Chehalis will provide flood protection to these cities while wetlands in western subwatersheds of the Basin do not. Municipal parks will provide greater benefits to the people who live close by and utilize them more often. Salmon returning to the Chehalis River Basin provide greater benefits locally.

To conduct this analysis with all local, Chehalis River Basin ecosystem service valuation studies would require a full suite of over 140 valuations in the Chehalis River Basin and would be prohibitive both in cost and time. An appraisal approach, bringing in studies from similar areas, reduces cost and improves accuracy. Whether the services are measurable or not, or whether valuation studies are present or not, people do receive benefits, and many of these services play a critical role in the economics and quality of life of people in Chehalis River Basin.

Valuation of the Chehalis Watershed

In this section we consider different methods of assigning base dollar value to the natural goods and services produced by the ecosystems within the Chehalis Watershed, and we consider how to determine the ***present value*** *of these natural assets using several different* ***discount rates****. Base value is established using the* ***benefit transfer methodology****, which, using 8 basic valuation techniques, determines value based on a complex, and comprehensive database that includes comparable data from similar studies. Using the benefit transfer methodology here, we find that* ***partial valuation of 12 ecosystem services, across 15 land cover types in the Chehalis River Basin calculates out to an annual flow of $1.3 billion to $11.6 billion per year****. This range is likely to narrow, with values rising, as more primary valuation studies are able to be incorporated. Following a discussion about the way flood projects are valued over time, we use the Army Corps of Engineers recommended discount rate of 2.7% to arrive at a* ***present value of ecosystems in the Chehalis River Basin of between $43 – 400 billion****. If we instead use a 0% discount rate and treat the value these ecosystems will provide to future generations as equal to that of present generations, a proxy asset or present value of ecosystem services in the Chehalis River Basin would be $127 billion – 1.1 trillion.*

Benefit Transfer Methodology

Benefit transfer methodology is like a house appraisal. Studies from other areas are utilized to provide a high and low range in estimated values, based on the high and low values in the peer reviewed journal literature. This generally provides an underestimate because many ecosystem services are not valued, studies used on the low end are generally outdated, and there may be benefits not yet identified.

Study Approach

Benefit or value transfer methodology is used when the option of conducting original studies for every ecological service on every site for every vegetation type is cost and time prohibitive. It is a widely accepted economic methodology in which the estimated economic value of an ecological good or service is determined by examining previous valuation studies of similar goods or services in other comparable locations.

In the case of a house appraisal an appraiser considers the sale price of other houses with similar attributes in a given area, the number of bedrooms, condition of the roof, presence of a finished basement, or views of the mountain. All contribute to the additive value for estimating the full value of the house.

The value of the ecosystem services, like rooms in a house, is additive. An acre of forestland provides a water regulation and filtration service. It also provides aesthetic, flood protection and habitat benefits. One study may establish the value per acre of a watershed in water filtration for a drinking water supply. Another study may examine the value per acre of wildlife habitat, or recreation. To determine the full per acre value provided by a vegetation type, ecosystem service values are summed up and multiplied by the acreage.

There are eight basic valuation techniques used to derive the values for ecosystem services. These feed into a complex, and comprehensive database, and were primarily developed within environmental and natural resource economics. As Table 3 indicates, these techniques include direct market pricing, replacement cost, avoided cost, factor income method, travel cost, hedonic pricing, and contingent valuation.

Table 3. Valuation Methodologies

Avoided Cost (AC): services allow society to avoid costs that would have been incurred in the absence of those services; storm protection provided by barrier islands avoids property damage along the coast
Replacement Cost (RC): services can be replaced with man-made systems; nutrient cycling waste treatment provided by wetlands can be replaced with costly treatment systems.
Factor Income (FI): services provide for the enhancement of incomes; water quality improvements increase commercial fisheries catch and the incomes of fisher folk.
Travel Cost (TC): service demand may require travel, which has costs that reflect the implied value of the service; recreation areas can be valued at least by what visitors are willing to pay to travel there, including the imputed value of their time.
Hedonic Pricing (HP): service demand may be reflected in the prices people will pay for associated goods, for example housing prices along the coastline tend to exceed the prices of inland homes.
Marginal Product Estimation (MP): service demand is generated in a dynamic modeling environment using a production function (Cobb-Douglas) to estimate the change in the value of outputs in response to a change in material inputs.
Contingent Valuation (CV): service demand may be elicited by posing hypothetical scenarios that involve some valuation of alternatives; for instance, people generally state that they are willing to pay for increased preservation of beaches and shoreline.
Group Valuation (GV): this approach is based on principles of deliberative democracy and the assumption that public decision making should result, not from the aggregation of separately measured individual preferences, but from open public debate.

Adapted from Farber et al 2006

The Economics of Flood Protection and Time

As helpful as it is to assign a dollar value to natural goods and services within the Chehalis Basin, no analysis is complete without looking at how that value translates over time. Flood protection projects are largely selected and funded based on the provision of public safety and an estimate of the economic benefits of flood protection projects. This economic analysis is founded on an estimate of the costs and benefits of flood protection projects provided over time. Because flood protection projects are relatively long-lived investments, the dollar value of benefits and costs often pivots on how short term and long-term economic value is treated. In general, if the value of flood protection over the long run is treated by economic analysis as relatively unimportant (higher discount rate), then built projects that depreciate but provide greater flood protection in the short term to high value economic assets, such as levees defending freeways, will be more heavily weighted. On the other hand if greater value is placed on long run flood protection (lower discount rate with value further into the future), flood protection projects that do not depreciate over 30 years, such as natural capital, and which provide benefits more widely distributed in the watershed over the long run (and to a wider suite of economic activities) will receive greater value.

For example, the use of a 50-year time horizon for costs/benefits analysis of hurricane protection in Louisiana gives greater weight to levees, which provide their greatest benefits over a 50-year period (20 years of construction and 30 years of useful life). A levee provides the greatest protection value the day it is completed. As the structural integrity of the levee is degraded, by weathering, the protection value is also degraded, until maintenance or reconstruction investments bump up the value again. Using a 100 year time horizon for the cost and benefit analysis of hurricane protection weights greater economic value to a coastal restoration approach to hurricane buffering, as coastal restoration provides consistently increasing and more robust hurricane buffering over time against hurricanes approaching from any angle.

In fact, the choice is not either:or. Both wetland restoration and levees are required to provide the best outcome for hurricane protection. Greater wetlands allow for lower levee height, greater levee longevity, and more robust performance of levee structures. The difficulty is that these natural and built assets are very different in the way they provide hurricane buffering across time, and a "one size fits all" economic analysis has difficulty incorporating these differences. How economic analysis treats flood protection over the next decade vs. the next 100 years has a profound impact on the selection of actual hurricane protection investments.

Healthy ecosystems are self-organizing, requiring little or no maintenance. Ecosystems, unlike built capital, do not depreciate, but instead can provide goods and services in perpetuity. Because the longevity of natural production systems is several orders of magnitude greater than built capital systems (that often last no more than a few decades), healthy natural systems retain vast amounts of value into the distant future while built structures do not. Non-renewable resources, such as gasoline or human-built capital, are used up, depleted, or depreciate quickly over time. The benefits of built capital and non-renewable resources are recovered in the short term, close to the present. This is an important distinction between natural and human-built capital. In addition, the values of many ecological services rapidly increase as they become scarcer (Boumans et al. 2002). For instance, the water provided by the Cedar River today is far more valuable than the water provided in 1906, partially because a much larger population is dependent upon it.

This discussion has a direct bearing on flood protection projects, because the economic value of flood protection in the short term and the long run are treated differently. There are two critically important issues for project selection: 1) What is included as a benefit or cost, and 2) How is value treated across time?

If fisheries, agriculture, drinking water and other ecosystem based benefits are not counted as valuable in flood protection analysis, and only built structures, such as Interstate 5, are counted as valuable, then flood protection projects will be heavily biased to protecting these valued built assets. In addition, if short term flood protection is heavily weighted, while long-term flood protection is heavily discounted, then built structure may score more highly than watershed-wide approaches, which may be more robust, and in fact less costly over the long-run.

What is a suitable time horizon for making flood protection investments? A study on the Cedar River in King County showed that a long-term strategy of 100 years using a watershed approach provides greater and more resilient (able to handle greater variability in flood events) flood protection for economic assets. It also improves public safety at a lower cost than a strategy of confining the river, building higher levees, and reconstructing these levees after damage caused by major flood events (Swedeen and Pittman, 2007).

Discounting Capital

Because of the unique nature of ecosystem services, the issue of how to treat this stream of renewable benefits earned across time (and generations) is a critically important and difficult issue. Discounting provides a simple, though unsatisfactory way of comparing assets like natural systems that provide value over vast periods of time, with built capital assets, that focus on benefits in the short term. This creates an ethical conflict, because discounting by its nature favors projects that pull benefits to the present and push costs into the future, which may be unsustainable.

Discounting calculates a present value for a future benefit. The vernacular justification for discounting future value goes like this: would you rather have a dollar today or a dollar in a year? You would rather have a dollar today because you can put it in the bank and earn interest. So the dollar in the future is worth less than a dollar today by the amount of interest you could earn. If the interest rate is five percent, then you could have $1.05 in a year, so receiving a dollar in one year is worth five percent less than a dollar today. The discount rate in this case would be five percent.

Note that this is true only when there is no risk of bank failure or losing your investment; depending on risk it might be preferable to have that guaranteed dollar next year. Also, natural capital does not fit well into this scenario. Drinking water is really not a now or later option: it's needed now and in one year. Overabundance may result in flooding, too little in drought.

Why is all value converted into present value in the economic analysis of flood protection? Because then projects that provide benefits and costs differently across time can be condensed into one "present value" number and compared. The present value criterion is what economic analysis utilizes to value and choose projects. The project with the highest present value, or rate of return on investment, is most often selected.

However, a person in the future would have no interest in maximizing today's present value; that person would rather see high value (flood protection or otherwise) in the future. So the present value criterion has been criticized as being inconsistent across time and generations. If people ten years from now were making today's decisions (even if they were the same people) they would aim to maximize value in year 10. That would result in the selection of a different set of projects than maximizing "present value" for the present year.

Perhaps the most essential aspect is the economic goal. If the goal of flood protection is short-term, to maximize "present value" over the next few decades, then a larger discount rate is justified in economic decision-making. If the goal is to establish flood protection over a longer term, including economic assets that are ecosystem related, then a lower discount rate is justified.

The economics of present vs. future value were actually developed around built capital, to the exclusion of natural capital and with an assumption that all capital depreciates.

The selection of a particular discount rate, 0%, 2%, 3.5%, 5% or 7% is arbitrary. The discount rate for different valuations may be based on the prime rate, or a market rate, or a rate set internally by an agency or corporation. The Federal Office of Management and Budget sets annual discount rates based on economic predictions for the coming year. The latest set of recommendations was released in December 2009, and is used by agencies such as the Army Corps. The current nominal discount rate is 4.5% for projects lasting 30 or more years. This rate is most commonly used for lease-purchase analysis.

The real discount rate, adjusted to exclude the inflation premium, is 2.7% for projects of 30 or more years, and is used for constant-dollar flows. Further, the 4.5% rate does not reflect the historically unique state of the current recession which has resulted in the U.S Federal Reserve Bank significantly lowering the interest rate at which it lends to private banks to 0.25 percent. In the past, this was used as a discount rate for some projects, however, it is so low that for now the federal government has abandoned using it.

The use of a zero discount rate over the life of ecosystems would set the value of ecosystem services, which are provided in perpetuity, as infinite and without an arbitrary time limitation. In this case, a square foot of sod, producing any positive ecosystem service value, would be of infinite value. Thus, a zero discount rate is also flawed. Ecological economists solve this dilemma by defining a sustainable scale, one where basic ecosystem services within a watershed are kept intact. This ensures ecological sustainability, and that future generations are not left with a set of ecological systems that are not viable.

We used two calculations: 1) the Army Corps of Engineers' 2.7% discount rate for renewable natural resources; and 2) a 0% discount rate, which treats the present and future generations equally, looks at value across time, and recognizes intergenerational responsibility.

Earth Economics Ecosystem Service Valuation Analysis

In this section we summarize the data used to arrive at the base dollar values.

Land Cover Data Used

A total of 23 ecosystem services were identified in the Chehalis River Basin. Valuation of 12 ecosystem services and land cover types is shown in Table 4.

Table 4. Valued Ecosystem Services for Each Land Cover Type

	Pasture	Rivers & Lakes	Urban Green Space	Beach	Estuary	Salt Marsh	Marine Water
Gas and Climate Regulation			✓				
Disturbance Regulation				✓		✓	
Water Flow Regulation			✓			✓	
Water Quality							✓
Water Supply		✓			✓		
Habitat Refugium		✓			✓	✓	
Pollination							
Soil Erosion Control							
Soil Formation	✓						
Biological Control							
Aesthetic and Recreational	✓	✓	✓	✓	✓	✓	
Cultural						✓	

Using information drawn from Washington State databases, Table 5 shows the acreage of riparian land cover in the Chehalis River Basin. The most recent (2001) National Land Cover Data (NLCD) from the U.S. Environmental Protection Agency defines cover types and estimates area coverage. Valuation data exists for eelgrass beds, though the NLCD does not include area coverage of eelgrass beds. Eelgrass data were drawn from surveys conducted by Washington State Department of Natural Resources 2005. A hydrography layer (OR/WA Hydrography Framework Partnership, 2005) was used to identify the riparian area of the Chehalis Basin within a 50 meter buffer. To avoid double counting, riparian areas were deducted from the total area of forest or shrub vegetation classes, and eelgrass area was subtracted from estuary waters in NLDC figures.

Table 5. Riparian Land Cover

Riparian Land Cover	Acres	Source and Notes
Early Forest	481,420	Interagency Vegetation Mapping Project (IVMP)
Pole Forest	232,275	Interagency Vegetation Mapping Project (IVMP)
Mid Forest	289,667	Interagency Vegetation Mapping Project (IVMP)
Late/Old Forest	78,243	Interagency Vegetation Mapping Project (IVMP)
Riparian forest pole	43,068	Interagency Vegetation Mapping Project (IVMP), within 50 m of lakes and rivers, as defined by Washington DNR hydrography layer
Riparian Forest mid to late	38,020	Interagency Vegetation Mapping Project (IVMP), within 50 m of lakes and rivers
Riparian Shrub	4,176	NLCD, within 50 m of lakes and rivers
Fresh Wetland	104,395	NLCD, excluding wetlands within 200 m of coastline
River/Lakes	35,931	Washington DNR hydrography layer
Shrub/Scrub	177,302	NLCD
Grassland/herb	87,479	NLCD
Agriculture	12,785	NLCD
Pasture	73,153	NLCD
Urban green space	78,046	NLCD's "Developed open space"
Beach	2,188	Within 200 m of coastline
Salt Marsh	4,876	Wetlands within 200 m of coastline
Eel grass beds	36,419	Washington DNR Shore Zone Inventory
Estuary Waters	21,010	Grays Harbor (Washington DNR hydrography layer), excluding areas with eelgrass coverage
Marine Waters	40,102	Marine waters outside Grays Harbor, included in Washington Department of Ecology WRIA maps
Snow and Ice	23	NLCD
Barren and developed land	73,816	NLCD
Total	**1,914,394 acres**	

This represents the best available GIS data for the Chehalis Basin.

Forest Successional Stage

Not all forests provide the same set, or equal amounts, of ecosystem services. A recently cut and planted area does not prevent flooding, nor does it provide water filtration or recreational values in the way that a mature or an old growth forest does. Thus, an overlay of stand size is required to yield categories of age class. For the purposes of this study, timber diameter is referred to as successional stage. Table 6 shows the successional stages and acreage of forest areas in the Chehalis Basin.

To avoid overestimating the value of forests, five forest successional stages for the Chehalis Basin were identified, based on recent successional stage mapping data (Interagency Vegetation Mapping Project, 2004). This data was provided as total forest acreage; the areas for coniferous, deciduous, and mixed forests could not be separated. Because this database does not match the NLCD for total forest acres, which is a common issue when comparing different GIS data sets, it was assumed that each of the forest types, including riparian, has the same ratio of stages in the NLCD database as the total forested area in the Interagency Vegetation Mapping Project. NLCD data in Table 6 was used to calculate the ecosystem services. Because logging in riparian areas is restricted, this assumption underestimates the actual successional stage for riparian areas; the value riparian areas provided is embodied within the ecosystem services examined, and is therefore an underestimate.

Table 6. Forest Stand Size Data

Ranges in Diameter (Inches)	Forest Stand Type	Area (Acres)
0-4.9	Early Successional, non-riparian	481,420
5-9.9	Pole, non-riparian	232,275
10-19.9	Mid Successional/non-riparian	289,667
20-30+	Late Successional/Old Growth, non-riparian	78,243
0-9.9	Riparian forest early/pole	43,068
10-30+	Riparian forest mid/late	38,020
	Total	**1,162,693**

Ecosystem Service Values Used

Earth Economics maintains, and is continually expanding, a database of ecosystem service valuation studies. The following tables (7-12) describe ecosystem service value estimates per acre, both high and low. These tables are based on peer-reviewed academic journal articles using the benefit transfer methodology. Each ecosystem service/land cover combination is shown with low and high values, where they exist. The “low” values represent a lower boundary of ecosystem service values based on the lowest established values in the literature. The “high” values are derived from the highest values in the academic literature for each of the twelve ecosystem services examined. This is not an upper boundary however, because not all services identified have valuations. For example, though snow pack has water storage value, academic studies have not yet been completed to examine this benefit.

Table 7. High and Low Dollar per Acre Estimates for Estuary, Salt Marsh, and Marine Water

	Estuary		Salt Marsh		Marine Waters	
	Low	High	Low	High	Low	High
Gas and Climate Regulation						
Disturbance Regulation			$242.91	$95,951.00		
Water Flow Regulation			$109.78	$17,673.84		
Water Quality					$259.34	$772.68
Water Supply	$5.90	$127.84				
Habitat/Refugium	$11.55	$1,385.51	$1.17	$1,017.08		
Pollination						
Soil Erosion Control						
Soil Formation						
Biological Control						
Aesthetic and Recreational	$1.17	$355.16	$4.88	$97.56		
Total by Cover Type	**$18.62**	**$1,868.51**	**$358.74**	**$114,739.48**	**$259.34**	**$772.68**

Table 8. High and Low Dollar per Acre Estimates for Rivers and Lakes, Urban Green Space and Beach

	Rivers and Lakes		Urban Green Space		Beach	
	Low	High	Low	High	Low	High
Gas and Climate Regulation			$26.81	$874.79		
Disturbance Regulation					$22,213.11	$36,006.72
Water Flow Regulation			$5.72	$170.89		
Water Quality						
Water Supply	$32.34	$834.44				
Habitat/Refugium	$17.13	$1,479.84				
Pollination						
Soil Erosion Control						
Soil Formation						
Biological Control						
Aesthetic and Recreational	$1.69	$19,699.00	$1,261.31	$3,697.42	$140.21	$45,521.29
Total by Cover Type	**$51.16**	**$22,013.28**	**$1,293.84**	**$4,743.10**	**$22,353.32**	**$81,528.01**

Table 9. High and Low Dollar per Acre Estimates for Grassland, Agriculture and Pasture

	Grassland/Herb		Agriculture		Pasture	
	Low	High	Low	High	Low	High
Gas and Climate Regulation	$3.85	$3.85				
Disturbance Regulation						
Water Flow Regulation	$1.65	$1.65				
Water Quality	$47.91	$47.91				
Water Supply						
Habitat/Refugium						
Pollination	$13.77	$13.77	$2.40	$12.10		
Soil Erosion Control	$15.97	$15.97				
Soil Formation	$0.54	$0.54			$6.22	$6.22
Biological Control	$12.66	$12.66				
Aesthetic and Recreational	$1.01	$1.01	$27.50	$27.50	$0.03	$0.03
Total by Cover Type	**$97.36**	**$97.36**	**$29.90**	**$39.60**	**$6.25**	**$6.25**

Table 10. High and Low Dollar per Acre Estimates for Riparian Shrub, Fresh Wetland and Shrub

	Riparian Shrub		Fresh Wetland		Shrub/Scrub	
	Low	High	Low	High	Low	High
Gas and Climate Regulation	$24.75	$495.00	$29.43	$267.53	$6.20	$62.30
Disturbance Regulation	$3.78	$117.87				
Water Flow Regulation			$6,357.71	$6,357.71		
Water Quality						
Water Supply	$2.58	$6,507.54	$199.11	$31,404.56		
Habitat/Refugium	$0.09	$134.96	$58.89	$12,537.14	$1.23	$500.24
Pollination						
Soil Erosion Control						
Soil Formation						
Biological Control						
Aesthetic and Recreational	$4.29	$5,312.07	$31.47	$9,347.33	$0.09	$318.91
Total by Cover Type	**$35.49**	**$12,567.43**	**$6,676.61**	**$59,914.27**	**$7.52**	**$881.45**

Table 11. High and Low Dollar per Acre Estimates for Non-Riparian Forests

	Early/Pole Forest		Mid Forest		Late/ Old Growth Forest	
	Low	High	Low	High	Low	High
Gas and Climate Regulation	$6.20	$62.30	$27.43	$623.33	$43.56	$990.00
Disturbance Regulation						
Water Flow Regulation	$4.80	$4.80	$9.61	$9.61	$9.61	$9.61
Water Quality						
Water Supply						
Habitat/Refugium	$0.62	$250.12			$269.85	$500.24
Pollination			$31.49	$141.41	$62.97	$282.82
Soil Erosion Control						
Soil Formation						
Biological Control						
Aesthetic and Recreational	$0.09	$318.91	$4.89	$318.91	$9.78	$637.81
Total by Cover Type	**$11.71**	**$636.13**	**$73.42**	**$1,093.26**	**$395.77**	**$2,420.48**

Table 12. High and Low Dollar per Acre Estimates for Riparian Forests

	Riparian Forest Pole		Riparian Forest Mid/Late		Eelgrass Beds	
	Low	High	Low	High	Low	High
Gas and Climate Regulation	$24.75	$495.00	$43.56	$990.00		
Disturbance Regulation	$3.78	$117.87	$7.56	$235.73		
Water Flow Regulation						
Water Quality						
Water Supply	$2.58	$6,507.54	$2,105.00	$13,015.08		
Habitat/Refugium	$0.09	$134.96	$269.85	$500.24		
Pollination						
Soil Erosion Control						
Soil Formation						
Biological Control						
Aesthetic and Recreational	$4.29	$5,312.07	$1,043.00	$10,624.14		
Nutrient Cycling					$5,507.00	$15,421.00
Total by Cover Type	**$35.49**	**$12,567.44**	**$3,468.97**	**$25,365.19**		

Important conclusions can be drawn from the values provided. Estuaries and salt marshes provide significant habitat and water regulation values. Rivers and lakes with beaches are high in aesthetic and recreational value. The channel of conveyance that rivers provide contributes to valuable flood protection, indeed most water is drained via rivers, groundwater or transpiration. However, valuation studies examining river conveyance value have not yet been conducted. While the dollar value of levees and dams can be established through costs, natural rivers and lakes, which convey and store flood waters at no cost, are valuable flood protection assets, and should be included in both flood modeling and valuation. Again, flood protection investments are best evaluated in combinations of natural, built, and social infrastructure that will provide robust and sufficient flood protection at least cost.

Note that grasslands, agriculture and pasture are significantly undervalued because the values of agricultural crops, horses, and livestock have not been fully included. These areas are also likely to have high values for flood protection, as many farming practices are compatible with seasonal winter flooding. Studies in China have shown significant flood protection value provided by agricultural land. The government of Beijing reimburses farmers monthly, with payment for flood protection based on the measured floodwater acceptance of upstream farmlands and a calculation of resulting reduced damages downstream.

Riparian areas have been under-examined historically. However, the hydrology of flooding shows how important these areas are, and they also rank highly in salmon, recreation and aesthetic values. More ecosystem service studies have been completed for wetlands than for any other land cover type. Wetlands provide significant flood protection, drinking water, habitat, aesthetic, and recreational value.

Studies linking forests to flood protection value are scarce, and those that exist are typically outdated; forest cover most certainly contributes more to flood protection than these figures indicate. Further, this is a rough-cut analysis. Within the sub-basins of the Chehalis, it is clear that some forested areas, such as those with more permeable soils, will contribute more to flood protection than other areas do. A careful GIS analysis of the type and quality of forest, wetland, or other land cover areas, specific to each Chehalis sub-basin, could be conducted in conjunction with the Army Corps' general investigation and hydrological studies. This would help us to understand where investments in, or *changes* in land use regarding natural capital could contribute significantly to flood protection.

The tables above are significant because they show that the different land cover types in the Chehalis basin provide flood protection and other ecosystem benefits, and are essentially flood protection assets in a similar way to a levee or dam. These economic values should be included in flood protection project cost/benefit analysis.

Complete Valuation Summary

This section provides an overall value for the natural capital of the Chehalis Basin for 12 ecosystem services, including flood protection.

The "per acre" values for each land cover type, across twelve ecosystem services, were summed up. Table 13 shows the acreage of each land cover type within the watershed, and the total dollars/acre for that vegetation type across the ecosystem services, where values exist. Valuation studies do not exist for some vegetation type/ecosystem service value combinations, so the estimates for some ecosystem services are clearly underestimates (see Table 4).

Table 13. Preliminary Estimate of Annual Value Provided by the Chehalis Basin Ecosystem Services

Cover Type	Acres	Low	High	Low (aggregate)	High (aggregate)
Early forest	481,420	$7.52	$881.45	$3,620,278.40	$424,347,659.00
Pole forest	232,275	$7.52	$881.45	$1,746,708.00	$204,738,798.75
Mid forest	289,667	$73.42	$1,093.26	$21,265,902.81	$316,679,896.09
Late/Old forest	78,243	$395.77	$2,420.48	$30,966,232.11	$189,385,616.64
Riparian forest pole	43,068	$35.49	$12,567.43	$1,528,267.98	$541,254,075.24
Riparian forest mid to late	38,020	$3,468.97	$25,365.19	$131,890,239.40	$964,384,523.80
Riparian shrub	4,176	$35.49	$12,567.43	$148,185.36	$52,481,587.68
Fresh wetland	104,395	$6,676.61	$59,914.27	$697,004,700.95	$6,254,750,216.65
River/Lakes	35,931	$51.16	$22,013.28	$1,838,229.96	$790,959,163.68
Shrub/Scrub	177,302	$7.52	$881.45	$1,333,311.04	$156,282,847.90
Grassland/Herb	87,479	$97.36	$97.36	$8,516,955.44	$8,516,955.44
Agriculture	12,785	$29.90	$39.60	$382,271.50	$506,286.00
Pasture	73,153	$6.25	$6.25	$457,206.25	$457,206.25
Urban green space	78,046	$1,293.84	$4,743.10	$100,979,036.64	$370,179,982.60
Beach	2,188	$22,353.32	$81,528.01	$48,909,064.16	$178,383,285.88
Salt marsh	4,876	$358.74	$114,739.48	$1,749,216.24	$559,469,704.48
Eel grass beds	36,419	$5,507.00	$15,421.00	$200,559,433.00	$561,617,399.00
Estuary waters	21,010	$18.62	$1,868.51	$391,206.20	$39,257,395.10
Marine waters	40,102	$259.34	$772.68	$10,400,052.68	$30,986,013.36
Snow and ice	23	$0.00	$0.00	$0.00	$0.00
Barren and developed land	73,816	$0.00	$0.00	$0.00	$0.00
Totals	**1,914,394**			**$1,263,686,498.12**	**$11,644,638,613.54**

These results are important, because they reveal an overall value for the ecosystem services provided within the Chehalis Basin by natural capital assets, including agricultural lands, of between $1.3 and $11.6 billion per year. This is of major significance. The natural capital of the Chehalis Basin is an economic asset of great value, in part because of the flood protection it provides.

One of the recurring errors in flood planning has been a planning and investment framework that includes only built capital as flood protection assets. As natural capital providing flood protection has deteriorated, investments in built capital have been less effective than expected, or they have failed. Underinvestment in natural capital has resulted in less than achievable flood protection for those investment levels. Flood protection planning in the Chehalis Basin is better informed by understanding of the direct flood benefits provided by natural systems, and their co-benefits (such as salmon habitat and drinking water). Including the dollar value that these systems provide allows for the consideration of ecosystem services in traditional flood protection cost/benefit analysis.

Appendix B is a reference section for the peer-reviewed academic journal articles utilized in this valuation. Appendix C displays the land cover type, ecosystem service, and authors of each study utilized; the lowest value presented in the literature; and the highest value utilized in this study. This information is listed for full transparency to the reader.

Now refer back to the partial valuation estimate of 12 ecosystem services, across 15 land cover types in the Chehalis River Basin, which was determined using Benefit Transfer Methodology to show an annual flow of $1.3 billion to $11.6 billion per year.

From this annual flow of value, a capital asset value, analogous to an “asset value”, can be calculated. This is analogous to the difference between the sum of monthly mortgage payments across a year (an annual flow of value from living in a house for one year) and the full sales value of a house (the asset value, or present value). In order to determine an asset value, such as that of the Chehalis River Basin to society, we apply a depreciation (or discount) rate of 2.7% over 100 years from the present day to obtain the *present value*. This discount rate is the same used by the Army Corps of Engineers and is set annually by the federal government. There is also a discussion in this report about why natural assets appreciate, rather than depreciate; in this sense the present value is probably far greater. Using a 2.7% discount rate, the asset or present value provided by the annual value of these 12 ecosystem services provided by the Chehalis River Basin is between $43 – 400 billion. The range of values will decrease as additional valuation studies are conducted and included. Using a 0% discount rate, which treats the value that these ecosystems will provide to future generations as equal to that of present generations, the asset or present value of ecosystem services in the Chehalis River Basin would be $127 billion – 1.1 *trillion*.

These values, even on the low side, justify significantly higher investments in restoration and conservation than is currently occurring. The asset value of ecosystems in the watershed is certainly in the billions, with annual benefits in the hundreds of millions. In the 1920s, the best investment to increase salmon production was in more boats and nets i.e. built capital. However, boats and nets are now abundant. Investment in more boats and nets will not produce greater economic value. Investing to increase the natural productivity of salmon, flood protection and other ecosystem services is a far better investment.

An approach based on science + analysis of public safety + economics (that takes into account both the value of built assets and ecosystem services), with further testing and calibration, is a powerful tool for the Flood Authority to use when weighing different flood protection investment options.

Gaps in the Valuation

A total of 12 of 23 ecosystem services were valued for the Chehalis River Basin. Some of those not included are: biodiversity, food, materials, human disease control, primary productivity, and spiritual, scientific and educational values. Aesthetic and recreation values are combined. Ecosystem services important to the general population and the Chehalis Tribe have been identified but not valued.

Some ecosystem services that are crucial to human well-being, such as nutrient cycling (the natural processing of nitrogen, phosphorus and other nutrients) and disease regulation (the natural control of disease pathogens), have few or no valuation studies. Taxol, a drug for treating breast cancer, was discovered in the bark of the Northwest Pacific yew tree, yet there is no inclusion of medicinal value in this study. These and other important natural services are not easy to quantify in monetary terms, so they may be consistently under-represented in economic valuation studies. A full discussion of this study's limitations is included in Appendix B.

Modeling Flood Protection

*In this section we introduce **ARIES**, a sophisticated computer modeling tool being developed to "make flood protection and other environmental asset decisions better informed, more effective, less costly, and less contentious." Data about the Chehalis Basin was used to produce preliminary maps (included) exploring the beneficiaries of flood protection, the sources of flood damage and the provisioning of flood protection events in the Chehalis River Basin.*

What is a flood protection model framework that would enable scenarios analysis, the application of criteria and selection of projects?

Floods are complex events, difficult to predict and even more difficult to protect against. Typically, a watershed's hydrology is poorly understood; weather is notoriously difficult to forecast. Using every tool of modern science, we cannot predict the next big flood. Human land use and development, as well as climate change, are transforming the "playing field" of flood protection. Decisions on flood protection have generally been based on hydrological modeling that provides a best guess at 50, 100, or 500-year flood levels.

Flood protection analysis, project selection and prioritization would be greatly strengthened if modeling could include all landscape influences on flooding and flood protection, including both natural and built capital. The capacity to run different flood scenarios would be a powerful tool to aid in flood prediction and prevention. The ability to explore not just single project scenarios, such as installation of a dam, but project combinations, such as land use planning, levees and longer forest rotations for portions of the watershed, against other project combinations would enable more effective choices for decision-makers. Computer technology to provide this level of specificity within a watershed is being developed. Earth Economics is working with researchers developing a new tool to model flood protection as accurately as possible: ARtificial Intelligence for Ecosystem Services (ARIES).

ARtificial Intelligence for Ecosystem Services (ARIES)

ARtificial Intelligence for Ecosystem Services (ARIES) is a technology designed for Ecosystem Service Assessment (ESA) including flood protection. ARIES can be accessed over the web. Because developers are continually adding to the system, it is up and available about half-time. The ARIES web site includes data and analysis from the Chehalis Basin (see Appendix E for website and instructions).

ARIES is in a beta stage, still under development. However it does provide a clear framework and basic information for assisting in the planning and project selection for flooding. The purpose of ARIES is to make flood protection and other environmental asset decisions better informed, more effective, less costly, and less contentious. ARIES helps us discover, understand, and quantify environmental assets and factors that influence their values in a given geographic area. ARIES is being developed by an international partnership of non-profit organizations, policy-makers, and scientists.

Initial ARIES development was funded by a three-year, $925,000 National Science Foundation Grant, which will be completed in 2010. The grant was awarded to the University of Vermont's Gund Institute for Ecological Economics, Earth Economics, and Conservation International. A component of this grant was allocated to demonstrate the framework for, and potential of, flood modeling, and Earth Economics nominated the Chehalis Basin for the initial study.

ARIES Approach to Flood Protection

ARIES is a web-based computer program that utilizes geographic information system (GIS) data in models to provide information on ecosystem services, including flood protection. For this study, ARIES utilizes GIS data specifically from the Chehalis River Basin. The GIS data, layers, reference sources, resolution, geographic coverage and year(s) of coverage used by ARIES in this analysis are shown in Table 14. All data, whether sourced from counties, the State of Washington, or national databases is specific to the Chehalis River Basin. The references for these sources are listed in Appendix F. This GIS data is yet incomplete for full modeling.

The Chehalis Basin specific data in Table 14 used in ARIES modeling includes land use cover, soils, precipitation and snow presence over the year, run-off, dam storage, timber diameter (called successional stage), vegetation types, vegetation heights, percent vegetation, monthly rainfall averages, impervious surfaces, slope, floodplains and floodplain width, levees, bridges, highways, dams and other structures, farmland and housing.

This data is not complete. For example, levee data for Grays Harbor and Thurston Counties have not yet been obtained, whereas data for Lewis County is included. Housing data for Grays Harbor and Thurston Counties is in hand, but that data for Lewis County is not. Data for retention basins for these counties is lacking. GIS data estimating the distribution of peak rainfall during the 2007 and 2009 floods and LIDAR is not available at present. Data on the position of housing and other structures within property boundaries would be greatly helpful. With it, modeling of the cost of elevating structures, or moving them within property boundaries to higher elevations could be examined. These are data aspects of the ARIES application in the Chehalis River Basin that require further work.

Table 14. Spatial Data for Flood Regulation Modeling in the Chehalis Basin

Model	Layer	Source	Resolution	Extent	Year
Flood source – Puget Sound	Hydrologic soils group	NRCS soil surveys	30 x 30 m (rasterized vector data)	Puget Sound	n/a
	Land use-land cover	NLCD 2001	30 x 30 m	Washington & parts of surrounding states	2001
	Monthly precipitation	USDA-NRCS Geospatial Data Gateway	800 x 800 m	Western Washington	1971-2000
	Monthly temperatures	SAGE/Univ. of Wisconsin	0.5 x 0.5 degree	Global	1961-1990
	Monthly snowmelt	Univ. of Delaware	0.5 x 0.5 degree vector point file	Global	1950-1999
	Snow presence	Washington State Dept. of Natural Resources	Vector shapefile	Washington State	1991
	Runoff	SAGE/Univ. of Wisconsin	0.5 $degree^2$	Global	
Flood sink – Puget Sound	Detention basins	County GIS offices	Vector point file	King, Pierce, San Juan Counties	Variable
	Dam storage	Oak Ridge National Laboratory	Vector point file; digitized shapefile of reservoirs for Puget Sound	United States	2005
	Mean days of precipitation per month	PRISM/Oregon State Univ.	Vector shapefile	Continental United States	1971-2000
	Successional stage	BLM/Interagency Vegetation Mapping Project	25 x 25 m	Western Washington & Oregon	1996
	Vegetation % cover	NLCD 2001	30 x 30 m	Washington & parts of surrounding states	2001
	Vegetation type	NLCD 2001	30 x 30 m	Washington & parts of surrounding states	2001
	Vegetation height	Puget Sound LIDAR Consortium	3 $foot^2$ & 6 $foot^2$, downsampled to 30 x 30 m	Parts of Western Washington	2000-2006
	Monthly temperatures	SAGE/Univ. of Wisconsin	0.5 x 0.5 degree	Global	1961-1990
	Hydrologic soils group	NRCS soil surveys	30 x 30 m (rasterized vector data)	Puget Sound	n/a
	Slope	Derived from National Elevation Dataset	30 x 30 m	Puget Sound	n/a

	Impervious surface cover	NLCD 2001	30 x 30 m	Washington & parts of surrounding states	2001
	Floodplain width	FEMA & Washington State Dept. of Ecology	Vector shapefile	Western Washington	
	Levees	County GIS offices	Vector line file	King, Lewis, Pierce Counties	Variable
	Bridges	Washington State Dept. of Transportation	Vector line file	Washington State	2004
Flood use – Puget Sound	Floodplains	FEMA & Washington State Dept. of Ecology	Vector shapefile	Western Washington	
	Farmland	NLCD 2001	30 x 30 m	Washington & parts of surrounding states	2001
	Structures	County assessors' offices	Vector shapefiles	Clallam, Grays Harbor, Jefferson, King, Kitsap, Mason, Snohomish, Thurston Cos., WA	2004 (Kitsap Co.), 2006 (King Co.); uncertain for others
	Highways	Washington State Dept. of Transportation	Vector line file	Washington State	2007
	Railways	Washington State Dept. of Transportation	Vector line file	Washington State	1996
	Presence of housing	County assessors' offices	Vector shapefiles	Clallam, Grays Harbor, Jefferson, King, Kitsap, Mason, Snohomish, Thurston Cos., WA	2004 (Kitsap Co.), 2006 (King Co.); uncertain for others

How ARIES Operates

This data is run in models to provide outputs on ecosystem services. Flood protection was specifically examined in the Chehalis Basin. Other ecosystem services can also be examined. Carbon sequestration in soils and forests in the Chehalis Basin was also run, and model results are shown in Appendix E.

AIRIES applies sophisticated mathematics called Bayesian network models (see Appendix F and the ARIES website for further description). Bayesian network models are capable of handling great quantities of spatially specific data, such as GIS data. Using existing models, they can build new ones. In addition, this framework of information greatly expands the capability for running scenarios. Not only single project scenarios can be run, but combinations of projects under different scenarios of rainfall, temperature, soil saturation and other characteristics can be as well.

This should be valuable to decision-makers in helping choose among different flood project proposals because it includes elements of flood protection that current hydrological models and cost/benefit analysis alone cannot include. For example, the value forests, wetlands, aquifers, levees and dams, and changes in land use could be modeled with different combinations of flood protection investments. Flood maps showing how different scenarios benefit or harm different stakeholders within the watershed could also be examined (see scenario section below).

ARIES provides three flood protection framework models (each of which contains smaller modeling units). These three framework models are created for each ecosystem service, and include:

1. a model of the source of flooding;
2. a model of flood protection (provisioning);
3. a model of the beneficiaries of flood protection.

These three models rely on the data specific to the Chehalis River Basin provided in Table 14 above. The general structures of these framework models are shown in Appendix E.

A Model of Source Flooding: This includes data and modeling of rainfall, soil saturation, groundwater levels, hydrological soils groups, water retention, land use, vegetative cover, precipitation, temperature, snow presence and snowmelt, the shapes of the flood plain and riverbed. A map showing the areas of greatest floodwater sources can be provided. Because peak rainfall data was not available, a map based on average monthly precipitation was developed as an example. This map is included in Appendix E.

A Model of Flood Protection or Provisioning: This includes all the natural and built assets that provide flood protection from forests that break up rainfall. It also includes wetlands, dams and lakes that store water, as well as attributes that guide or contain water - the volume capacity of rivers, or the width and shape of the flood plain. This modeling can also map impairments to flood protection, such as filling in a floodplain, or building bridges which constrict water conveyance by rivers. A framework of this model is provided in Appendix E.

A Model of the Beneficiaries of Flood Protection: These "beneficiary maps" provide an idea of who would be flooded given different flood and flood protection scenarios. Frameworks for beneficiaries, including residential, private business and public beneficiaries are included in Appendix E.

As noted above, ARIES is still under development. Therefore, a very simple hydrological model was applied for the Chehalis River Basin. Hydrosheds data (Lehner et al., 2008) for flow direction were used to route floodwater across the Chehalis Basin landscape. While this is a highly simplistic way to move water and water-related ecosystem services (e.g., drinking water, flood water, suspended sediment, dissolved nutrients), it has the benefit of being applicable in the Chehalis River Basin. In the future, ARIES should be able to apply hydrological models developed for the

Chehalis River Basin by the Army Corps of Engineers, US Geological Survey or others, and could run scenarios with different hydrological models.

With the GIS input data listed above, modeling based on the three flood protection frameworks produces flood protection provisioning maps (see Appendix E) and will increasingly provide modeling outputs such as estimated flood elevations and duration in sub-watersheds under different scenario conditions (expected in July 2009).

Modeling Flood Scenarios

The ARIES team is currently developing scenario analysis that can model floods with data from the Chehalis River Basin.

The ARIES design for scenario analysis provides for the mapping of benefits resulting from flood protection action alternatives. The benefits can be measured in lowered peak floodwaters, floodwater attenuation, people and assets moved away from flood prone areas, and protection or enhancement of economic assets (including built and ecosystem services). Often, flood protection actions may protect one area, and increase risk in other areas. ARIES is also being structured to model the overlap between flood protection projects such as levee setbacks, and salmon restoration, with the input of salmon restoration project information. ARIES should also show people and assets that could be damaged by the adoption of particular flood protection options or by the failure of flood protection assets. In addition, because ARIES already has county level assessor property and building values, it will be capable of estimating floodwater elevations and the potential value of damage at each elevation. Other ecosystem services, such as salmon restoration projects, carbon sequestration, or recreation areas within the Chehalis River Basin, can be modeled and mapped with flood protection.

The structure of ARIES is such that many people can run scenarios simultaneously. They can transparently see the models and data utilized and make choices about scale (location of analysis), initial conditions (snow pack, temperature, rainfall distribution, etc.), models (choice of hydrological models, if choices are available) and output (flood elevations, overlapping ecosystem services, etc.).

ARIES flood scenario analysis is being designed to proceed with the following steps:

1. The area of interest is selected, e.g. the full Chehalis River Basin, upper basin or a sub-watershed. GIS data and models are pulled from the ARIES database (less than one minute). Bayesian network models of flood source, flood protection, and beneficiary would be accessed (less than one minute). This serves as a basis to compute flood protection scenarios.

2. The baseline scenario would be defined in terms of precipitation events, level of ground water saturation and other inputs, and in terms of actions or policies to be simulated on the landscape (e.g. land use, levees). Modeling can include a default hydrological model

developed within ARIES, or, eventually, any desired hydrological model. The design allows models to be “bolted” onto ARIES for scenario testing. Thus, ARIES will be able to test different hydrological models for scenarios under different model applications.

3. The future scenario would then be defined and could include different levee alignments, longer timber rotations, widening of the floodway, dams, elevated housing, land use changes, and other options. After the baseline and future scenarios have been defined, the model is run.

4. The products include a set of maps that detail the quantity, speed and elevation along which floodwater moves across the landscape and either reaches structures and beneficiaries, or is intercepted and diverted (beneficiaries may have moved out of the way, or are protected by levees, dams, natural systems or a combination of these). The model could compare scenarios with changes in land use patterns, elevated structures, increased forest cover, greater permeability to groundwater, dams, levees, roads, bridges, filling of the riverbed with sediment and other potential scenarios. Potential risks to public safety (how fast flood waters approach, depth of flood waters across roads) could be examined. Estimated extent and duration of the flood, and the economic cost, could also be examined. Impact on other ecosystem services is in the scenario design as well.

5. Because ARIES models individual beneficiaries, it can compute areas of flood protection provisioning or source flood waters on the landscape. Unlike other model designs, ARIES retains every pixel of GIS and other data during the process. In this way, it is anticipated that the fine-grained effects of policy or global changes can be studied with scenarios overall and on a household-to-household basis.

6. ARIES also computes other ecosystem services besides flood protection (currently carbon dioxide mitigation, aesthetic value, proximity to open space, and soon soil erosion, drinking water, salmon and others). The overall value of each scenario can be compared at a glance, showing the influence on other ecosystem services and their beneficiaries.

7. ARIES should be able to compute not only the provision of each ecosystem service, but also the fraction of benefits that actually reach beneficiaries (and the explicit spatial routes of this provision). The efficiency of provision (the ratio of the potential benefit to the actual benefit provided) can be calculated under each scenario. In other words, the benefit of greater forest cover for reducing a flood, a levee or dam, or widening of the floodway can be tracked from each contributing flood protection action/asset to each beneficiary. If a longer rotation of forests reduces peak flow by a foot over a 24 hour period, the benefits can be estimated. If a levee or dam protects an area from flooding, the floodwater elevation that is relieved as a result can be calculated, the beneficiaries mapped, and the avoided damage can be valued. If salmon habitat is enhanced or damaged, it can be mapped, and if the science is available, estimated economic values of population impacts can be made.

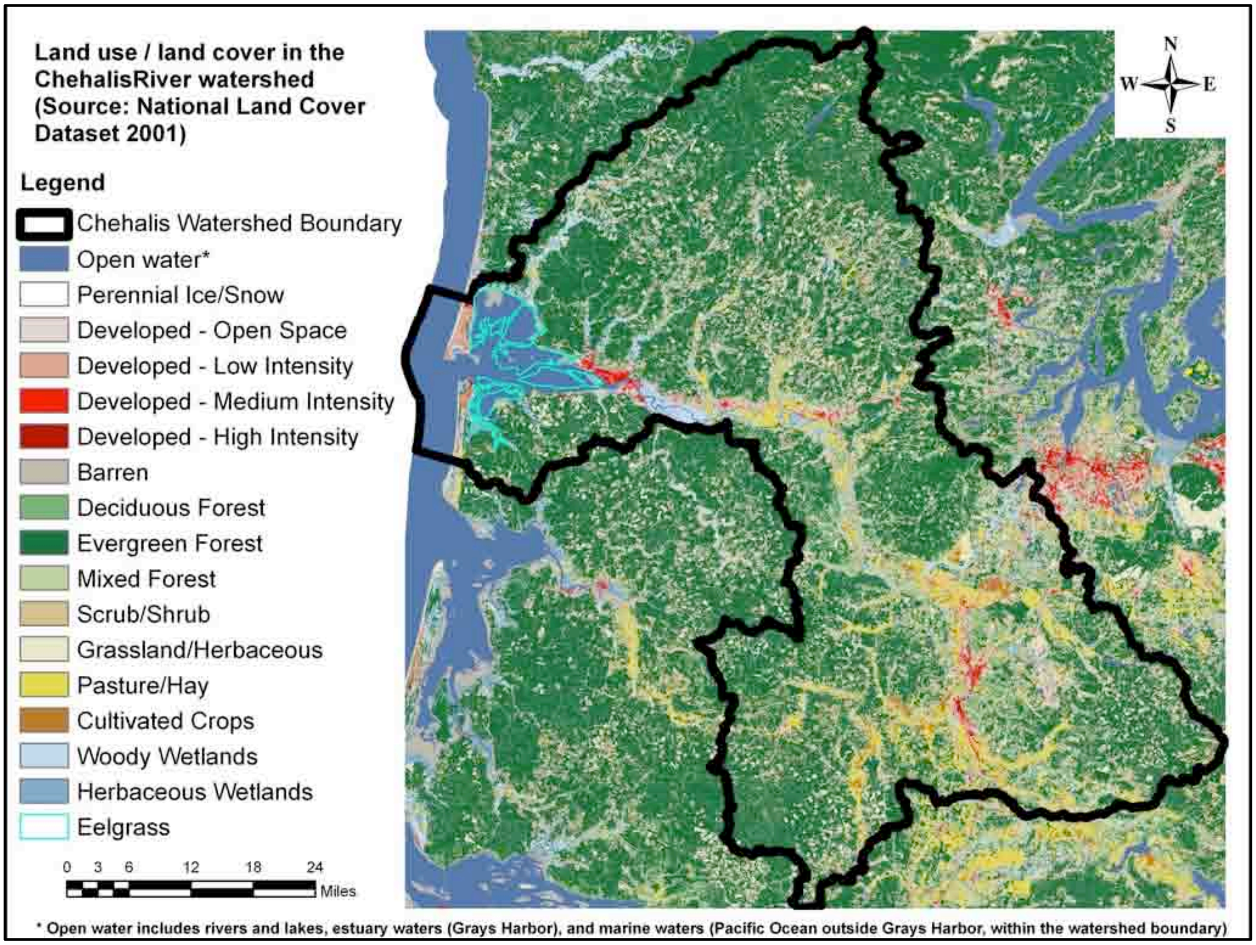
8. One scenario of actions/investments can then be compared to other flood protection investments. Or, combinations of flood protection investments can be compared to show how much benefit was received by which beneficiaries across the landscape, and how efficient or co-dependent each investment was in providing these benefits (examples of co-dependence are *wetlands* and *barrier islands* in Louisiana that protect *levees* against storm damage, and together, *these three* provide hurricane protection for communities). Flood protection scenarios could be compared in terms of various criteria including residences flooded, value of economic damage, lowered floodwater stages, fewer people and economic assets in the floodplain, and reduced flood hazard.

ARIES Mapping Results in the Chehalis Basin

The next section discusses initial ARIES mapping and results for the Chehalis River Basin, utilizing geographic information systems data specific to the Chehalis River Basin. This modeling is available on the ARIES website and is accessible with instructions provided in Appendix E. Mapping and understanding the beneficiaries, flood sources and flood protection provisioning also sets in place the basis for a funding mechanism for the Chehalis River Basin Flood Authority.

This is an initial analysis, and requires review and inputs from stakeholders, local governments, agencies, the State, and most significantly the Chehalis River Basin Flood Authority. The topography, vegetation, soils, hydrology, flood creating rain events, impermeable surfaces, levees, dams, locations of farms, residents, businesses, and public infrastructure are all important factors in flooding, safety, and flood protection. The map in Figure 5 is a starting point, and shows the land cover/land use types in the Chehalis River Basin.

Figure 5. Land Use and Land Cover in the Chehalis River Basin



This land use map, like the other maps included in this report, provides spatially specific data on the land cover type throughout the watershed. This spatial data, in the form of data pixels, is utilized within ARIES for modeling. ARIES received the National Science Foundation Grant because of its capacity to combine GIS data with complex modeling, and account for uncertainty. This is very important for decision-makers who would like to understand the outcomes of different scenarios, and the reliability of these results.

ARIES is built on basic science and our understanding of how natural systems work. The better the data on, and modeling of, hydrology, topography, soils, and other determining factors, the better ARIES can perform.

In the case of the Chehalis River Basin and flood protection, the basic GIS data was first gathered, then, mathematical procedures were used to bring it into compatibility (because rainfall data, slope, vegetation cover and other data are often assembled on different scales). Next, conceptual models for each of the beneficiary, flood source and flood protection systems were constructed.

Diagrams of the basic relationships, model frameworks, are presented in Appendix E. The Bayesian models that generated the outputs in this report are complex mathematical models, and are available upon request.

These models are currently based on many assumptions. To fully develop this model would require close collaboration with the Flood Authority, the Army Corps of Engineers, and US Geological Survey utilizing the best available data, LIDAR and hydrological models. **The ARIES maps produced here do represent real results using real data from, and models specifically constructed for, the Chehalis River Basin for examining flood protection**. The beneficiary maps are more accurate than the final flood protection maps because the hydrology is not fully included (or understood), and these models require further refining. The provisioning maps, in particular, should be seen as a very preliminary and an incomplete rendition of what could be produced with further work.

Beneficiary Group Mapping and Modeling

The following output map illustrates local beneficiaries of flood protection. The full set of beneficiary maps not produced here, (due to scope and budget limitations) would map the beneficiaries of flood protection in all the affected counties, and people living outside the Chehalis River Basin, such as those who benefit from the I-5 corridor, rail lines, and recreational areas. These beneficiaries would be mapped from Vancouver, BC to Los Angeles, and based on the traffic and value of transported goods, could be graded according to the size of economic benefits they receive.

Three basic beneficiary groups were identified in the Chehalis River Basin: residential owners, private owners (not including residential owners) and public owners, such as public schools, utilities and governments. The basic modeling relationship structures for these three sets of beneficiaries are provided in Appendix E. These results could be strengthened further if the location of each house, building and asset were specifically identified within the property where it occurs. The GIS data for the Chehalis Basin does not show the exact locations of structures within property boundaries. Because properties have different elevations, knowing where assets are on the property provides even more specific data than shown in these GIS examples, and would eventually enable scenario planning that could provide detail including partially flooded properties. This would enable more accurate consideration of actions and scenarios that would modify/move buildings and other assets within property boundaries to avoid flood damage.

With existing GIS maps, initial local flood protection beneficiary maps have been produced. For example, residences at risk of flooding in Grays Harbor are shown in Figure 6. Farms at risk in Lewis County are shown in Figure 7.

This flood map is scaled out; it is possible to zoom into a specific area with the web-based tool and see individual properties. Changes in conditions change these maps, for example, residents on the western end of Grays Harbor will not be flooded during a low tide when floodwaters drain well. Grays Harbor residents at risk depends on the timing and elevation of the high tide with peak floodwaters as they reach the lower reaches of the Chehalis River causing backing up on the river and tributaries.

Figure 6. ARIES Map showing Grays Harbor Residents at Risk of Flooding

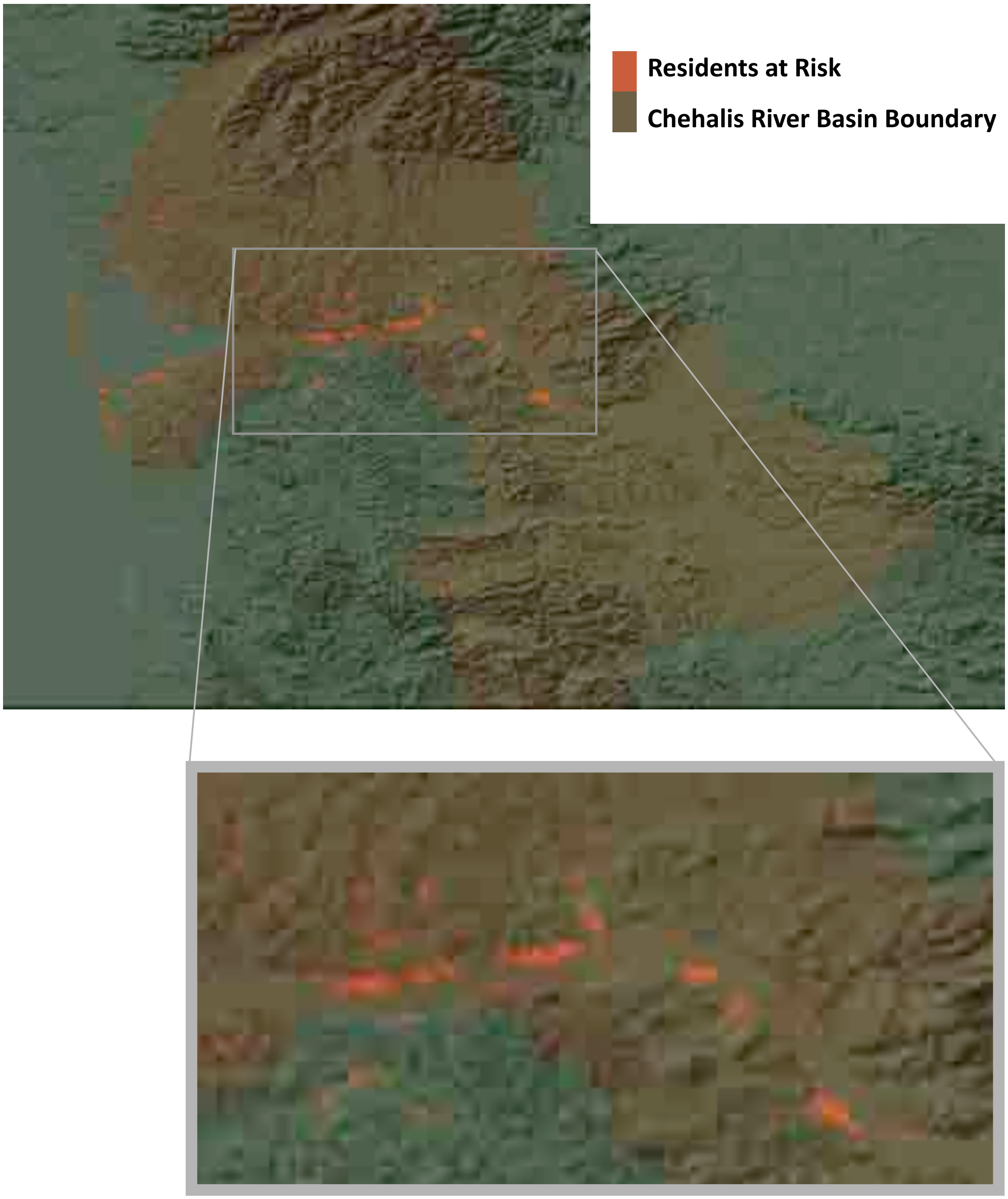
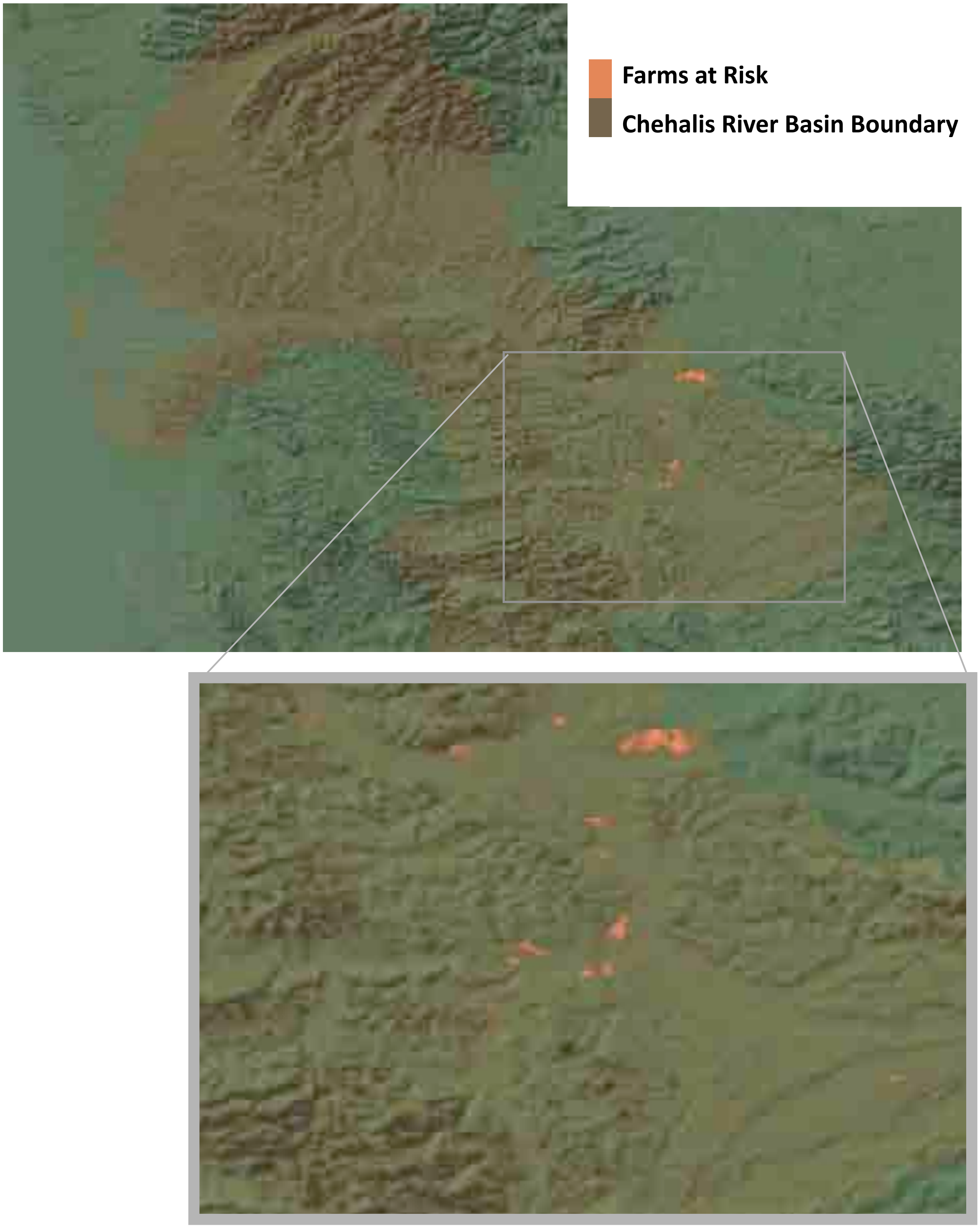


Figure 7. ARIES Map showing Grays Harbor Farms at Risk of Flooding



Flood Protection Modeling

Flood protection modeling and mapping is based on Chehalis River Basin data. Sets of models are used to produce maps of flood protection assets including built and natural capital. The amount of flood protection provided can be measured as lowered flood elevations, reduction in damage value, or other criteria. The conceptual framework for flood protection models is shown in Appendix E.

Input GIS data, modeling framework and input maps for the rudimentary hydrological functions and flood protection models are included in Appendix E.

Depending on the location of heavy rainfall, the flood protection value of both natural and built flood protection infrastructure can shift dramatically. Warm heavy rain on snow will cause snow elevations to rise and an elevation band to shift from providing flood protection, to becoming sources of floodwaters. Land above the snowline provides flood protection as precipitation forms snow pack. If heavy precipitation occurs with low temperatures, lower elevations provide flood protection as snow pack. If a warm heavy rainfall arrives and raises the snow line, snow pack below the freezing elevation will flip to become a source area of floodwaters.

The provisioning of flood protection includes built capital, natural and social capital. Built capital infrastructure, such as dams and levees, are included in flood protection modeling. Natural, or green infrastructure, such as forests, wetlands, soils, impermeable surfaces, and groundwater recharge are also included in flood protection modeling. Social actions, such as raising structures or early warning systems have not yet been included in ARIES modeling. From the input data and modeling the absorption, infiltration, and/or detention of floodwater can be calculated and mapped across the landscape. Figure 8 shows the provisioning of flood protection by green infrastructure (natural capital). Similar maps can be developed for the flood provisioning value of built capital, and for the combination.

A few of the input GIS data maps for the Chehalis Basin are provided in Appendix E. One of these, slope, is shown in Figure 9.

Figure 8. Green Infrastructure Map

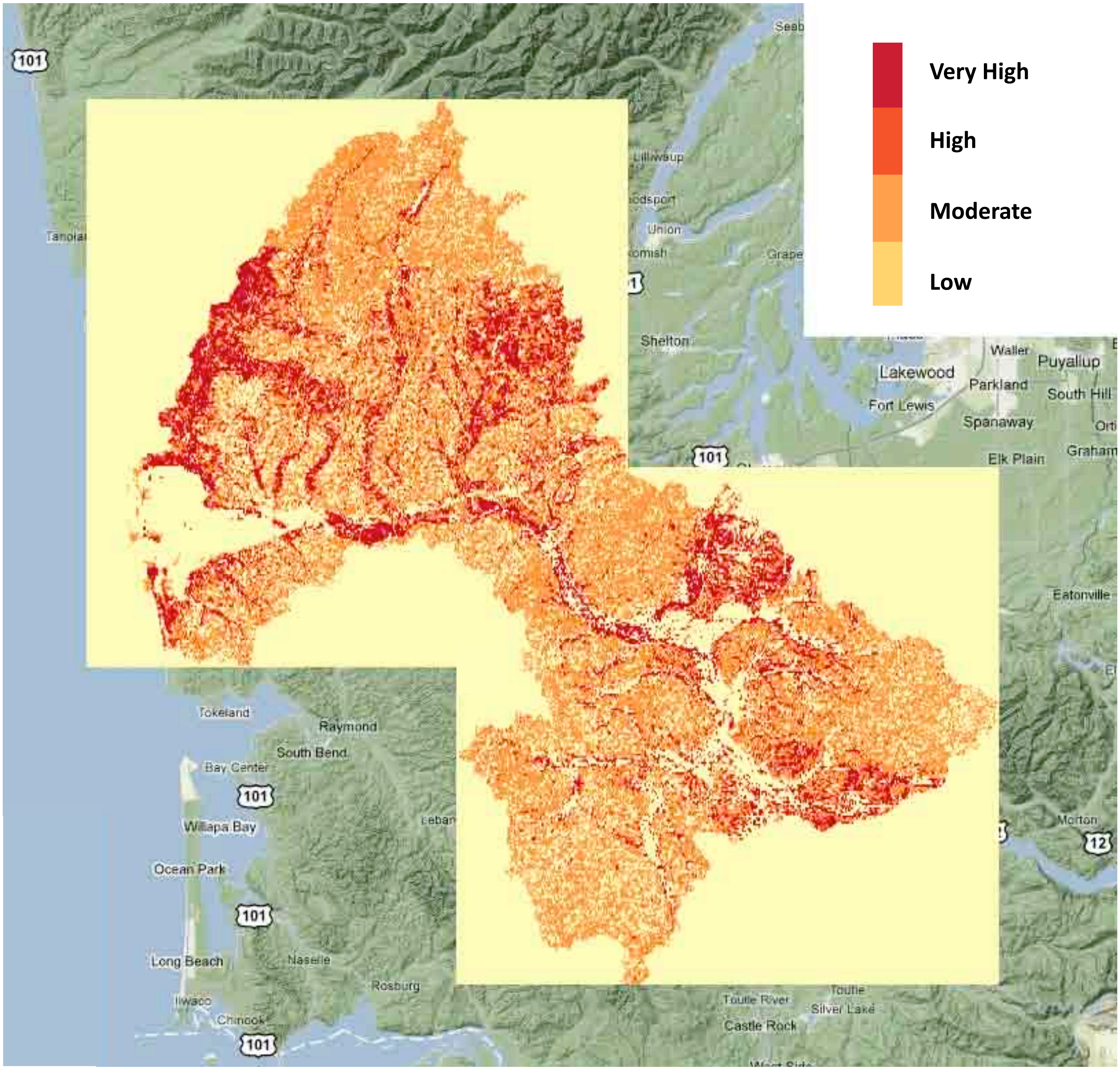
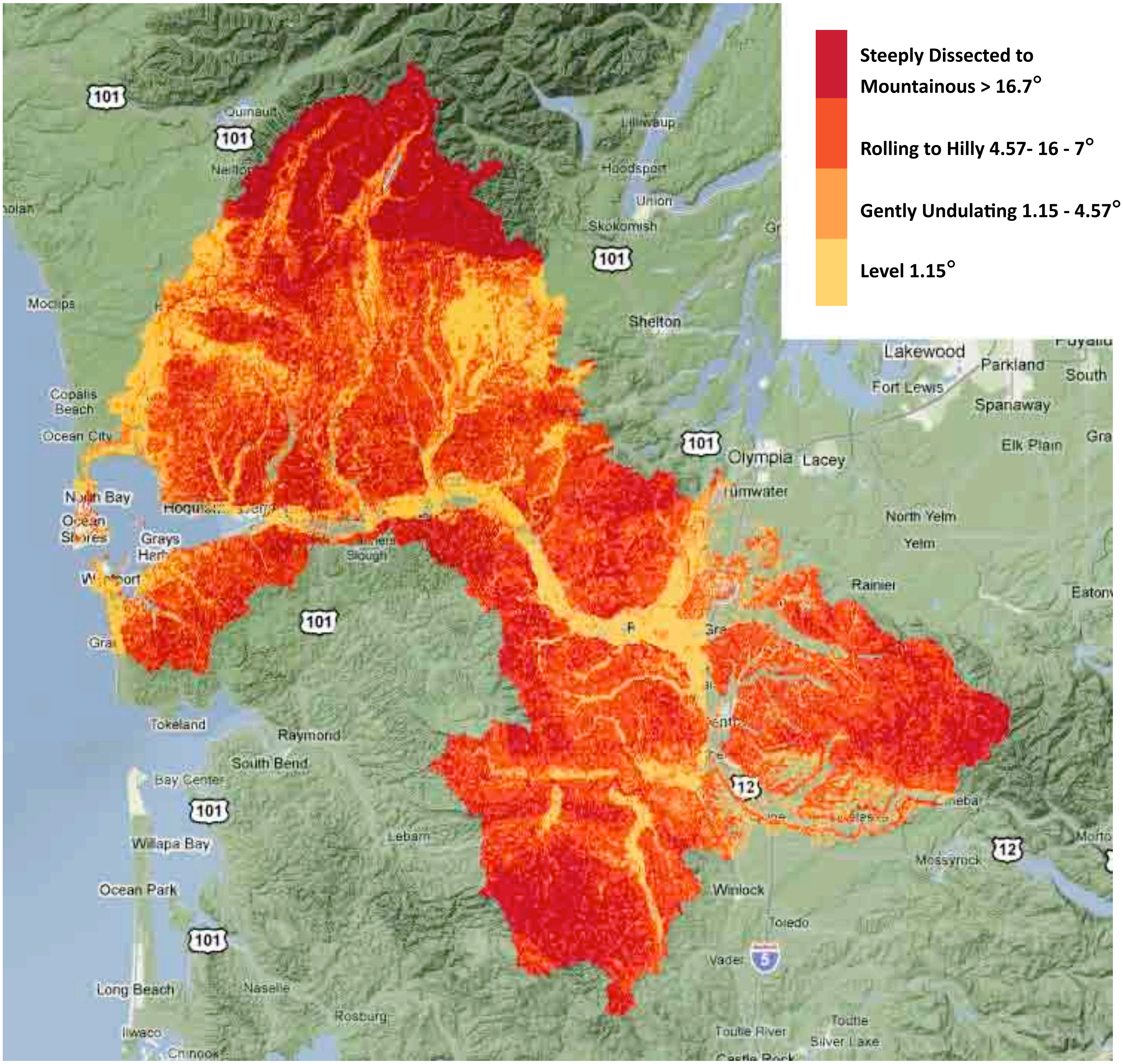


Figure 9. Slope Map



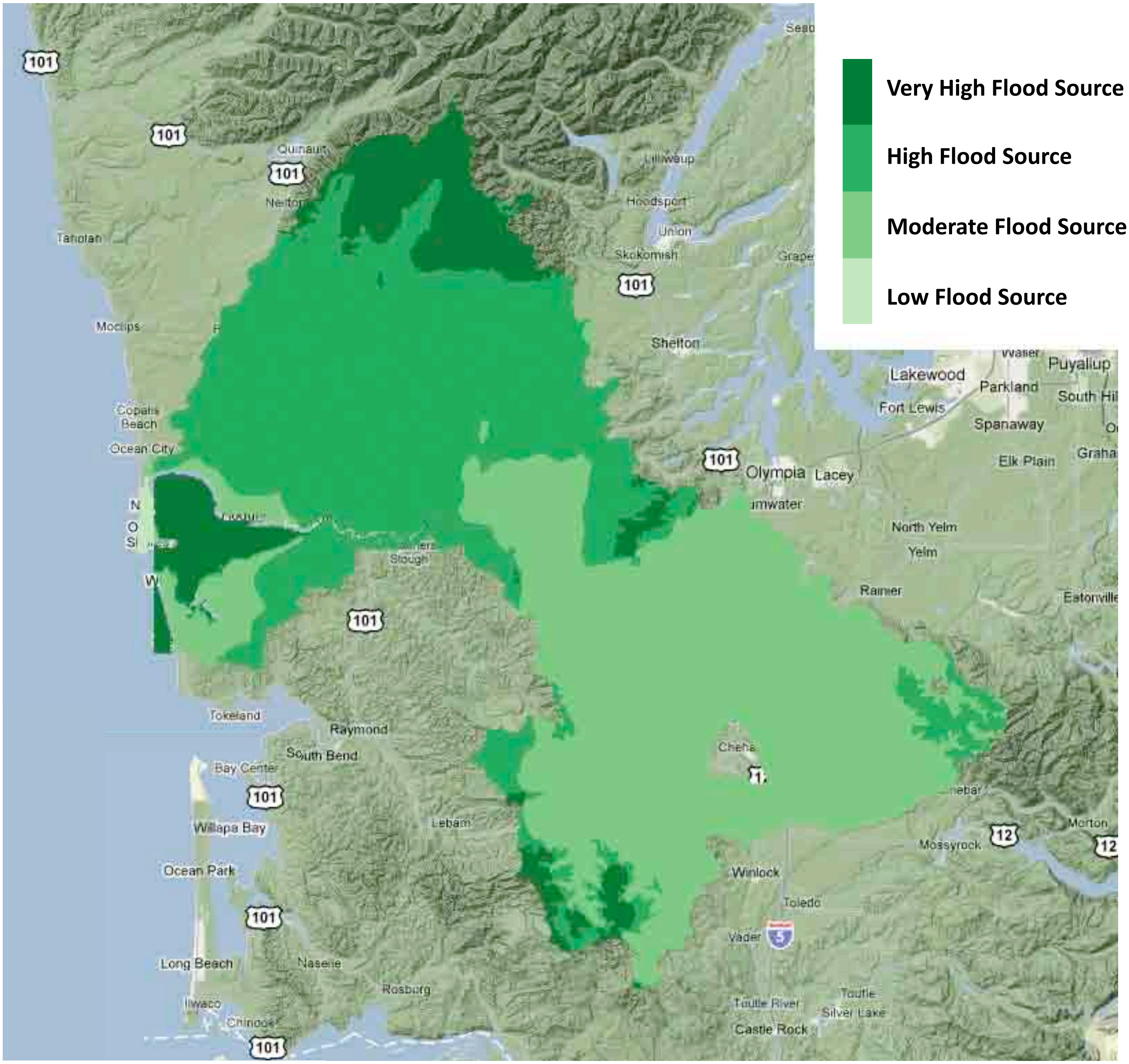
Flood Source Modeling

Output maps, called flood source maps, show the causes of flooding. These are draft and incomplete, and employ simple hydrology. ARIES will have the capacity to "bolt" hydrological models developed by the US Army Corps of Engineers or others into ARIES models and GIS data to provide scenario planning.

To generate these maps, many data layers are automatically extracted from the ARIES GIS database constructed from actual Chehalis Basin GIS maps. Among the flood source factors are precipitation, snow, slope, soils, vegetation cover, forest successional stage and more. Rainfall is a crucial input; currently the modeling uses only monthly averages, but it has the capacity to include high rainfall events and take into account the distribution of this rain across the landscape to create different levels of flooding. Flood rainfall data by inches, temperature and location can be entered at present. The modeling framework for the sources of flooding is provided in Appendix E. Built capital, such as levees, bridges and dams can also be mapped, and their hydrological properties included. Existing levees in Lewis County have been mapped and included in ARIES.

Finally, with input data spatially specific to the Chehalis Basin, and modeling of how floodwaters move across the landscape, flood source maps can be produced. A Floodwater source map is shown below in Figure 10. This map shows the areas that generate floodwaters.

Figure 10. Floodwater Source Map



The Future of ARIES

With further development in 2010, it is expected that ARIES will better calculate the distribution of floodwaters and flood protection capacity across the Chehalis Basin. With calibration of the basic modeling, flood scenarios with different rainfall patterns, temperature changes, and other variables will be conducted. At the same time scenarios of different flood protection actions will then be run.

These three sets of data, models, and maps show decision-makers the beneficiaries of flood protection, the sources and distribution of floodwaters and flood damage, and the assets or actions that provide flood protection, as well as how much benefit is provided, and to which beneficiaries it goes. In the future, ARIES is expected to generate a robust flood scenario planning tool which can run different combinations of potential flood protection actions with different rainfall, saturation and other flood causing scenarios.

Because flood protection is just one of the ecosystem services ARIES examines, there is another layer of scenarios and modeling available.

Additional Modeling Scenarios

Just as ARIES models the beneficiaries, problem sources (flooding) and benefit provisioning (flood protection) for flooding, systems have been developed for other ecosystem services. This provides a better understanding of what potential flood protection investments may do to improve or damage other ecosystem service benefits. It also provides the requirements for robust scenario analysis used to develop a built and natural capital strategy. It simulates the benefits of flood protection projects and prioritizes them in terms of location, funding, and sequencing.

Understanding the goals for salmon restoration, drinking and irrigation water, and carbon sequestration can not only help achieve goals in these areas, but help to increase co-funding for flood protection also. For example, levee setbacks in the transition zone benefit juvenile salmon and widen the floodway providing greater floodwater conveyance. Longer forest rotations can increase the vertical and subsurface (roots) forest structure, promoting slope stability, transpiration and groundwater infiltration. These functions help attenuate peak flows and recharge groundwater for salmon and drinking water. Longer forest rotations also increase carbon sequestration in timber and soils, contributing to climate stability.

Understanding these ecosystem services opens up potential funding mechanisms for forest-based rural areas, such as the Chehalis River Basin. One funding mechanism that would increase flood protection and bring in funding from outside the basin to complement a locally funded flood district would be a carbon sequestration funding mechanism.

Using ARIES, Earth Economics ran carbon sequestration mapping for the Chehalis River Basin. The Basin is a net carbon sink. Drinking and irrigation water, salmon, storm water and flood protection ecosystem services have great overlap, which means potential for co-financing mutually beneficial projects.

Legislation to create a carbon trading system in the United States has been proposed in 2010. A carbon trading or tax/rebate system applied in Washington State, the west coast states or nationwide would create an income stream for rural carbon sequestering communities, such as the Chehalis Basin. This income could fund watershed activities such as flood protection.

Management Implications: The Case for Investing in Flood Protection

This section provides a restatement and summary of some of the critical issues raised in this report which lead to the conclusion that investment in flood protection is vital—indeed ***investment in flood protection provides a high, sustainable, and fair rate of return for people today and in the future.***

Communities and economic development are built on investment. Investments in flood protection, storm water, salmon restoration, energy generation, drinking water, and other services are best made when informed by knowledge of the effects of these investments on other ecosystem services. The development planning of counties, towns, and cities must also be considered.

The economy and local quality of life in the Chehalis River Basin depends on sufficient flood protection. An initial analysis, this study should not be taken as the final word on ecosystem service valuation for the Watershed. It is a first step towards understanding the significant contributions that functioning ecosystems make to the economic well being of communities within the Watershed.

A combination of built structures, natural systems and social actions (such as warning systems and land use planning) are likely today's most efficient and effective ways to provide flood protection and build a healthy and prosperous economy. However, it is important to determine the right level of investment, to choose the right projects, and to balance projects between built structures, which require higher maintenance costs, natural systems, which provide a variety of other valuable ecosystem services in addition to flood protection, and social actions that prevent people from being in harm's way.

There are more than financial costs to consider. The Chehalis Tribe, for instance, has treaty rights to fish and other resources. Clean water, healthy air, and biodiversity contribute to a stable economy that supports a healthy and sustainable quality of life. Our nation has passed the Clean Air Act, Clean Water Act, and Endangered Species Act, laws that conserve aspects of the environment important to our quality of life, for present and future generations.

Flood protection investments are significant, and are intended to protect citizens, economic assets, and valuable ecological functions. Nature's goods and services offer a bargain--and a good investment opportunity. When natural systems are healthy, nature provides vast amounts of economic value for free or at little cost; once degraded, natural systems require investments to restore the flow of goods and services. When healthy, natural systems are self-maintaining and provide benefits over time. Because they are increasingly scarce, many natural assets are appreciating in value. In addition, unlike financial assets, such as investments in the stock market, which can dramatically rise or fall in minutes, natural systems that provide drinking water, flood protection, salmon and other benefits are not so easily lost.

The people who live in the Chehalis River Basin are the ones who most benefit from flood protection and other ecosystem services provided by the Basin. They receive drinking water, flood protection, recreation, and aesthetic value on a daily basis. However, the benefits to Washington State and the nation are also significant, and justify investment from the State of Washington and federal agencies such as the Army Corps of Engineers. The investment in flood protection provides a high, sustainable, and fair rate of return for people today and in the future, both locally and regionally.

Suggested Flood Project Selection Criteria

Criteria for selection of flood protection projects need to reflect the goals of the communities, and those of both appointed and elected representatives serving within the Chehalis River Basin. They are not presented in a prioritized order. No system for scoring or weighting these criteria is suggested here, though the Flood Authority may find it helpful to create a scoring or weighting scheme. These criteria do not suggest that greater priority be given for investment in natural or built systems or any particular flood protection proposal.

Suggested criteria are broken into two categories:

1. What are the **expected impacts of the project**?
2. What are the **resource and governance requirements**?

Expected Project Impacts

Contribution to public safety:

1.1 Does the suggested project result in greater public safety?

1.2 Is there a spatial analysis of where public safety is enhanced and where risks to public safety may be increased due to this project?

1.3 What are the risks of project failure and the implications for public safety?

Contribution to flood protection:

1.4 Does the suggested project prevent flood damage and reduce flood hazards?

1.5 What are the risks of and from project failure?

1.6 Does the project ensure people and assets are out of the way of floods, or protect economic assets including residences, businesses, transportation corridors, agriculture, and ecosystem services?

There is no single measure for flood protection. It must be measured with social, physical, economic, and ecological measures. These can include: 1) reduction in the number of people threatened with death or physical harm (measures such as evacuation population and evacuation time can be included); 2) geographic estimates of peak flood water heights and attenuation in subwatersheds and the main basin under different rain fall/snow/saturation/tidal scenarios; 3) reduction of economic assets threatened by flooding; and 4) increase or reduction of ecosystem services, measured by all of the physical expectations impacted by flood protection actions, i.e., number of salmon present and the dollar values of ecosystem services.

Cost/Benefit (including ecosystem services):

1.7 What is the cost/benefit ratio of this project?

This analysis should include ecosystem services and a discussion of the distribution of the benefits.

Enhancement of Chehalis River Basin development:

1.8 To what extent does the project contribute to economic development within the Chehalis River Basin?

1.9 What is the spatial distribution of these benefits within and outside the Chehalis River Basin?

This should include both long-term job creation and jobs created as a result of restoration of systems that provide valuable ecosystem services.

Enhancement of ecosystem services:

1.10 Does the project enhance natural processes?

1.11 Does the project utilize, enhance, or reduce associated ecosystem services such as salmon habitat, water quality, recreation and other benefits listed in Table 2?

Distribution of benefits:

1.12 How are the benefits (safety, economic and ecological) of this project distributed?

1.13 To what extent are benefits provided to those outside the Chehalis River Basin, and within the Chehalis River Basin?

1.14 What is the spatial distribution of these benefits within the Chehalis River Basin?

Resource, maintenance and governance requirements over time

Project cost:

2.1 What is the cost of this project?

2.2 What are the maintenance and operations costs of the project?

2.3 Will this project require reconstruction at some point due to flood or other causes of damage?

Funding:

2.4 What are the sources of funding for this project?

2.5 Are there co-funding/matching funds available?

2.6 What are the future budgetary requirements for this project?

Resilience:

2.7 How resilient is the flood protection this project provides to states of change, such as budgetary reductions, earthquakes, climate change and greater than historic rainfall patterns?

Lifespan:

2.8 What is the effective flood protection lifespan of the project?

2.9 Does the flood protection it provides increase with time, or decrease?

Maintenance and operations costs:

2.10 What are the maintenance and operations, or potential reconstruction, costs associated with the project?

Clear and feasible project governance:

2.11 Does the project have clear on-going governance that can manage, maintain and fund this project?

Conclusions

The annual flow of value shown by the partial valuation of 12 ecosystem services across 18 land cover types in the Chehalis River Basin is roughly between $1.3 billion and $11.6 billion. These figures would rise by including additional ecosystem services. This wide range includes all high and low assessments for all ecosystem services valued, reflecting significant uncertainty. It is clear, however, that **ecosystem services in the Chehalis River Basin represent a tremendous economic asset - on the scale of at least $1.3 billion annually.** These natural systems represent tremendously valuable assets, worthy of protection and further investment.

From this annual flow of value, a capital "asset value" can be calculated. This is like considering the difference between the sum of monthly mortgage payments across the year (an annual flow of value for living in the house in one year) and the full sale value of a house (the "asset value, or present value). To determine *asset value* of ecosystems to society, we apply, over 100 years from the present day, the depreciation (or discount) rate of 2.7% recommended by the Army Corps , which results in a finding that these 12 ecosystem services in the Chehalis Basin provide an annual asset value of $43 – 400 billion. This figure would narrow as the analysis is refined, and more local ecosystem service values are determined.

Because most natural assets appreciate, rather than depreciate, the true present value figure is likely even higher. As previously stated, to represent this asset appreciation, we use a 0 percent discount rate, treating the value these ecosystems will provide to future generations as equal to that of present generations. **The result is an *asset value* of ecosystem services in the Chehalis River Basin of between $127 billion – 1.1 trillion.** This is the value to people in the Chehalis River Basin if all people benefiting for 100 years were all treated equally (normally, value to people in the future, even next year, is discounted).

The results of this study conclude the following:

- Both natural and built infrastructure, provide flood protection in the Chehalis Basin. In addition to flood protection, Chehalis River Basin ecosystems provide 22 other economically valuable goods and services, including water supply, food, and habitat.
- A partial valuation of 12 Chehalis Basin ecosystem services shows a range of economic benefits between $1.3 and $11.6 billion in value to citizens every year.
- The present value of the annual flow of these benefits (analogous to an asset value) is between $43 billion and $400 billion, at a 2.7% discount rate.
- These benefits are provided to people living inside and outside of the River Basin.
- The best investments for achieving flood protection are likely a combination of natural capital (such as floodplains), built capital (such as dams and levees) and social capital (land use planning, moving flood prone built assets, early warning systems).

- Some Chehalis Basin beneficiaries of flood protection were provisionally identified and mapped in Lewis and Grays Harbor Counties. All beneficiaries could be mapped and this information could be used in modeling and comparing project and flood scenarios.
- By understanding the set of ecosystem services provided, where flood protection is provisioned, who and where the beneficiaries are and different flood scenarios, funding mechanisms for the Flood Authority or District can be developed.
- An integrated approach with other ecosystem services may provide greater value in basin-wide economic value and allow access to funding mechanisms with other ecosystem services such as carbon sequestration.
- Additional studies using more complete data, modeling, mapping, and hydrology could provide additional information for identifying, prioritizing, and selecting flood protection projects.

Overall, this analysis shows that flood protection expenditures of the local, state and federal agencies are strongly justified. The selection of flood protection projects should be informed by their benefits (or damages) to associated ecosystem services. Understanding these benefits makes flood protection investments more successful, and can enhance other economic assets, allowing them to contribute more effectively to basin-wide economic development.

Next Steps

Flooding in the Chehalis River Basin is a natural process. Many floods have occurred over the last 100 years. Yet development patterns, climate change, rainfall variability, and other factors may have contributed to the recent severe floods in 2007 and one in 2009.

This report provides a "first view" of the value of flood protection provided by natural capital, and a methodology for looking at how natural and built capital can better provide flood protection. In addition it lays out a framework for flood modeling and economic analysis. Flood protection project criteria were suggested. The modeling, economics and criteria described in this report lay out the foundation for identifying, prioritizing, selecting and sequencing flood protection projects. In addition, all this information should be useful for additional and currently planned studies.

Following are some brief suggestions on where to proceed from here:

1. **Develop further modeling and mapping capacity.** The basin-wide general investigation and characterization led by the U.S. Army Corps of Engineers, and hydrological studies, should be coupled with further development of ecosystem service and scenario tools. The ARIES tools for identifying, mapping, and valuing flood protection,for identifying beneficiaries of flood protection, and for prioritizing flood protection project options and scenarios are still in development, but lay out a framework for better flood protection planning. Maps of ecosystem services can include:

- **Provisioning maps** to show where flood protection and other ecosystem services and goods are produced;
- **Beneficiary maps** to show who is benefiting from existing ecosystem services;
- **Flood source maps** to show how flooding is created, and where provisioning of flood protection and other ecosystem services are being impaired, such as a bridge that might restrict the floodway causing increased flooding upstream, or a steep and unstable slope that could slide to block river flows;
- **Critical Path maps** to show how the service of flood protection is transferred to beneficiaries (which can include moving people out of the floodway), and identify critical areas for flood protection and ecosystem service provisioning. For example, peak flows may be reduced by upland forests, wetlands and lakes and improve the performance and longevity of dams and levees.

2. **Develop scenario analysis.** Create scenario analysis with modeling to help judge project proposals against established criteria. These analyses might include:
    - Scenarios of different flood levels and rainfall patterns across the watershed;
    - Scenarios of single flood protection projects and combinations of projects;
3. **Develop project prioritization and reporting methodology.** Prioritize flood projects based on clear criteria, best science, public safety and a complete economic analysis of flood protection value of natural and built capital. Investigate robust reporting options to keep stakeholders and the community informed of project status, location and performance.
4. **Develop funding mechanisms.** Examine improved cross-disciplinary funding mechanisms for flood protection and other ecosystem services to ensure the sustainability of flood protection projects and outcomes.
5. **Develop innovative funding sources.** Create complementary funding sources. Flood protection has generally been funded by federal and local agencies for construction costs and through local taxes and fees. There are other funding mechanisms, such as a watershed investment district or carbon trading regime, which could provide complementary funding mechanisms to supplement these traditional approaches.
    - **Seek cross-jurisdictional partnerships.** Develop funding mechanisms with a wide consideration of a combination of complementary federal, state and local funding mechanisms.
6. **Improve Comprehensive Planning.** Continue to advance land use planning, building standards, and warning and evacuation systems in the basin. These are likely some of the most effective ways of providing flood protection and creating a more efficient and prosperous economy. Examining ecosystem services within the watershed, in light of economic development planning, would also be a logical next step.

In conclusion, flood protection will likely be one of the largest investments (over one hundred million dollars) in the Chehalis River Basin for some decades. Understanding the hydrology and science of the Basin is key to successful flood protection investments and to fully accounting for the public safety. Understanding the economic value of built and natural capital is essential to providing an accurate economic analysis of flood protection proposals. To select and prioritize projects requires the determination of selection criteria, and the modeling of the provision of flood protection, location of beneficiaries, and the impediments to flood protection. Tools for examining flood scenarios to test their overall economic costs and benefits as well as the distribution of benefits could greatly benefit decision-makers. In addition, a solid governance structure for project selection, funding, sequencing and implementation, will help decision-makers secure flood protection success. This study assists with a number of these key components.

Literature Cited

Azar, C. and T. Sterner. 1996. Discounting and distributional considerations in the context of global warming, Ecological Economics, 19: 169-184

Balmford, A., A. Bruner, P. Cooper, R. Costanza, S. Farber, R. E. Green, M. Jenkins, P. Jefferiss, V. Jessamy, J. Madden, K. Munro, N. Myers, S. Naeem, J. Paavola, M. Rayment, S. Rosendo, J. Roughgarden, K. Trumper, and R. K. Turner. 2002. Economic reasons for conserving wild nature. *Science* 297: 950-953

Batker, David. 2005. Supplemental Ecological Services Study: Tolt River Watershed Asset Management Plan. Seattle Public Utilities, Seattle, Washington

Batker, David, Elizabeth Barclay, Roelof Boumans and Terry Hathaway. 2005. Ecosystem Services Enhanced by Salmon Habitat Conservation in the Green/Duwamish and Central Puget Sound Watershed. Water Resources Inventory Area 9, Seattle, Washington.

Beyers, W. B. 1991. "Trends in Service Employment in Pacific Northwest Counties: 1974-1986." *Growth and Change.*

Birdsey, R.A. 1996. Regional Estimates of Timber Volume and Forest Carbon for Fully Stocked Timberland, Average Management After Final Clearcut Harvest. *In Forests and Global Change: Volume 2, Forest Management Opportunities for Mitigating Carbon Emissions*, eds. R.N. Sampson and D. Hair, American Forests, Washington, DC.

Boumans, R., R. Costanza, J. Farley, M. A. Wilson, R. Portela, J. Rotmans, F. Villa, and M. Grasso. 2002. Modeling the dynamics of the integrated Earth system and the value of global ecosystem services using the GUMBO model. *Ecological Economics* 41: 529-560

Buchanan, J.B., D.H. Johnson, E.L. Greda, G.A. Green, T.R. Wahl, S.J. Jeffries. 2001. Wildlife of coastal and marine habitats. In, *Wildlife Habitat Relationships in Oregon and Washington*, D.H. Johnson and T.A. O'Neil, Managing Directors. Oregon State University Press, Corvalis, OR.

Bullard, R., P. Mohai, R. Saha, and B. Wright. 2007. Toxic Waste and Race at Twenty. A report prepared for the United Church of Christ and Witness Ministries, Cleveland, OH.

Carey, A.B., Kershner, J., Biswell, B. and L. Dominguez de Toledo. 1999a. Ecological scale and forest development: Squirrels, dietary fungi, and vascular plants in managed and unmanaged forests. *Wildlife Monographs* 142:1-71.

Carey , A., Elliott, C., Lippke, B., Sessions, J., Oliver, C., Franklin, J. and M. Raphael. 1996. *Washington Forest Landscape Management Project: A Pragmatic, Ecological Approach* *to Small Landscape Management*. USDA Forest Service, Washington Department of Fish and Wildlife, and Washington Department of Natural Resources, Olympia, WA.

Carpenter, S. 2001. Alternate states of ecosystems: Evidence and its implications for environmental decisions. In, M.C. Press, N. Huntley and S. Levin, eds. *Ecology: Achievement and Challenge.* Blackwell, London.

Cederholm, C. J., D.H. Johnson, R.E. Bilby, L.G. Dominguez, et al. 2001. Pacific salmon and wildlife – ecological contexts, relationships, and implications for management. In, *Wildlife Habitat Relationships in Oregon and Washington*, D.H. Johnson and T.A. O'Neil, Managing Directors. Oregon State University Press, Corvalis, OR.

Chappell, C.B., R.C. Crawford, C. Barret, J. Kagan, D.H. Johnson, et al. 2001. Wildlife habitats: Descriptions, status, trends, and system dynamics. In, *Wildlife Habitat Relationships in Oregon and Washington*, D.H. Johnson and T.A. O'Neil, Managing Directors. Oregon State University Press, Corvalis, OR.

Chehalis Basin Partnership 2002. Chehalis Basin Level 1 Assessment. Prepared for Chehalis Basin Partnership, by Envirovision Corportation.

Chehalis Basin Partnership 2004. Chehalis Basin Watershed Management Plan.

Chehalis River Basin Flood Authority. 2009. Chehalis River Basin. Draft Comprehensive Flood Hazard Management Plan. Prepared by ESA Adolfson for the Chehalis River Basin Flood Authority.

Chehalis River Council Chehalis Basin Watershed Planning Issue Paper. Agriculture and Water Management. Retrieved February 2010 from http://www.crcwater.org/cbp/20030922ag.html.

Costanza, R. 2006. Nature: valuing ecosystems without commodifying them. *Nature* 443:749.

Costanza, R., J.C. Cumberland, H.E. Daly, R. Goodland, and R. Norgaard. 1997(a). *An Introduction to Ecological Economics*. St. Lucie Press, Boca Raton, 275 pp.

Costanza, R., d'Arge, R., de Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R. V., Paruelo, J., Raskin, R. G., Sutton, P., & Belt, M. van den. 1997b. "The Value of the World's Ecosystem Services and Natural Capital." *Nature.* 38, 253-260.

Collins, S.J., Ingram, D., Brown, H., 2007. Forest Certification and the National Forest System. Discussion Paper, US Forest Service. Retrieved February 2010 from http://www.fs.fed.us/news/2009/briefings/06/certification.shtml.

Costanza, R and J Farley. 2007. "Ecological Economics of Coastal Disasters." Ecological Economics, Volume 63, Issues 2-3, 1 August 2007, Pages 344-354.

Costanza, R., M. Wilson, A. Troy, A. Voinov, S. Liu, and J. Agostino. 2007. The Value of New Jersey's Ecosystem Services and Natural Capital. The Gund Institute of Ecological Economics, Burlington, VT and The New Jersey Department of Environmental Protection, Trenton, New Jersey.

Costanza, R., O. Perez-Maqueo, M.L. Martinez, P. Sutton, S. Anderson, and K. Mulder. In review. "The value of coastal wetlands for hurricane protection." BioScience.

Cowlitz Wahkiakum Council of Governments 2009. Lewis County 2007 Flood Disaster Recovery Strategy.

Daily, G., ed. 1997. Nature's Services. Island Press, Washington, D.C., Covelo, CA, and London.

Daly, H. and J. Cobb. 1994. *For the Common Good*. Beacon Press, Boston.

Daly, H. and J. Farley. 2004. *Ecological Economics: Principles and Applications*. Island Press, Washington, D.C., Covelo, CA, and London.

Day, J., R. Barras, et. al. 2005. Implications of global climatic change and energy cost and availability for the restoration of the Mississippi Delta. *Ecological Engineering* 24(5): 253-265.

DeGroot, R., M. A. Wilson and R. M. J. Boumans. 2002. Ecosystem functions, goods and services: Classification, description and valuation guidelines. *Ecological Economics* 41: 393-408.

Desvouges, W. H., Johnson, F. R., & Banzhaf, H. S. 1998. *Environmental Policy Analysis with Limited Information: Principles and Applications of the Transfer Method.* Northhampton, MA: Edward Elgar.

DOLETA Website. US Department of Labor. Employment and Training Administration. Accessed February 2010 at
http://www.doleta.gov/wired/files/3g_Pacific_Mountain_Washington.pdf.

Downing, M., and T. Ozuna. 1996. Testing the reliability of the benefit function transfer approach. *Journal of Environmental Economics and Management* 30: 316-322.

Eade, J. D. and Moran, D. 1996. "Spatial economic valuation: benefits transfer using Geographic Information Systems." *Journal of Environmental Management* 48: 97-110.

Easterlin, R. A. 1995. Will raising the incomes of all increase the happiness of all? *Journal of Economic Behavior & Organization* 27(1): 35-47.

Easterlin, R.A., 1974. Does Economic Growth Improve the Human Lot?, in: David, P.A., Reder, M.W. (Eds.), Nations and Households in Economic Growth: Essays in Honor of Moses Abramovitz. Academic Press, Inc., New York.

ECONorthwest. 1999. The Sky Did Not Fall: The Pacific Northwest's Response to Logging Reductions. Prepared for Earthlife Canada Foundation and Sierra Club of British Columbia. ECONorthwest, Corvalis, OR.

Edwards, S. F. and F.J. Gable. 1991. "Estimating the value of beach recreation from property values: an exploration with comparisons to nourishment costs." *Ocean & Shoreline Management* 15:37-55.

Embrey, S.S., and Inkpen, E.L., 1998, Nutrient transport in rivers of the Puget Sound Basin, Washington 1980-1993: U.S. Geological Survey Water-Resources Investigation Report 97-4270, 30 p.

Environmental Protection Agency. 2007. National Estuaries Program Coastal Conditions Report. EPA-842/B-06/001 2006. Office of Water and Office of Research and Development, Washington, D.C.

Erickson, D.R., 1994. Effects of Leakage from Four Dairy Waste Storage Ponds on Ground Water Quality. Prepared for Washington State DOE. Retrieved February 2010 from http://www.ecy.wa.gov/pubs/94109.pdf.

ESA Adolfson, 2010. Chehalis River Basin Draft Comprehensive Flood Hazard Management Plan. Prepared for the Chehalis River Basin Flood Authority.

ESD 113 Website. Chehalis Basin Education Consortium. Accessed January 2010 at http://tnl.esd113.org/191910116152619890/site/default.asp?

Farber, S., R. Costanza, et al. 2006. "Linking ecology and economics for ecosystem management." *Bioscience* 56(2): 121-133.

Forest Ecosystem Management and Assessment Team. 1993. *Forest Ecosystem Management: An Ecological, Economic and Social Assessment.* U.S. Department of Agriculture Forest Service, U.S. Department of Interior Fish and Wildlife Service, U.S. Department of Interior Bureau of Land Management, U.S. Department of Interior National Park Service, U.S. Department of Commerce National Oceanic and Atmospheric Administration National Marine Fisheries Service, and Environmental Protection Agency, Washington D.C.

Franklin, J.F. T.A. Spies, R. Van Pelt, A.B. Carey et al. 2002. Disturbance and structural development of natural forest ecosystems with silvicultural implications, using Douglas-fir forests as an example. *Forest Ecology and Management*. 155:399-423.

Funtowicz, S.O. and J.R. Ravetz. 1994. The worth of a song bird: ecological economics as a post-normal science. *Ecological Economics* 10:197-207.

Garber, J.H., J.L. Collins, and M.W. Davis. 1992. Impacts of estuarine benthic algal production on dissolved nutrients and water quality in Yaquina River Estuary, Oregon. Water Resources Research Institute, Report WRRI-112, Oregon State University, Corvalis, OR.

Goodland, R., H.E. Daly, and S. El Serafy. 1992. *Population, Technology, and Lifestyle.* Island Press, Covelo, CA, Washington D.C., and London.

Governor Chris Gregoire Policy Brief 2007. Storm Recovery.

Graham, C., 2005. Insights on Development from the Economics of Happiness. World Bank Research Observer 20, 201-231.

Grays Harbour County 2004. Chehalis Basin Watershed Management Plan.

Green, R., Miles, S., Gulacsik, G., Levy, J., 2008. Quick Response Report: Business Recovery Related to High-Frequency Natural Hazard Events. Institute for Global and Community Resilience, Huxley College of the Environment, Western Washington University. Retrieved February 2010 from http://www.wwu.edu/resilience/Publications/Biz_Flood_Recovery-Report08.pdf.

Guber, D.L. 2001. Voting preferences and the environment in the American electorate. *Society and Natural Resources* 14(6):455-469.

Hall, D.C., J.V. Hall, and S.N. Murray. 2002. Contingent valuation of marine protected areas: southern California intertidal rocky ecosystems. *Natural Resource Modeling* 15(3): 335-368.

Harmon, M.E., W.E. Ferrell, and J.F. Franklin. 1990. Effects on carbon storage of conversion of old-growth forests to young forests. *Science* 247:699-702.

Heinzerling, L. and F. Ackerman. 2002. *Pricing the Priceless: Cost-Benefit Analysis of the Environment.* Georgetown University Press, Washington, D.C.

Interagency Vegetation Mapping Project 2004. Project contributors: Bureau of Land Management, U.S. Forest Service, and U.S. Forest Service Pacific Northwest Research

Station. Data available at: ftp://ftp.blm.gov/pub/OR/gisweb/

IPCC, 2007: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 996 pp.

Johnston, R. J., Grigalunas, T. A., Opaluch, J. J., Mazzotta, M. and Diamantedes, J. 2002. Valuing estuarine resource services using economic and ecological models: the Peconic Estuary System study. *Coastal Management* 30(1): 47-65.

Kline, J.D. 1998. The demand for local access to coastal recreation in southern New England. *Coastal Management* 26(3):177-190.

Konrad, C.P. 2003. Effects of urban development on floods. U.S. Geological Survey Fact Sheet FS-076-03, 4 pp.

Kriete, B. 2007. Orcas in Puget Sound. Puget Sound Nearshore Partnership Report No. 2007-01. Published by Seattle District, U.S. Army Corps of Engineers, Seattle, Washington.

Kresch, D.L., and Dinicola, Karen, 1997, What causes floods in Washington state? U.S. Geological Survey Fact Sheet FS-228-96, 2 p.

Kreuter, U. P., Harris, H. G., Matlock, M. D., and Lacey, R. E. 2001. Change in ecosystem service values in the San Antonio area, Texas. *Ecological Economics* 39:333-346.

Kruckeberg, A. 1991. *A Natural History of the Puget Sound.* Weyerhaeuser Press, Seattle, WA.

Limburg, K.E., R.V. O'Neill, R. Costanza, S. Farber. 2002. Complex systems and valuation. *Ecological Economics* 41:409–420.

Lingley, L., Gregory, D., 2009. Biennium 2006-2007 Compliance Monitoring Summary Report. Forest Practices Division, Washington State DNR. Retrieved October 7, 2009 from Http://www.dnr.wa.gov/Publications/fp_06_07_compliance_monitoring.pdf.

Loomis, J. B. 1992. The evolution of a more rigorous approach to benefit transfer: benefit function transfer. *Water Resources Research* 28(3):701-705.

Magurran, A.E. 1988. *Ecological Diversity and its Measurement.* Princeton University Press, Princeton, N.J.

Marcot, B. 1997. Lessons from our elders. In, Kathryn A. Kohm and Jerry F. Franklin, eds. *Creating a Forestry for the 21st Century: The Science of Ecosystem Management*. Island Press, Washington D.C. and Covelo, CA.

Mates, W. 2007. Valuing New Jersey's Natural Capital: An Assessment of the Economic Value of the State's Natural Resources. Part III: Nature's Goods. State of New Jersey, New Jersey Department of Environmental Protection. April, 2007.

Mayo, J., 2009. Mapping software shows where logging and landslides collide, The IRE Journal. Winter Issue. Retrieved Feb 2010 from http://findarticles.com/p/articles/mi_qa3720/is_200901/ai_n31513010/

Mayo, J., Bernton, H., 2008. Logging and landslides: What went wrong?, Seattle Times. Retrieved February 2010 from http://seattletimes.nwsource.com/html/localnews/2008048848_logging13m.html.

McCauley, D. 2006. Selling out on nature. *Nature* 443:27-28.

McConnaughey, B.H. and E. McConnaughey. 1985. *Audubon Society Nature Guides: The Pacific Coast.* Alfred Knopf, New York.

Mittge, B., 2004. County farmland zoning scrutinized The Chronicle. Retrieved February 2010 from http://www.crcwater.org/issues15/20040119fnews.html.

Moore, R. Dan; Wondzell, S.M. 2005. Physical hydrology and the effects of forest harvesting in the Pacific Northwest: a review. *Journal of the American Water Resources Association* 41(4): 763-784.

Moran, D. 1999. Benefits transfer and low flow alleviation: What lessons for environmental valuation in the UK? *Journal of Environmental Planning and Management* 42(3): 425-436.

Mumford, T.F. 2007. Kelp and Eelgrass in Puget Sound.Puget Sound Nearshore Partnership Report No. 2007-05. Published by Seattle District, U.S. Army Corps of Engineers, Seattle, Washington.

National Research Council. 2000. *Environmental Issues in Pacific Northwest Forest Management.* National Academy Press, Washington, D.C.

Newell, R. G. and W. A. Pizer. 2003. Discounting the distant future: how much do uncertain rates increase valuations? *Journal of Environmental Economics and Management*. 46:52-71.

OR/WA Hydrography Framework Partnership. 2005. Watercourses Oregon/Washington. Bureau of Land Management, Portland, Oregon. http://hydro.reo.gov

Orr, J.C., V. Fabry, O. Aumont, et al. 2005. Anthropogenic ocean acidification over the twenty-first century and its impact on calcifying organisms. *Nature* 437:681-686.

Pauly, D. and V. Christensen, 1995. Primary production required to sustain global fisheries. *Nature* 374:1245-1271.

Palmquist, R.B. 2002. Hedonic models. In, *Handbook of Environmental and Resource Economics.* Jeroen C.J.M. va den Bergh, ed. Edward Elgar Publishing, Cheltenham, UK.

Parson, E.A., 2001. Potential Consequences Of Climate Variability Ana Change For The Pacific Northwest, in: National Assessment Synthesis Team, U.G.C.R.P. (Ed.), Climate Change Impacts on the United States. The Potential Consequences of Climate Variability and Change. Retrieved February 2010 from http://www.usgcrp.gov/usgcrp/Library/nationalassessment/09PNW.pdf.

Parsons, E.C.M, C.A. Warburton, A. Woods-Ballard, A. Hughes, and P. Johnston. 2003. The values of conserving whales: The impact of cetacean-related tourisms on the economy of rural West Scotland*. Aquatic Conservation: Marine and Freshwater Ecosystems* 13:379-415.

Peterson, C.H. and J. Lubchenco. 1997. Marine ecosystem services. In, G.C. Daily, ed., *Nature's Services: Societal Dependence on Natural Ecosystems*. Island Press, Washington, D.C., Covelo, CA, and London.

Pew Oceans Commission. 2003. America's Living Oceans: Charting a Course for Sea Change. Report to the Nation – Recommendations for a New Ocean Policy. Pew Charitable Trusts, Washington, D.C.

Pimm, S. L. 2001. *A Scientist Audits the Earth.* Rutgers University Press, New Brunswick, New Jersey.

Pittman, James and Batker, David. June, 2006. Special Benefit from Ecosystem Services: Economic Assessment of the King Conservation District. King Conservation District, Seattle, Washington.

Polis, G.A., W.B. Anderson, and R.D. Holt. 1997. Towards an integration of landscape and food web ecology: the dynamics of spatially subsidized food webs. *Annual Review of Ecology and Systematics* 28:289-316.

Pompe, J.J. and Rinehart, J.R. 1995. Beach quality and the enhancement of recreational property values. *Journal of Leisure Research*. 27(2):143-154.

Power, T.M. 1991. Ecosystem preservation and the economy in the Greater Yellowstone area. *Conservation Biology* 5 (3), 395–404.

Power, T.M. 1996. Lost Landscapes and Failed Economies. Island Press, Washington, D.C., Covelo, CA, and London.

Power, T.M. and Barret. 2001. The Post-cowboy Economy. Island Press, Covelo, CA and Washington, D.C.

Pringle, C.M. 2000. Threats to U.S. public lands from cumulative hydrological alterations outside their boundaries. *Ecological Applications* 10(4):971-989.

Puget Sound Action Team. 2007. The State of the Sound. The Puget Sound Action Team, Olympia, WA.

Puget Sound Partnership 2008. Puget Sound Action Agenda. Protecting and Restoring the Puget Sound Ecosystem by 2020. Retrieved February 2010 from http://www.psp.wa.gov/downloads/ACTION_AGENDA_2008/Action_Agenda.pdf.

Jackson, J., M.X. Kirby, et al. 2001. Historical overfishing and the recent collapse of coastal ecosystems. *Science* 293:629-638.

Rabalais, N. 2005. The potential for nutrient overenrichment to diminish marine biodiversity. In, E.A. Norse, and L.B. Crowder, eds. *Marine Conservation Biology: The Science of Maintaining the Sea's Biodiversity.* The Marine Conservation Biology Institute and Island Press, Washington, D.C., Covelo, CA., and London.

Rosenberger, R.S. and T.D. Stanley, 2006. Measurement, generalization, and publication. Sources of error in benefit-transfer and their management. *Ecological Economics* 60:372-378

Ruggiero, L.F., K.B. Aubry, A.B. Carey and M.H. Huff, eds. 1991. Wildlife and vegetation of unmanaged Douglas-fir forests. General Technical Report PNW-GTR-285. USDA Forest Service Pacific Northwest Research Station, Portland, OR.

Sachs, J. 2005. *The End of Poverty: Economic Possibilities for Our Time*. Penguin Press, New York.

Silberman, J., D. A. Gerlowski, and N. A. Williams. 1992. Estimating existence value for users and nonusers of New-Jersey Beaches. *Land Economics* 68:225-236.

Smith, V. K. 1992. On separating defensible Benefit Transfers from 'smoke and mirrors'. *Water Resources Research*, 28, 685-694.

Snelgrove, P.V.R., M.C. Austen, S.J. Hawkins, et al. 2004. Vulnerability of marine sedimentary ecosystem services to human activities. In, D. H. Hall, editor, *Sustaining Biodiversity and*

Ecosystem Services in Soils and Sediments. SCOPE Series, Island Press, Washington, D.C., Covelo, CA, and London.

Sommers, P., Beyers, W.B., Wenzl, A., 2008. Industry Cluster Analysis for Washington State Workforce Development Areas. A Report Prepared For the Washington State Workforce Board.

Stern, N. 2007. *The Economics of Climate Change: The Stern Review.* Cambridge University Press, Cambridge, UK.

Spash, C.L., S. Stagl, and M. Getzner. 2005. Exploring alternatives for environmental valuation. In, Getzner, M., C.L. Spash and S. Stagl, eds. *Alternatives for Environmental Valuation*. Routledge, London and New York.

Spash, C.L. and A. Vatn. 2006. Transferring environmental value estimates: Issues and alternatives. *Ecological Economics* 60(2):379-388.

Sumaila, U. R. and C. Walters. 2005. Intergenerational discounting: a new intuitive approach. *Ecological Economics* 52:135-142.

Swedeen, P. 2004. The potential for sustainable forestry in Washington State: A discursive and institutional analysis. Ph.D. Dissertation. The Union Institute and University, Cincinnati, OH.

Swedeen, P. and J. Pittman. 2007. Ecological Economic Assessment of King County's Flood Hazard Management Plan. Earth Economics. Report commissioned by the King County Department of Natural Resources, Seattle, WA.

United Nations Environment Program. 2005. *The Millennium Ecosystem Assessment. Ecosystems and Human Well-being: Current Status and Trends, Volume 1*. R. Hassan, R. Scholes, and N. Ash, eds. Island Press, Washington D.C., Covelo, CA, and London.

United Nations Environment Program, 2006. Marine and Coastal Ecosystems and Human Well-being: Synthesis. A synthesis report based on the findings of the Milennium Ecosystem Assessment. Brown, C., E. Cocroan, P. Herkenrath, and J. Thonell, eds. UNEP, Nairobi, Kenya.

U.S. Commission on Ocean Policy, 2004. An Ocean Blueprint for the 21st Century. Final Report. Washington, D.C.

U.S. Environmental Protection Agency. 2006. National Land Cover Data. http://www.epa.gov/mrlc/nlcd-2006.html.

Vemuri and R. Costanza. 2006. The role of human, social, built, and natural capital in explaining life satisfaction at the country level: Toward a National Well-Being Index (NWI). *Ecological Economics* 58:119-133.

Vitousek, P.M. et al.1986. Human appropriation of the products of photosynthesis. *BioScience* 34(6):368-373.

Villa, F., L. Tunesi, T. Agardy. 2002. Zoning marine protected areas through spatial multiple-criteria analysis: the case of the Asinara Island National Marine Reserve of Italy. *Conservation Biology* 16 (2), 515–526.

Vleming, J., 2009. Pacific Mountain Consortium (Grays Harbor, Lewis, Mason, and Pacific Counties) Labour Area Summary. Volume 2009, Number 11.

Washington State Department of Ecology Press Release, 2001. Most upper-Chehalis farms get clean bill of health for environment. Retrieved February 2010 from http://www.ecy.wa.gov/news/2001news/2001-010.html.

Washington State Department of Natural Resources, 2009. Economic and Revenue Forecast. Fiscal Year 2009, Fourth Quarter. Retrieved February 2010 from http://www.dnr.wa.gov/Publications/obe_econ_rprt_revfrcst_june09.pdf.

Washington State Department of Natural Resources Press Release 2009a. DNR releases first report of compliance with forest practices rules on state and private forestlands: Report finds most comply with rules, still room for improvement. Retrieved October 7th, 2009 from http://www.dnr.wa.gov/BusinessPermits/News/Pages/nr09_060.aspx.

Washington State Department of Natural Resources Press Release 2009b. New Rules to Protect Fish and Water Quality on More Than 10 Million Acres of Working Forestlands: State Forest Practices Board Agrees to Expand Buffer Zones Around Streams in Forests. Retrieved 14 October, 2009 from Http://www.dnr.wa.gov/BusinessPermits/News/Pages/nr09_139.aspx

Washington State Department of Transportation, 2008. Flooding in the Chehalis River Basin: Synthesis. Prepared for WSDOT by Aaron Poor, TRAC Synthesis Editor.

Washington State Department of Transportation, 2008. STORM-RELATED CLOSURES OF I-5 AND I-90: FREIGHT TRANSPORTATION ECONOMIC IMPACT ASSESSMENT REPORT Winter 2007-2008. Retrieved February 2010 from http://www.wsdot.wa.gov/research/reports/fullreports/708.1.pdf

Weeks, H. and A. Merems. 2004. 2003 Nearshore Rocky Reef Habitat and Fish Survey, and Multi-year Summary. Oregon Department of Fish and Wildlife Marine Habitat Project, Marine Resources Program. Salem, OR.

Weslawski, J.M., P.V.R. Snelgrove, L.A. Levin, M.C. Austen, R.T. Kneib, T.M. Iliffe., J.R. Garey, S.J. Hawkins, R.B. Whitlatch. 2004. Marine sedimentary biota as providers of ecosystem goods and services. In, D. H. Hall, editor, *Sustaining Biodiversity and Ecosystem Services in Soils and Sediments*. SCOPE Series, Island Press, Washington, D.C., Covelo, CA, and London.

West, T.O. and W.M. Post. 2002. Soil carbon sequestration by tillage and crop rotation: A global data analysis. *Soil Science Society of America Journal* 66:1930-1946.

Wilson, M. and J. Hoehn. 2006. Valuing environmental goods and services using benefit-transfer: state-of-the-art and science. *Ecological Economics* 60(2):335-342.

Woods Hole Observatory, 2006. Major HAB-related events in the coastal U.S. http://www.whoi.edu/redtide/HABdistribution.

Workforce Explorer Website, 2010. http://www.workforceexplorer.com/cgi/databrowsing/localAreaProfileQSResults.asp?selectedarea=Lewis+County&selectedindex=21&menuChoice=localAreaPro&state=true&geogArea=5304000041&countyName=.

Worm, B., E.B. Barbier, et al. 2006. Impacts of biodiversity loss on ocean ecosystem services. *Science* 314:787-790.

Appendix A: How Ecosystem Goods and Services Provide Value in the Chehalis

Provisioning Services

Although provisioning services are often among the easiest to value in the market, it is important to keep in mind that they will cease to be valuable if the critical supporting and regulating services upon which they rely are lost. For example, pollination, which relies on a diverse array of animal species, is critical to crop growth. We cannot build a valuable house without a foundation, and we cannot build economically valuable agricultural systems without biodiversity and animal habitat.

Fresh Water

Fully functioning forest ecosystems play a strong role in the provisioning of drinking and irrigation water. This includes provisioning of surface water and ground water for large metropolitan areas, well water systems, industry, and irrigation for crops. Water is supplied through the hydrological cycle, which is mediated by evapotranspiration of vegetation including forested areas. Local ecosystems in the Chehalis Basin capture precipitation in the form of rain and snow.

Water is filtered through forests and other vegetation, cleansed, and returned into ground water and surface water downstream. In the contiguous United States, 53% of water supply is provided by forestland, which only covers 29% of total land area (Collins et al., 2007). In addition to supplying water for irrigation and human use, forests release water back into the aquifer. This is essential to maintaining adequate annual water supplies.

In the Chehalis Basin, precipitation is approximately 73-80 inches per year, with the majority of rain falling between November and March.[7] Approximately 1% of this water is used for consumptive uses such as agricultural irrigation, domestic, and commercial use, although up to 23% of total precipitation has been allocated through existing water rights. Although supplies are currently beyond adequate for human uses, land use patterns will continue to affect the future availability of water supplies for human and fish populations. Increasing loss of forest cover has been shown to correlate with decreases in water supply, due to lower ground water recharge and to lower reliability of flows (Vorosmarty et al., 2005).

The 2003 Chehalis Basin Water Quantity Evaluation identified 5 priority basins where water shortages may become apparent:

1. Sub-basin 5, South Fork Newaukum River
2. Sub-basin 6, North Fork Newaukum River
3. Sub-basin 7, Newaukum River
4. Sub-basin 8, Salzer Creek
5. Sub-basin 9, Skookumchuck River

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The study found all of these basins to be at or near their allocation limits during periods of low flow. The largest right holders were power and agricultural entities. Additionally, three of these basins were found to be using much more water than is provided each year by precipitation alone. A few factors could explain the apparent deficit, such as an overestimate of water flow relative to demand, imperfect accounting for transfers across sub-basins, or other reasons[8]. However, if the estimates are taken to be fairly accurate, it is clear that in some areas of the basin, human withdrawals are beginning to exceed overall sustainable water withdrawals. Extracting water beyond the watershed's ability to recharge supply can lead to a host of issues beyond provisioning for drinking water, including habitat changes, soil accretion, and changes to water regulation services (which include flood protection, ground water infiltration among other regulating services.

Food

Biomass for human consumption is provided by a web of organisms and a functioning ecosystem.

In the Puget Sound Basin, agriculture lands produced $1.1 billion worth of crops and livestock in 2002, the latest year for which data is available (USDA, 2002). Recently, locally produced vegetables have been increasingly marketed directly to consumers through farmers markets and community-supported agriculture programs (Evergreen Fund Consultants, 2004). In the Chehalis Basin, both fish species and agricultural crops provide a great deal of market and food value.

Farming in particular contributes significantly to the local economy, despite occupying only 7% of land cover. Some estimates suggest the value may be as high as $150 million a year (Chehalis River Council). Agriculture is often centered in low valleys near the Chehalis, or major tributaries such as the South Fork Chehalis, Newaukum, Skookumchuck, Black, Satsop, and Wynoochee Rivers, and Scatter Creek. Primary farming activities include dairy farming and cattle ranching, Christmas tree farms, pasture, and production of berries, hay, peas, and some other grains and vegetables. Additionally there are a few aquaculture facilities near Grand Mound/Rochester (Chehalis Basin Partnership 2002). Salmon, steelhead, sturgeon, goeduck clams, crab, sea urchins, sea cucumbers, shrimp, oysters, clams, mussels, and groundfish are all commercially harvested in the Puget Sound, accounting in 2006 for $72 million in ex vessel value (price for the catch that is received by the fisherman at the dock). Some of the commercial fish and seafood caught in the Puget Sound are shipped to other states or overseas.

In some instances, however, agricultural practices may negatively affect the provisioning of other services, such as water quality and waste absorption, nutrient regulation, and oyster or salmon habitat. In 1998, the Department of Ecology inspected 78 farms in the Chehalis area, finding 42 farms potentially contributing significant amounts of water pollution (Washington DOE Press Release 2001). Runoff from livestock has been found to add fecal coliform and dissolved oxygen to water, and a 1993 study found that portions of the Chehalis are quite sensitive to such pollution (Erickson, 1994). Just 3 years later, when the DOE revisited the 42 high risk farms, they found that

8 Ibid.

most, with free technical assistance and support from local conservation districts and through voluntary actions, had improved their practices for reducing pollution, (Washington DOE Press Release 2001). It is critical to manage agricultural lands so that they provide maximum value in food production and other ecosystem services.

When properly managed, agricultural lands provide a host of ecological and economic benefits to the economy. Currently, some of the best farmland in the Chehalis Basin is threatened by development. The above map highlights areas within the Basin where high-quality farmland is threatened by either high development pressure or low development pressure. Local farmers faced with increasingly high land prices, may be forced to sell their land. In Lewis County, debate has raged over zoning for agricultural lands (Mittge, 2004). The challenge is to both protect valuable farmland and balance competing economic interests, such as residential development.

Although residential development can increase the market value of property, it is critical to consider the fact that development may reduce other ecosystem services and provide only temporary jobs; on the other hand, agriculture provides more employment, pollination, local food supply, open space, soil retention, and nutrient cycling.

Fuelwood and Fiber

Fuelwood and fiber includes biological materials used for fuel, art and building; and geological materials used for construction or other purposes.

Washington State produced 34 billion board feet of commercial timber harvest in 2006, mostly from State and private lands (WDNR, 2006). Federal lands have been extensively harvested in the past, but environmental, social, and legal limitations were reached on these lands by the early 1990s; they now account for a small portion of the regional timber harvest (Swedeen, 2004). In the Chehalis Basin, the vast majority of harvested lands are held in private ownership.

The Washington State Department of Natural Resources, which monitors the enforcement of both state and federal forestry laws, includes the Chehalis Basin in its Pacific Cascade Region. The 3.5 million acres that make up this region include private lands, state-owned lands, natural resource conservation areas, recreation sites, and natural preserves.[9] The DNR policy for timber harvesting covers “all removal of timber from forested lands in commercial operations, commercial thinning, salvage of timber, re-logging merchantable material left after prior harvests, post-harvest cleanup, and clearing of merchantable timber from lands being converted to other uses” (WDNR, 2009). The agency aims for guidelines that protect, restore, and maintain aquatic resources, preserve healthy riparian environments, and protect wetland areas during timber harvest.

9 http://www.dnr.wa.gov/About DNR/Regions/Pages/Default.aspx. 2009. Accessed 7 October 2009.

Since February 2004, the DNR has approved 1,889 acres in the Chehalis watershed for logging, an average permit of 40 acres.[10] A recent DNR report on general compliance with forest practice policies found that in the Pacific Cascade Region, 76 of the sites surveyed were in compliance, while 14 were non-compliant (Lingley and Gregory, 2009). While specific compliance information for the Chehalis watershed is not available, the DNR concluded that 75% of logging activities adjacent to streams (and other forest work not related to road construction) in the state followed forest practice guidelines (WDNR Press Release 2009a).

Beginning in August 2009, the DNR began enforcing a new set of harvest rules and limitations, designed to improve ecological health, particularly fish habitat and water quality. The primary tools for accomplishing these goals are widened buffer zones around streams, and requirements that more trees be left standing after each harvest (WDNR Press Release 2009a). Rules regarding timber take are tailored to land cover types. There is no particular limit on the amount of timber taken; rather, limitations are based on percentages calculated to protect the function of ecosystems at each particular site, or on width of buffer zones around streams. There are also some limitations based on the number and locations of standing trees that must remain after logging has ended (WDNR Press Release 2009a). These new rules were adopted as of August 12, 2009, and while they do not retroactively affect approved logging permits, the DNR allows streamlined application renewal for landowners who implement the additional protections (WDNR Press Release 2009b).

Debate about the changes among the state, the timber industry, tribes, and environmentalists has been going on for years, culminating with the implementation of this science-based guideline structure (WDNR Press Release 2009b). While there is no doubt that timber harvests can provide jobs and economic revenue, they also affect ecosystem services so dramatically that the associated costs have, at times in the past, outweighed the value to the local region. Harvest practices, as the Chehalis Basin has experienced, affect water quality, soil erosion control, climate and gas regulation, biodiversity and habitat, water provisioning, nutrient cycling, and flood protection.

Medicinal Resources

Medicinal Resources have rarely been valued in ecosystem service literature or in traditional economic analyses. For example, Taxol, a cure for cancers of the ovary and breast, was discovered from the bark of the Pacific Yew tree (Taxus brevifolia), a tree native to the Northwest. This has led to the semi-synthetic production of taxol from the needles and twigs of Taxus baccata. We do not yet know the extent of the value these trees have in the Chehalis Basin, but maintaining ecologically diversity is crucial to ensure that we maintain the genetic and biological resources for future medical discoveries.

10 Figures collated by Earth Economics staff from individual Forest Practice Applications, available from the DNR, in the Chehalis watershed. The take time period for approved applications are generally over two years, so the logged acres for recently approved applications are to some extent expected take, not current or past take.

Regulating Services

Regulating services moderate the flow, temperature, concentration, timing, transport and other factors around both non-living and living systems. For example, the flow of water, infiltration, peak flows are all related to water regulation. Natural predators that keep pest populations at bay provide a regulating function as well. Natural regulation is an essential requirement for both quality of life for people and for natural and economic processes.

Gas and Climate Regulation

Ecosystems play a vital role in maintaining the global climate within a stable range. This is greatly facilitated by the capture and long-term storage of carbon as a part of the global carbon cycle.

Gas regulation refers to the role that ecosystems play in regulating the gaseous portion of nutrient cycles which affect atmospheric composition, air quality, and climate regulation. Forests and individual trees play an important role in regulating the amount of oxygen in the atmosphere and in filtering pollutants out of the air, including removal of tropospheric ozone, ammonia, sulfur dioxide, nitrogen oxide compounds carbon monoxide, and methane. The removal of forests and other vegetation, and the burning of biomass, reduce air quality and contribute to global climate change.

American Forests (1998) calculated that urban forests remove 78 million pounds of pollutants per year in the Puget Sound area. Based on the value of avoided health care costs and other externalities, the authors valued this gas regulation service at $166.5 million per year for the year of 1996. The extensive forest cover of the entire Puget Sound Basin thus likely provides a significant amount of gas regulation services that is very valuable in terms of public health.

Carbon sequestration is a specific and important type of gas regulation. Forests, agricultural lands, wetlands, and marine ecosystems all play a role in carbon sequestration. Undisturbed old growth forests have very large carbon stocks that have accumulated over thousands of years. Replacing old growth forests with tree plantations results in net carbon emissions caused by the loss of hundreds of years of carbon accumulation in soil carbon pools, and large live and dead trees (Harmon et al., 1990).

Managed forests have the potential to sequester carbon at a rate that approaches old growth levels, but this requires longer rotations than current industrial standards, and structural retention after each harvest (Marks and Harmon, 2002). Agricultural soils can also sequester carbon, especially when low or no tillage practices are employed (West and Post, 2002).

Marine life, especially phytoplankton and marine benthic organisms, plays a crucial role in the global carbon cycle. The functioning of the ocean food web turns dissolved bicarbonate into solid form (skeletons and exoskeletons of plants and animals), which falls to the ocean floor. Sedimentation and benthic organisms sequester carbon in sediments.

Geologic processes, such as dewatering, time, pressure and heat, convert sediments into sedimentary rock and move carbon from the biosphere to the lithosphere. This allows more CO_2 to be dissolved into ocean waters, keeping atmospheric CO_2 levels lower than they would be without life and oceanic biological and geological processes (Peterson and Lubchenco, 1997). Since some species are more palatable to marine grazers than others, the composition of phytoplankton diversity affects this process, thus determining the amount of uptake and pumping of carbon to the ocean floor (UNEP 2005, Vol. 1, Chapter 11). In addition, the availability of oxygen in oceanic basins regulates carbon retention in sediments. This is another important connection between biological diversity, ecosystem services, gas regulation, and topography.

Coastal and estuarine wetlands also sequester carbon through photosynthesis and long-term storage in wetland soils. In fact, wetlands may rival or outperform temperate forests and agricultural sequestration projects under some circumstances (Boumans et al., unpublished paper).

Disturbance Regulation

Land use plays a critical role in the flow and absorption of water. It can also impact the cost of damages, if valuable development occurs in an area not protected from regular flood events. Estuaries and bays, coastal wetlands, headlands, intertidal mudflats, seagrass beds, rock reefs, and kelp forests provide storm protection. The same wave energy absorption capacity of these areas also reduces the energy of powerful waves from storm events. Estuaries, bays, and wetlands are particularly important for absorbing floodwaters (Costanza et al., in review; UNEP, 2005).

Storm events in Western Washington are part of normal weather patterns that appear to have become more frequent and more intense with climate change. Where significant infrastructure exists and where wetlands and wave-absorbing structures in the nearshore environment have been lost, higher levels of property damage could already be occurring as a result of this diminished ecosystem service. Thus storm protection is an important ecosystem service for residents living close to the delta, oceanfront, or in other flood-prone areas. Given that significant infrastructure can be damaged during large storm events, tourism and recreation could be harmed as well. In the Chehalis Basin, natural flood protection from forests and wetlands can be enhanced to provide greater value.

Wetlands and intact riverine floodplains, including riparian forests, absorb increased river flows during storm events and high snow-melt. Upland forests also absorb rainwater, reducing its downhill flow into major stream and river systems. Flood damage increases when wetlands are lost, riparian areas are disconnected from rivers and streams, and forest land is replaced by houses and commercial development (Kresch and Dinicola, 1997). The U.S. Geological Survey estimates that urban development leads to increases in flood peak discharge flows of 100-600% for 2-year storm events, 20-300% for 10- year events, and 10-250% for 100-year events (Konrad, 2003). Development within the floodplain can exaggerate flooding, as the water cannot be absorbed by built areas as it can by vegetated or agricultural lands.

One local study found that wetlands provide over $40,000 per acre of flood damage protection in Renton (Lechine, 1997). A recent pilot study for King County demonstrated that flood hazard reduction projects that widen the floodway of the Cedar River could avoid $468 to $22,333 per acre per year in damages to homes and county flood control facilities (Swedeen and Pittman, 2007). Retention of forest cover and restoration of floodplains and wetlands provide a tangible and valuable ecosystem service in reduced damage from floods to property, lost work time, injury, and loss of life.

Soil Erosion Control

Estuaries and bays, rocky islets, headlands, intertidal areas, rock reefs, sea grass, and kelp beds all buffer against wave energy and littoral drift (the transport of sediments along a coast). Shorelines are built and maintained naturally with interactions of the physical aspects of these structures, wave energy, tides, and sediment deposition. The biota in mudflats and nearshore soft bottom sediments also play a key role in maintaining the structure of sediments and preventing erosion (Weslawski et al., 2004). When these features are removed or significantly altered, dramatic changes and loss of shorelines can occur. Coastal wetlands and natural processes of land accretion are also very important for maintaining the line between land and sea, especially in the face of rising sea levels. Loss or sudden change in shoreline can result in private property damage, public infrastructure damage, loss of wildlife habitat, and in extreme cases, loss of life. Coastal erosion is a natural process along the Puget Sound's shoreline. Soil erosion prevention is provided by forests and vegetation.

Water Regulation

The amount and timing of water flow in the Chehalis Basin is important for many reasons, among them, the supply of adequate amounts of cool water at critical times for salmon migration, provision of drinking and irrigation water, and the maintenance of adequate water flows to generate electricity for hydroelectric dams.

The forest cover, riparian vegetation, and wetlands all contribute to modulating the flow of water from upper portions of the watershed to streams and rivers, and finally into the Sound. Agricultural and urban development that removes forest cover and the removal of riparian vegetation are the most important causes of loss of fresh water flow to coastal wetlands and bays. When forested basins are so heavily harvested that they are dominated by recently clear-cut or young stands, the remaining vegetation and litter layer on the forest floor absorb less water. More water then flows overland into streams and rivers, contributing to higher peak flows, flood events (Moore and Wondzell, 2005), erosion and landslide issues. It also leads to a loss of the ability of forests to slowly release water during dry summer months, lower stream flows, and higher stream temperatures. The soil from erosion entering streambeds injures fish and fills spawning beds.

Riparian vegetation in otherwise agricultural or developed landscapes also contributes to modulating stream flows. Coastal freshwater wetlands form a salinity gradient with saltwater marshes and the ocean. These freshwater wetlands keep salt water from intruding on coastal freshwater supplies, both at the surface and in aquifers (UNEP, 2005, Vol. 1, Chapter 19). Alteration of hydrology by diverting water to estuaries is considered to be a major threat to coastal areas (Pringle, 2000). Hypersalinization can occur when too much fresh water is prevented from reaching estuaries, threatening not only fresh water supplies but the several other services that estuaries provide.

The City of Seattle has protected its upstream areas in the Cedar and Tolt Watersheds since 1899 (Seattle Public Utilities, 2008). These two watersheds provide almost all of the water for 1.3 million residents and businesses located in Seattle. One way to understand the economic value of intact watersheds is to compare it to the cost of building and maintaining water supply and treatment facilities. To the extent that loss of ecological systems results in reduced supply, value can also be ascertained through the cost of having to import water from elsewhere. These are examples of what economists call replacement costs (see section on valuation methods, Table 3)

As the population in the Chehalis Basin has grown, groundwater throughout the basin has been tapped for consumption. In addition, land use practices such as forest clear-cutting and the filling in of wetlands, as well as the growth of impervious surfaces, disturb the normal hydrologic regime by causing an increase in runoff and a decrease in the opportunity for groundwater recharge. This combined demand on groundwater supplies and reduction of recharge has resulted in lower than average base flow contributions in some of the basin's rivers and streams (Smith et al., 2001).

Biological Control

Biological Control is the ability of ecosystems to limit the prevalence of crop and livestock pests and diseases. A wide variety of pest species destroy human agricultural crops, reducing worldwide harvest by an estimated 42%, thereby causing a loss of $244 billion dollars each year (Pimentel et al., 1997). A number of natural predators for pest species contribute to natural control of damages. These predators also play a role in protecting forests from pests. Birds, for example, are a natural predator of some harmful insects. Unfortunately, many exotic pests, for which no natural predators exist, have been introduced to areas beyond their natural range. These new pests have caused annual damage ranging from $1.1 to $134 million dollars in the United States alone (Chapin et al., 2000).

In recent years, humans have turned increasingly towards pesticides to control crop losses. While pesticides can reduce the risk of specific pest attacks, they can also harm natural predator populations and lead to resistance among pests, making them even more difficult to control in the future. Overuse of pesticides is also known to reduce provisioning of some other ecosystem services, particularly water quality. While there may be a role for pesticide control in agricultural practice, there are also ways to manage crops so as to enhance biological control services. These techniques include crop diversification and genetic diversity, crop rotation, and promoting an abundance of smaller patches of fields (Dordas, 2009; Risch et al., 1983).

Water Quality and Waste Processing

Microorganisms in sediments and mudflats of estuaries, bays, and nearshore submerged lands break down human and other animal wastes (Weslawski et al., 2004). They can also detoxify petroleum products. The disruption of the ecology of these organisms by physical destruction of habitat, alteration of food webs, or overload of nutrients or waste products disrupts its disease regulation and waste processing services. Alteration of ecosystems can also create breeding sites for disease vectors where they were once non-existent. People can be exposed to disease in coastal areas through direct contact with bacterial or viral agents while swimming or washing in fresh or saltwater, and by ingesting contaminated fish, seafood, or water. The recent rise of cholera outbreaks in the southern hemisphere is associated with degradation of coastal ecosystems (UNEP, 2006).

The Puget Sound area has had several incidents of shellfish and beach closures due to red tide and amnesic shellfish poisoning in recent years (Woods Hole Observatory, 2006). While the algae that cause toxic blooms are native to west coast waters, and toxic blooms can occur as natural events, there are concerns and direct evidence that increasing pollution loads and climate change exacerbate the conditions that lead to toxic blooms (Rabalais, 2005). Many areas in Puget Sound also have health advisories due to high bacteria counts from human and domestic animal waste, especially in late summer, and many shellfish harvest areas have had to be closed (PSAT, 2007). Reduced access to beaches, fish, and shellfish due to disease has obvious impacts to human health and economic activity in the Puget Sound counties.

Wetlands, estuarine macroalgae, and nearshore sedimentary biota play a crucial role in removing nitrogen and phosphorous from water (Garber et al.1992, Weslawski et al. 2004). The removal of these nutrients maintains offshore water conditions that are conducive to native fish and invertebrate biota. The rise of nutrient overload and hypoxic zones caused by a combination of agricultural run-off, failed septic systems, and the dumping of fish carcasses have become a major issue in Hood Canal in recent years (PSAT, 2007). Land use patterns also play an important role. Researchers have found that more agriculturally active and heavily urbanized watersheds contribute three times the nitrogen and phosphorous loads to the Puget Sound than the forested watersheds of the Olympic Mountains (Embrey and Inkpen, 1998).

Supporting Services

Supporting services, such as nutrient cycling and chemical changes, for example nitrogen from a gaseous form in the atmosphere moving to a "fixed" form that plants can utilize, are the building blocks for all the other ecosystem service categories. Without soil formation or available nitrogen, plants cannot grow.

Soil Formation

Soil formation is the breakdown of minerals and rocks, as well as the addition of organic material and living organisms, which create and build, or develop, soils. Soil formation is critical to terrestrial ecosystems and processes such as forest succession.

Nutrient Cycling

Nutrient Cycling refers to the transfer of nutrients from one place to another; transformation of critical nutrients from unusable to usable forms

There are 22 elements that are essential to the growth and maintenance of living things on earth. Some of these elements are needed only by a small number of organisms, and in small amounts in specific circumstances, but all living things need the major planetary nutrient cycles of carbon, nitrogen, phosphorous, and sulfur in relatively large quantities. These are the cycles that human actions have most affected. Silicon and iron are also important elements in ocean nutrient cycles because they affect phytoplankton community composition and productivity. It is living things that facilitate the movement of nutrients between and within ecosystems and which turn them from biologically unavailable forms, such as rocks or the atmosphere, into forms that can be used by others. Without functioning nutrient cycles, life on the planet would cease to exist.

Living organisms mediate nutrient cycling. On land, plants depend on biologically mediated breakdown of organic matter to make the nutrients they need for growth available. As plants and plant parts die, they contribute to the pool of organic matter that feeds the microbial, fungal and micro-invertebrate communities in soils. These communities facilitate the transformation of nutrients from one form to another. Larger animals play a crucial role in nutrient cycles by moving nutrients from one place to another in the form of excrement and through the decomposition of their bodies after they die. Animals play a role in transporting nutrients between terrestrial and aquatic ecosystems. Salmon and marine birds bring marine nutrients into terrestrial and freshwater ecosystems, thereby enhancing the productivity of these systems throughout several trophic layers of the food web (Cedarholm et al., 2001; Polis et al., 1997).

Forests play a very significant role in global nutrient cycles; they hold large volumes of the basic nutrients, keep them within the system and buffer global flows. Deforestation has played a large part in altering global carbon and nitrogen cycles (Vitousek et al., 1997).

The marine role in the carbon cycle, in terms of its significance for climate change, was briefly described above. The marine environment plays a central role in all major global nutrient cycles. The movement of nutrients is also important locally and regionally for ecosystem productivity. Nutrient cycling takes place at multiple scales in the marine environment, from bacteria and other microorganisms in sediments in estuaries, shelf, and deep sea floors to the global scale of ocean current patterns. Marine organisms fix nitrogen and take up carbon, phosphorous, and sulfur from the water or from other organisms. Much of the mass of these macronutrients is deposited in sediments where it is either stored for the long term or taken back up to surface waters by upwelling. Phosphorous, nitrogen, and carbon cycles are interlinked in marine environments; their relationship depends on whether sediments are oxygen-rich (oxic) or oxygen-poor (anoxic). Organism composition and external nutrient loads in turn affect these conditions.

Changes to benthic communities can therefore have significant impacts on the nutrient cycling capacity of organisms in these communities. These changes come from the invasion of non-native species, physical disruption of habitat through dredging of waterways for navigation and bottom-trawling, the overloading of nutrients beyond the system's capacity to absorb, and changes to the food web caused by trophic cascades after the removal of top predators (Snelgrove et al., 2004 and references therein).

The removal of forests, riparian areas, and wetlands has had a significant effect on nutrient cycles. These ecosystems trap and retain nutrients that would otherwise run off into streams and rivers, and eventually end up in the ocean. A combination of increased use of fertilizers and the loss of the buffering capacity of these ecosystems has led to fresh water, estuarine, and ocean systems suffering nutrient overloads, which leads to blooms of phytoplankton above normal levels. As phytoplankton die and sink to the ocean floor, they consume most of the available oxygen, causing resident marine life to leave or die. Loss of commercially, recreationally, and culturally important fish species has occurred as a result. The number of marine dead zones in the world has doubled every decade since the advent of nitrogen fertilizers after World War II (UNEP, 2005). The presence of these dead zones is a clear indication that global nutrient cycles have been severely altered by human actions.

Nutrient cycling is a supporting service because many other services depend on it. Given that ecosystem productivity would cease without it, and is impaired when these cycles become significantly altered, nutrient cycling is a fundamental precursor to ecosystem and economic productivity. However, due to this fundamental role that cannot be fully substituted by human-made solutions, and because they operate at multiple overlapping scales, it is difficult to arrive at an accurate economic value for these services (Farber et al, 2006). Both production function and replacement cost methods deal with the problem of input prices being inaccurate due to subsidies of agricultural production and energy costs of producing fertilizers (thus market prices of goods do not reflect real marginal costs). Therefore, attempts to value nutrient cycles economically usually produce underestimates. Given that such cycles are fundamental to the operation of life on the planet, this is one class of ecosystem services for which economic policy tools should only be used after biological limits to their functioning are used to set acceptable conditions external to the market (see scale discussion above).

Pollination

Pollination refers to the role that insects, birds, and mammals play in transporting floral gametes, e.g., pollen grains (De Groot et al., 2002). Pollination is important to wild plants that people depend on directly for food and fiber, and indirectly as part of ecosystem productivity. Many plant species would become extinct without animal and insect mediated pollination.

Biodiversity and Habitat

Biological diversity is defined as the number and types of life forms within a given ecosystem, biome, or on the entire Earth. It is measured at gene, population, species, ecosystem, and regional levels (Magurran, 1988). For all ecosystems, biodiversity is both a precondition of the flow of ecosystem services and an ecosystem service in itself (UNEP 2005, Vol. 1, Chapter 11). It is a precondition because ecosystems, with their full native complement of species, tend to be more productive and more resilient to change in environmental conditions or external shocks. Biodiversity itself is also an ecosystem service because novel products have been derived from genetic and chemical properties of species, it provides a secure food base (multiple sources of food with different seasonal availability), and people ascribe value to it simply for its existence. Likely, one of the more diverse areas in North America, the Puget Sound Basin is home to a rich assortment of species and ecosystems. A recent assessment found that there are at least 7,013 species, including animals (vertebrate and invertebrate), flowering plants, fungi, and marine algae in the habitat types of the Puget Sound Basin (Center for Biodiversity, 2004). Given that little is known about some invertebrates and most microorganisms, the total is likely much higher.

Western Washington forests are home to 82 species of mammals, 120 bird species, 27 amphibian species, 14 reptile species (Olson et al. 2001), and several thousand invertebrate species including fresh water mussels, insects, and arthropods (FEMAT, 1993). All seven species of salmonids found in the Puget Sound use forested streams and rivers for part of their life cycle. Many forest species depend on, or are at their highest abundance, in late-successional or old growth forests (FEMAT, 1993; Carey et al.1996).

Portions of the forest landscape in the Chehalis River Basin are managed as planted Douglas fir monocultures with short rotations (35-40 years on private lands and 60-80 years on state lands). These forests have simpler structure, perform fewer ecological functions, or perform them at lower levels, and have lower species diversity and abundances than late-successional forests or naturally young stands with biological legacies (Ruggerio et al.1991, FEMAT 1993, Carey et al.1996, Franklin et al., 2002). The species of which forest ecosystems are comprised participate in numerous ecological functions. Some contribute to properties that emerge in the later stages of natural forests; thus, the ways management influences these species will in large part determine how well-managed forests function (Marcot, 1997; Carey et al., 1999). The loss of forest complexity and associated biological diversity is then a concern in intensively managed landscapes (National Research Council, 1999).

Although a comprehensive survey of species in these habitats is lacking, marine and nearshore ecosystems are equally, if not more impressive, in terms of species diversity (Kruckeberg, 1991). There are 284 regularly occurring wildlife species, including 219 birds, 58 mammals, both terrestrial and marine, seven reptiles, three amphibians (Buchanan et al., 2001), and 211 species of vertebrate fishes. Invertebrate species (crabs, clams, starfish, sea cucumbers, and tube worms, for example) in the Puget Sound number in the thousands, and taxonomic families are represented. Benthic microorganisms, which are poorly cataloged, probably number in the thousands. A recent meta-analysis of marine data and studies examining the effects of biodiversity on ecosystem services found strong evidence that loss of biodiversity leads to fisheries collapse, lower potential for stock and system recovery, loss of system stability, and lower water quality. The relationship is one of an exponential loss of ecosystem services with declining diversity (Worm et al., 2006). In contrast, Worm et al. also found that restoration of biodiversity, including the establishment of marine reserves protected from fishing pressures, leads to a fourfold increase in system productivity and a 21% decrease in variability (thus, an increase in stability). This study provides the best evidence to date of the direct relationship between biological diversity and ecosystem services in the marine environment.

At a global scale, the loss of biodiversity in all ecosystems through over-harvest, habitat degradation and loss has been substantial in marine and coastal ecosystems, forests, grasslands and agricultural systems. This has large implications for maintenance of ecosystem services (UNEP, 2005 and 2006). Over-fishing and habitat loss have affected Puget Sound's fish stocks; urbanization and industrial development have led the loss of large portions of historical forest and wetland cover; and pollution and land loss to residential and commercial development continue to threaten the persistence of many species and ecosystems. There are currently 17 species listed as federally threatened or endangered that live in the Puget Sound Basin, though the Center for Biodiversity (2004) estimates that there are at least 285 species that are critically imperiled.

Habitat

Habitat is the biophysical space, i.e., the juxtaposition of physical structure, adequate food availability, chemical and temperature regimes, and protection from predators, in which wild species meet some or all of their life needs. Refugium functions are sometimes distinguished from nursery habitat. A refugium refers to general living space for organisms, while nursery habitat is specifically habitat where all the requirements for successful reproduction occur (De Groot et al. 2002). Habitat provides the places where biological diversity and commercially and culturally important species are maintained. In addition to the physical structure provided to species, food web relationships are important components of habitats that support all species. For instance, food webs based on kelp and eelgrass beds provide the conditions necessary for salmon, crab, sea cucumbers, and sea urchins – all commercially important species in the Puget Sound (Mumford, 2007). All terrestrial and aquatic habitats in the Puget Sound Basin have suffered degradation through physical alteration from development, conversion from a natural to a heavily managed type, logging, pollution, or the impact of invasive species (Buchanan et al., 2001; EPA, 2007; Olson et al. 2001). Loss of non-federal forestlands to residential and commercial development has been occurring at a yearly rate of 1.04% from 1998 through 2004 (University of Washington College of Forest Resources, 2007). Toxic and biological pollution continue to pose a threat to nearshore and pelagic habitats and their associated species (PSAT, 2007).

Habitat contributes significantly to other ecosystem services, namely, fisheries, recreation through wildlife watching, and cultural or spiritual values, which are often expressed though people's willingness to pay for protection of natural areas and through public or private expenditures on acquiring and protecting habitat.

Primary Productivity

Primary Productivity refers to growth by plants which provides basis for all terrestrial and most marine food chains. This is another supporting service upon which all other ecosystem services depend. It provides for the conversion of energy from sunlight into forms that are used by the vast majority of living organisms. Plants on land and in fresh and marine waters perform this function, using the sugars that are products of photosynthesis for their own respiration. All other life forms eat plants, animals that feed on plants, or the decaying matter of dead plants and animals. Human life depends directly on primary productivity through consumption of crops, wild plants, seaweeds, fish and seafood, and livestock. In the past, we depended mainly on the direct energy flow from food consumption to conduct the work of survival. Then we used the help of draft animals and simple machines. Since the onset of the industrial age, humans have increasingly depended on fossil fuels- - ancient energy stored by photosynthesis. Since humans started to perform work with the use of fossil fuels, the number of people and amount of consumption has far exceeded what would have been possible just by operating on current energy flows. Humans appropriate over 40% of the planet's terrestrial primary productivity. This share is increasing, and has massive ecological implications for the rest of the planet's organisms and energy budget (Vitousek et al., 1986; Pimm, 2001). One likely consequence is a loss of biological diversity, which, as discussed above, would have severe consequences on the delivery of many other ecosystem services.

About 8% of total primary productivity of ocean ecosystems supports human fisheries. However, when the calculation is confined to parts of the ocean where most primary productivity and fish catches occur, the number approaches the productivity of terrestrial systems, 25-30% (Pauly and Christensen 1995, Pimm, 2001). Again, if humans consume most ocean primary productivity in the form of fish and seafood, not much will be left to fuel the remainder of the food web and all the ecological processes that it drives (Pimm, 2001).

Terrestrial primary productivity comes mainly from forests, but ecosystem types. such as grasslands and meadows, also contribute, although at a much lower rate. Loss of forests to development decreases primary productivity. Such loss is an issue in the Puget Sound Basin, especially in the suburbanizing fringe.

Marine primary productivity comes from wetland plants, macroalgae, and sea grasses in the coastal and near shore environment, and from phytoplankton in the continental shelf and deep-sea waters. Most marine primary productivity occurs in the coastal zone out to the farthest extent of the continental shelf. Due to changes in currents, upwelling, and changes in water chemistry, which may affect the ability of diatomaceous phytoplankton to form calcerous shells, climate change has large implications for ocean productivity (Orr et al., 2005).

Cultural Services

Ecosystem services that provide humans with meaningful interaction with nature are identified as Cultural Services. These services include the role of natural beauty in attracting humans to live, work and recreate, and the value of nature for science and education

Aesthetic

Aesthetic value, as an ecosystem service, refers to the appreciation of and attraction to beautiful natural land and seascapes (De Groot et al., 2002). The existence of National Seashores, State and National Parks, Scenic Areas, and officially designated scenic roads and views attest to the social importance of this service. There is also substantial evidence demonstrating the economic value of environmental aesthetics through analysis of data on housing markets, wages, and relocation decisions (Palmquist, 2002 and see studies included in valuation results below). Puget Sound's islands, rocky beaches, and views of water, forests and mountains, are of major importance to the cultural and economic character of the region. There is also evidence substantiating the view that degraded landscapes are associated with economic decline and stagnation (Power, 1996).

Recreation and Tourism

Tourism and recreation are related to, but not totally encompassed by, aesthetic values. People travel to beautiful places for vacation, but they also engage in specific activities associated with the ecosystems in those places. Recreational fishing, scuba diving, surfing, kayaking, whale and bird watching, hunting, enjoying local seafood and wines, and beachcombing are all activities that would not occur, or be thoroughly enjoyed, without intact shorelines, healthy fish and wildlife populations, clean water and without the aesthetic quality of the area. Storm protection, shoreline stabilization, and waste treatment are also important ecological services associated with recreation and tourism because they help keep tourists safe and protect both private and public infrastructure needed for the tourist industry.

Tourism and recreation, significant parts of nearly all coastal economies throughout the world, are both a blessing and a curse. Development designed to attract tourists has been a major source of degradation in coastal environments causing water quality and habitat degradation (UNEP, 2006). Too much recreational fishing pressure and too many whale-watching boats can also put excessive pressure on the species that attract people in the first place. The concept of ecotourism has arisen in part to deal with these issues. It is, however, an incomplete solution to date (UNEP, 2005; 2006).

Recreation and tourism are, like aesthetics, an important part of the link between ecosystem services and the Puget Sound's economy. Nearly 80% of the state's revenue generated by tourism is generated in the Puget Sound (Office of Financial Management, 2007). More than half of recreational salmon that are caught in Washington State are from Puget Sound (Puget Sound Partnership, 2007).

Recreational fishing brings in substantial revenue to the state (approximately $500,000 in 2006 according to the Washington Department of Fish and Wildlife), and thus to the Puget Sound area. Healthy, fishable salmon populations are therefore important to the tourist economy. Grey whale and orca watching are also very popular tourist activities in the northern Puget Sound, with an estimated half a million visitors coming to see this population yearly (The Whale Museum, 2006). As Orca populations become increasingly stressed, and because the southern resident population is now listed as endangered, more restrictions are being contemplated for whale watching boats. Healthy marine wildlife populations are important not only in and of themselves, but as a source of income for numerous businesses in the Puget Sound.

Likewise, scuba diving, kayaking, bird watching, hiking, climbing, and nature photography draw people, both residents and visitors, to the natural areas of the watershed.

The Washington Department of Fish and Wildlife calculated that wildlife watching in Washington State brought in $980 million in 2001 (WDFW, 2002). It is interesting to note that in the year for which these spending statistics were reported, non-consumptive wildlife-viewing accounted for more than double the expenditures for hunting and exceeded spending on recreational fishing by nearly $130 million. Although not all of this spending occurred in the Puget Sound Basin, statistics on the proportion of overall tourism revenue generated in Washington that comes from Puget Sound indicates that more than half of this was likely spent in the region.

The State of Washington has also invested in ensuring that people have public access to the 35 State Parks located in the region without charge, while expending considerable fiscal resources. While teasing out the direct monetary contribution of the ecosystems themselves to the recreation and tourism economy, there is no doubt that attractive landscapes, clean water, and healthy fish and wildlife populations provide a necessary underpinning to this sector of the economy.

Scientific and Educational

Ecosystems are the subject of much scientific study for both basic knowledge and for understanding the contribution of functioning ecosystems to human well-being.

The number of educational and research institutions devoted to studying marine and terrestrial environments shows the scientific and educational importance of ecosystems. Government, academic, and private resources are all devoted to formal study of ecosystems in the Puget Sound Basin. Such pursuits benefit people through direct knowledge gained for subsistence, safety, and commercial purposes. The study of natural systems is also an important intellectual pursuit for helping people understand how complex systems work. Scientific and educational institutions devoted to both marine and terrestrial environments also provide locally significant employment. These institutions include Batelle Northwest, University of Washington biology and forestry schools, The Pacific Northwest Research Station of the U.S. Forest Service, and NOAA Pacific Fisheries Science Center.

The Chehalis Basin is home to the Chehalis Basin Education Consortium (CBEC), which includes Educational Service District 113, school districts, natural resource agencies, Grays Harbor College, the Chehalis River Council, and other nonprofit organizations. The CBEC aspires to "support stewardship of the Chehalis watershed through environmental education by linking Washington's learning goals and standards to environmental issues that are part of this watershed. In addition, the program aims to provide related professional development and enrichment opportunities for teachers" (ESD 113 Website). Although it is difficult to quantify, the value of such partnerships and learning opportunities is quite high.

Spiritual and Religious

Ecosystems and their components often play significant roles in the spiritual beliefs of people. This is especially important to indigenous cultures.

Other aspects of the linkage between ecosystem and culture include the spiritual significance that individuals and societies place on nature, and the scientific and educational value derived from studying natural systems. The watershed is especially important to the Chehalis Tribe from a spiritual perspective, as evidenced by their traditions around salmon and other marine organisms, and by their art and stories. These values do not lend themselves well to economic quantification.

Individuals of non-native origin also express the spiritual value of nature through various means. While it is challenging to ascribe economic value to spiritual significance , the willingness to take part in surveys for objectives like saving whales or spotted owls reveals that many people are unwilling to trade money or tangible goods for the loss of species or places; they rank the protection of nature above many aspects of material well-being. Some respondents to such survey instruments give "protest bids" which indicates that they are not willing to put a price on saving wildlife or wild places (Spash, 2005).

Appendix B: List of Value-Transfer Studies Used

Alvarez-Farizo, B., N. Hanley, R.E. Wright, and D. MacMillan. 1999. "Estimating the benefits of agri-environmental policy: econometric issues in open-ended contingent valuation studies." *Journal Of Environmental Planning And Management* 42:23-43.

Amigues, J. P., C. Boulatoff, B. Desaigues, C. Gauthier, and J. E. Keith. 2002. "The benefits and costs of riparian analysis habitat preservation: a willingness to accept/willingness to pay contingent valuation approach." *Ecological Economics* 43:17-31.

Anderson, G. D. and S. F. Edwards. 1986. "Protecting Rhode-Island Coastal Salt Ponds - an Economic-Assessment of Downzoning." *Coastal Zone Management Journal* 14:67-91.

Azar, C. and T. Sterner. 1996. "Discounting and distributional considerations in the context of global warming." *Ecological Economics* 19:169-184.

Batie, S.S. and J.R. Wilson. 1978. "Economic Values Attributable to Virginia's Coastal Wetlands as Inputs in Oyster Production." *Southern Journal of Agricultural Economics* July:111-118.

Bell, F. W. 1997. "The economic valuation of saltwater marsh supporting marine recreational fishing in the southeastern United States." *Ecological Economics* 21:243-254.

Bennett, Richard, Richard Tranter, Nick Beard, and Philip Jones. 1995. "The Value of Footpath Provision in the Countryside: A Case-Study of Public Access to Urbran-fringe Woodland." *Journal of Environmental Planning and Management* 38:409-417.

Bergstrom, J. C., J. R. Stoll, J. P. Titre, and V. L. Wright. 1990. "Economic value of wetlands-based recreation." *Ecological Economics* 2:129-147.

Bergstrom, J., B.L. Dillman, and J. R. Stoll. 1985. "Public environmental amenity benefits of private land: the case of prime agricultural land." *South Journal of Agricultural Economics* 7:139-149.

Berrens, R. P., P. Ganderton, and C. L. Silva. 1996. "Valuing the protection of minimum instream flows in New Mexico." *Journal of Agricultural and Resource Economics* 21:294-308.

Birdsey, R.A. 1996. Regional Estimates of Timber Volume and Forest Carbon for Fully Stocked Timberland, Average Management After Final Clearcut Harvest. *In Forests and Global Change: Volume 2, Forest Management Opportunities for Mitigating Carbon Emissions*, eds. R.N. Sampson and D. Hair, American Forests, Washington, DC.

Bishop, Kevin. 1992. "Assessing the Benefits of Community Forests: An Evaluation of the Recreational of Use Benefits of Two Urban Fringe Woodlands." *Journal of Environmental Planning and Management* 35:63-76.

Bocksteal, N.E., K.E. McConnell, and I.E. Strand. 1989. "Measuring the Benefits of Improvements in Water Quality: The Chesapeake Bay." *Marine Resource Economics* 6:1-18.

Bouwes, N. W. and R. Scheider. 1979. "Procedures in estimating benefits of water quality change." *American Journal of Agricultural Economics*:534-539.

Bowker, J.M., D. English, and J. Donovan. 1996. "Toward a value for guided rafting on southern rivers." *Journal of Agricultural and Resource Economics* 28:423-432.

Boxall, P. C. 1995. "The Economic Value of Lottery-Rationed Recreational Hunting." *Canadian Journal of Agricultural Economics-Revue Canadienne D Economie Rurale* 43:119-131.

Boxall, P. C., B. L. McFarlane, and M. Gartrell. 1996. "An aggregate travel cost approach to valuing forest recreation at managed sites." *Forestry Chronicle* 72:615-621.

Breaux, A., S. Farber, and J. Day. 1995. "Using Natural Coastal Wetlands Systems for Waste-Water Treatment - an Economic Benefit Analysis." *Journal of Environmental Management* 44:285-291.

Burt, O.R. and D. Brewer. 1971. "Estimation of net social benefits from outdoor recreation." *Econometrica* 39:813-827.

Christie, M., N. Hanley, J. Warren, K. Murphy, and R.E. Wright. 2004. "An economic valuation of UK biodiversity using stated preferences."

Cordell, H. K. and J. C. Bergstrom. 1993. "Comparison of Recreation Use Values among Alternative Reservoir Water Level Management Scenarios." *Water Resources Research* 29:247-258.

Costanza, R., R. dArge, R. deGroot, S. Farber, M. Grasso, B. Hannon, K. Limburg, S. Naeem, R. V. Oneill, J. Paruelo, R. G. Raskin, P. Sutton, and M. vandenBelt. 1997. "The value of the world's ecosystem services and natural capital." *Nature* 387:253-260.

Costanza, R. and J. Farley. 2007. “The Ecological Economics of Coastal Disasters.” Ecological Economics Vol. 63; Issues 2-3: 344-354.

Creel, M. and J. Loomis. 1992. "Recreation Value of Water to Wetlands in the San-Joaquin Valley - Linked Multinomial Logit and Count Data Trip Frequency Models." *Water Resources Research* 28:2597-2606.

Croke, K., R. Fabian, and G. Brenniman. 1986. "Estimating the Value of Improved Water-Quality in an Urban River System." *Journal of Environmental Systems* 16:13-24.

Danielson, L., T. J. Hoban, G. Vanhoutven, and J. C. Whitehead. 1995. "Measuring the Benefits of Local Public-Goods - Environmental-Quality in Gaston County, North-Carolina." *Applied Economics* 27:1253-1260.

Dodge, John and Alan Kenaga. Profiles of South Sound Inlets and Watersheds. www.theolympian.com/static/images/ps3images/pugetsoundpdf.pdf

Doss, C. R. and S. J. Taff. 1996. "The influence of wetland type and wetland proximity on residential property values." *Journal of Agricultural and Resource Economics* 21:120-129.

Duffield, J. W., C. J. Neher, and T. C. Brown. 1992. "Recreation Benefits of Instream Flow - Application to Montana Big Hole and Bitterroot Rivers." *Water Resources Research* 28:2169-2181.

Edwards, S. F. and F.J. Gable. 1991. "Estimating the value of beach recreation from property values: an exploration with comparisons to nourishment costs." *Ocean & Shoreline Management* 15:37-55.

Fankhauser, S. 1994. "The Social Costs Of Greenhouse-Gas Emissions - An Expected Value Approach." *Energy Journal* 15:157-184.

Farber, S. 1987. "The Value of Coastal Wetlands for Protection of Property against Hurricane Wind Damage." *Journal of Environmental Economics and Management* 14:143-151.

—. 1988. "The Value of Coastal Wetlands for Recreation - an Application of Travel Cost and Contingent Valuation Methodologies." *Journal of Environmental Management* 26:299-312.

Farber, S. and R. Costanza. 1987. "The Economic Value of Wetlands Systems." *Journal of Environmental Management* 24:41-51.

Garrod, G. D. and K. G. Willis. 1997. "The non-use benefits of enhancing forest biodiversity: A contingent ranking study." *Ecological Economics* 21:45-61.

Gramlich, F.W. 1977. "The demand for clean water:the case of the Charles River." *National Tax Journal* 30.

Greenley, D., R. G. Walsh, and R.A. Young. 1981. "Option value: empirical evidence from study of recreation and water quality." *The Quarterly Journal of Economics*:657-673.

Hanley, N., D. Bell, and B. Alvarez-Farizo. 2003. "Valuing the benefits of coastal water quality improvements using contingent and real behaviour." *Environmental & Resource Economics* 24:273-285.

Hayes, K.M., T.J. Tyrrell, and G. Anderson. 1992. "Estimating the benefits of water quality improvements in the Upper Narragansett Bay." *Marine Resource Economics* 7:75-85.

Henry, R., R. Ley, and P. Welle. 1988. "The economic value of water resources: the Lake Bemidji Survey." *Journal of the Minnesota Academy of Science* 53:37-44.

Hope, C. and P. Maul. 1996. "Valuing the impact of CO2 emissions." *Energy Policy* 24:211-219.

Hougner, C. To be published. "Economic valuation of a seed dispersal service in the Stockholm National Urban Park, Sweden." *Ecological Economics*.

Iyall, Cynthia. 2008. City, tribe team up on clean water project. *Seattle Daily Journal of Commerce: Environmental Outlook*. http://www.djc.com/news/en/11202008.html

Johnston, R. J., T. A. Grigalunas, J. J. Opaluch, M. Mazzotta, and J. Diamantedes. 2002. "Valuing estuarine resource services using economic and ecological models: the Peconic Estuary System study." *Coastal Management* 30:47-65.

Kahn, J. R. and R. B. Buerger. 1994. "Valuation and the Consequences of Multiple Sources of Environmental Deterioration - the Case of the New-York Striped Bass Fishery." *Journal of Environmental Management* 40:257-273.

Kealy, M. J. and R. C. Bishop. 1986. "Theoretical and Empirical Specifications Issues in Travel Cost Demand Studies." *American Journal of Agricultural Economics* 68:660-667.

Kenyon, W. and C. Nevin. 2001. "The use of economic and participatory approaches to assess forest development: a case study in the Ettrick Valley." *Forest Policy and Economics* 3:69-80.

Kline, J. D. and S. K. Swallow. 1998. "The demand for local access to coastal recreation in southern New England." *Coastal Management* 26:177-190.

Kreutzwiser, R. 1981. "The economic significance of the long point marsh, Lake Erie, as a recreational resource." *Journal of Great Kakes Resources* 7:105-110.

Kulshreshtha, S. N. and J. A. Gillies. 1993. "Economic-Evaluation of Aesthetic Amenities - a Case-Study of River View." *Water Resources Bulletin* 29:257-266.

Lant, C. L. and R. S. Roberts. 1990. "Greenbelts in the Corn-Belt - Riparian Wetlands, Intrinsic Values, and Market Failure." *Environment and Planning A* 22:1375-1388.

Lant, C. L. and G. Tobin. 1989. "The economic value of reparian corridors in cornbelt floodplains: a research framework." *Professinal Geographer* 41:337-349.

Leggett, C. G. and N. E. Bockstael. 2000. "Evidence of the effects of water quality on residential land prices." *Journal of Environmental Economics and Management* 39:121-144.

Leschine, T.M., and A.W. Petersen. 2007. Valuing Puget Sound's Valued Ecosystem Components. Puget Sound Nearshore Partnership Report No. 2007-07. Published by Seattle District, U.S. Army Corps of Engineers, Seattle, Washington. Available at www.pugetsoundnearshore.org.

Leschine, T. M., K F. Wellman and T. H. Green. 1997. The Economic Value of Wetlands: Wetland's Role in Flood Protection in Western Washington. Washington State Department of Ecology. Ecology Publication 97-100, Olympia, Washington.

Loomis, J. B. 1988. "The bioeconomic effects of timber harvesting on recreational and commercial salmon and steelhead fishing: a case study of the Siuslaw National Forest." *Marine Pollution Bulletin* 5:43-60.

Loomis, J.B. 2002. Quantifying Recreation Use Values from Removing Dams and Restoring Free-Flowing Rivers: A Contingent Behavior Travel Cost Demand Model for the Lower Snake River. Water Resources Research 38 (6)

Lynne, G.D., P. Conroy, and F.J. Prochaska. 1981. "Economic Valuation of Marsh Areas for Marine Production Processes." *Journal of Environmental Economics and Management* 8:175-186.

Maddison, D. 1995. "A Cost-Benefit-Analysis Of Slowing Climate-Change." *Energy Policy* 23:337-346.

Mahan, B. L., S. Polasky, and R. M. Adams. 2000. "Valuing urban wetlands: A property price approach." *Land Economics* 76:100-113.

Mapes, Lynda. 2002. Seattle Times. http://community.seattletimes.nwsource.com/archive/?date=20021116&slug=tide16m. Accessed 4.23.09.

Mathews, L. G., F. R. Homans, and K. W. Easter. 2002. "Estimating the benefits of phosphorus pollution reductions: An application in the Minnesota River." *Journal of the American Water Resources Association* 38:1217-1223.

Maxwell, Simon. 1994. "Valuation of Rural Environmental Improvements using Contingent Valuation Methodology: A Case Study of the Martson Vale Community Forest Project." *Journal of Environmental Management* 41:385-399.

McPherson, E. G. 1992. "Accounting for Benefits and Costs of Urban Greenspace." *Landscape and Urban Planning* 22:41-51.

McPherson, E. G., K. I. Scott, and J. R. Simpson. 1998. "Estimating cost effectiveness of residential yard trees for improving air quality in Sacramento, California, using existing models." *Atmospheric Environment* 32:75-84.

Morey, E. R., W. D. Shaw, and R. D. Rowe. 1991. "A Discrete-Choice Model of Recreational Participation, Site Choice, and Activity Valuation When Complete Trip Data Are Not Available." *Journal of Environmental Economics and Management* 20:181-201.

Mullen, J. K. and F. C. Menz. 1985. "The Effect of Acidification Damages on the Economic Value of the Adirondack Fishery to New-York Anglers." *American Journal of Agricultural Economics* 67:112-119.

Newell, R. G. and W. A. Pizer. 2003. "Discounting the distant future: how much do uncertain rates increase valuations?" *Journal Of Environmental Economics And Management* 46:52-71.

Nisqually Indian Tribe. 2007. Nisqually Watershed Detailed Implementation Plan, February 2007, 25 pp. http://www.ecy.wa.gov/apps/watersheds/planning/11.html

NJDEP. 2005. "COST OF NEW YORK CITY WATERSHED PROTECTION PROGRAM."

Nordhaus, W. D. 1991. "To Slow Or Not To Slow - The Economics Of The Greenhouse-Effect." *Economic Journal* 101:920-937.

Nordhaus, W. D. 1993. "Rolling The Dice - An Optimal Transition Path For Controlling Greenhouse Gases." *Resource And Energy Economics* 15:27-50.

Nordhaus, W. D. and D. Popp. 1997. "What is the value of scientific knowledge? An application to global warming using the PRICE model." *Energy Journal* 18:1-45.

Nordhaus, W. D. and Z. L. Yang. 1996. "A regional dynamic general-equilibrium model of alternative climate-change strategies." *American Economic Review* 86:741-765.

Nunes, Pald and Jcjm Van den Bergh. 2004. "Can people value protection against invasive marine species? Evidence from a joint TC-CV survey in the Netherlands." *Environmental & Resource Economics* 28:517-532.

Oster, S. 1977. "Survey results on the benefits of water pollution abatement in the Merrimace River Basin." *Water Resources Research* 13:882-884.

Parsons, G. R. and M. Powell. 2001. "Measuring the Cost of Beach Retreat." *Coastal Management* 29:91-103.

Patrick, R., J. Fletcher, S. Lovejoy, W. Vanbeek, G. Holloway, and J. Binkley. 1991. "Estimating Regional Benefits of Reducing Targeted Pollutants - an Application to Agricultural Effects on Water-Quality and the Value of Recreational Fishing." *Journal of Environmental Management* 33:301-310.

Pimentel, D., C. Wilson, C. McCullum, R. Huang, P. Dwen, J. Flack, Q. Tran, T. Saltman, and B. Cliff. 1997. "Economic and environmental benefits of biodiversity." *Bioscience* 47:747-757.

Piper, S. 1997. "Rigonal impacts and benefits of water-based activities: an application in the Black Hills region of South Dakota and Wyoming." *Impact Assessment* 15:335-359.

Plambeck, E. L. and C. Hope. 1996. "PAGE95 - An updated valuation of the impacts of global warming." *Energy Policy* 24:783-793.

Plummer, M. 2007. Welcome to the Data-Poor Real World: Incorporating Benefit-Cost Principles into Environmental Policymaking. Research in Law and Economics, 23:103-130.

Plummer, M. 2005. The Economic Evaluation of Stream and Watershed Restoration Projects. Pages 313-330 *in* Roni, P. (Ed.) Methods for monitoring stream and watershed restoration. American Fisheries Society, Bethesda, Maryland.

Pompe, J. J. and J. R. Rinehart. 1995. "Beach Quality and the Enhancement of Recreational Property-Values." *Journal of Leisure Research* 27:143-154.

Prince, R. and E. Ahmed. 1989. "Estimating Individual Recreation Benefits under Congestion and Uncertainty." *Journal of Leisure Research* 21:61-76.

Reilly, J.M. and K.R. Richards. 1993. "Climate change damage and the trace gas index issue." *Environmental & Resource Economics* 3.

Rein, F. A. 1999. "An economic analysis of vegetative buffer strip implementation - Case study: Elkhorn Slough, Monterey Bay, California." *Coastal Management* 27:377-390.

Reyes, J. and W. Mates. 2004. "The economic value of New Jersey State Parks and Forests." New Jersey Department of Environmental Protection.

Ribaudo, M. and D.J. Epp. 1984. "The importance of sample descrimination in using the travel cost method to estimate the benefits of improved water quality." *Land Economics* 60:397-403.

Rich, P. R. and L. J. Moffitt. 1982. "Benefits of Pollution-Control on Massachusetts Housatonic River - a Hedonic Pricing Approach." *Water Resources Bulletin* 18:1033-1037.

Robinson, W.S, R. Nowogrodzki, and R.A. Morse. 1989. "The value of honey bees as pollinators of US crops." *American Bee Journal*:177-487.

Roughgarden, T. and S. H. Schneider. 1999. "Climate change policy: quantifying uncertainties for damages and optimal carbon taxes." *Energy Policy* 27:415-429.

Sala, O.E. and f. M. Paruelo. 1997. "Ecosystem services in grassland." Pp. 237-252 in *Nature's services: Societal dependence on natural ecosystems*, edited by G. C. Daily. Washington, D.C.: Island Press.

Sanders, L. D., R. G. Walsh, and J. B. Loomis. 1990. "Toward Empirical Estimation of the Total Value of Protecting Rivers." *Water Resources Research* 26:1345-1357

Seattle Public Utilities. 2008. Water System History. Retrieved July 2, 2008, from http://seattle.gov/util/About_SPU/Water_System/index.asp

Schauer, M.J. 1995. "Estimation of the greenhouse gas externality with uncertainty." *Environmental & Resource Economics* 5:71-82.

Shafer, E. L., R. Carline, R. W. Guldin, and H. K. Cordell. 1993. "Economic Amenity Values of Wildlife - 6 Case-Studies in Pennsylvania." *Environmental Management* 17:669-682.

Silberman, J., D. A. Gerlowski, and N. A. Williams. 1992. "Estimating Existence Value for Users and Nonusers of New-Jersey Beaches." *Land Economics* 68:225-236.

Soderqvist, T. and H. Scharin. 2000. "The regional willingness to pay for a reduced eutrophication in the Stockholm archipelago." in *Beijer Discussion paper No. 128*.

Southwick, E. E. and L. Southwick. 1992. "Estimating the Economic Value of Honey-Bees (Hymenoptera, Apidae) as Agricultural Pollinators in the United-States." *Journal of Economic Entomology* 85:621-633.

Taylor, L. O. and V. K. Smith. 2000. "Environmental amenities as a source of market power." *Land Economics* 76:550-568.

Thibodeau, F. R. and B.D. Ostro. 1981. "An economic analysis of wetland protection." *Journal of Environmental Management* 12:19-30.

Tibbetts, John. 2006. Louisiana's Wetlands: A Lesson in Nature Appreciation. *Environmental Health Perspectives* 114(1): A40-A43.

Tidwell, J. 2006. The True Wealth of Nations: How Costa Rica prospers by protecting its ecosystems. Conservation Frontlines 6(1): 6-11

Tol, R. S. J. 1999. "The marginal costs of greenhouse gas emissions." *Energy Journal* 20:61-81.

Tol, R. S. J. and T.E. Downing. 2000. "The marginal costs of climate changing emissions." The Institute for Environmental Studies, Amsterdam.

Tyrvainen, L. 2001. "Economic valuation of urban forest benefits in Finland." *Journal of Environmental Management* 62:75-92.

Vankooten, G. C. and A. Schmitz. 1992. "Preserving Waterfowl Habitat on the Canadian Prairies - Economic Incentives Versus Moral Suasion." *American Journal of Agricultural Economics* 74:79-89.

Ward, F. A., B. A. Roach, and J. E. Henderson. 1996. "The economic value of water in recreation: Evidence from the California drought." *Water Resources Research* 32:1075-1081.

Whitehead, J. C. 1990. "Measuring Willingness-to-Pay for Wetlands Preservation with the Contingent Valuation Method." *Wetlands* 10:187-201.

Whitehead, J. C., T. L. Hoban, and W. B. Clifford. 1997. "Economic analysis of an estuarine quality improvement program: The Albemarle-Pamlico system." *Coastal Management* 25:43-57.

Willis, K. G. 1991. "The Recreational Value of the Forestry Commission Estate in Great-Britain - a Clawson-Knetsch Travel Cost-Analysis." *Scottish Journal of Political Economy* 38:58-75.

Willis, K.G. and G.D. Garrod. 1991. "An Individual Travel-Cost Method of Evaluating Forest Recreation." *Journal of Agricultural Economics* 42:33-42.

Worldwatch Institute. 2005. From Drinking Water To Disasters, Investing in Freshwater Ecosystems is Best Insurance Policy. Press Release, July 11, 2005. Available online: http://www.worldwatch.org/node/1819.

Young, C.E. and J.S. Shortle. 1989. "Benefits and costs of agricultural nonpoint-source pollution controls: the case of St. Albans Bay." *Journal of Soil and Water Conservation*:64-67.

Appendix C: Value-Transfer Source Literature Detailed Report

(All values in 2006 dollars using CPI conversion)

Table 1a. Land cover type, ecosystem services, valuation study authors, and values.

Land Cover Type				
		Values ($US 2006)		
Ecosystem Service		Low	High	Single
	Study Author(s)			

Shrub/Scrub				
Gas and Climate Regulation		***$6.20***	***$62.30***	
	Birdsey (2007) and USFS carbon calculator with Chicago Carbon Exchange value (2007)			$6.20
	Birdsey (2007) and USFS carbon calculator with Stern (2007) carbon sequestration value.			$62.30
Habitat/Refugium		***$1.23***	***$500.24***	
	Shafer, E. L. et. al.			$2.98
	Kenyon, W. and Nevin, C.			$500.24
	Haener, M. K. and Adamowicz, W. L.	$1.23	$8.46	
Aesthetic and Recreational		***$0.09***	***$318.91***	
	Willis, K. G.	$0.09	$318.91	
	Willis, K. G. and Garrod, G. D.			$4.11
	Prince, R. and Ahmed, E.	$1.49	$1.90	
	Maxwell, S.			$11.78
	Haener, M. K. and Adamowicz, W. L.			$0.20
	Boxall, P. C., McFarlane, B. L. and Gartrell, M.			$0.18
	Bennett, R., et. al.			$169.13
	TOTAL	$7.52	$881.45	

Fresh Wetland				
Gas Regulation		***$29.43***	***$267.43***	
	Bowmans and Day, have recently updated this with a higher estimate to be available in late 2010.	$29.43	$267.53	
Water Supply		***$199.11***	***$31,404.56***	
	Allen, J. et. al.	$10,488.00	$31,404.56	
	Pate, J. and Loomis, J.			$3,598.28
	Lant, C. L. and Tobin, G.			$199.11
	Lant, C. L. and Tobin, G.			$2,192.67
	Hayes, K. M., Tyrrell, T. J. and Anderson, G.	$1,287.83	$2,001.85	
	Creel, M. and Loomis, J.			$542.65
Water Regulation		***$6,357.71***	***$6,357.71***	
	Thibodeau, F. R. and Ostro, B. D.			$6,357.71
Habitat/Refugium		***$58.89***	***$12,537.14***	
	Allen, J. et. al.	$5,147.20	$12,537.14	
	Striner and Loomis 1996			$1,479.84
	Knowler, D. J. et. al.	$58.89	$269.91	
Aesthetic and Recreational		***$31.47***	***$9,347.33***	
	Allen, J.	$103.35	$9,347.33	
	Whitehead, J. C.	$1,044.66	$2,100.39	
	Thibodeau, F. R. and Ostro, B. D.			$656.33
	Thibodeau, F. R. and Ostro, B. D.	$31.47	$100.68	
	Mahan, B. L., Polasky, S. and Adams, R. M.			$34.75
	Hayes, K. M., Tyrrell, T. J. and Anderson, G.	$1,212.84	$2,318.09	
	Doss, C. R. and Taff, S. J.			$4,626.73
	Doss, C. R. and Taff, S. J.			$4,187.89
	TOTAL	$6676.61	$59,914.17	

Forest*				
Gas and Climate Regulation		***$6.20***	***$990.00***	
	Estimates for early/pole forests are not available, however, these values are larger than shrub sequestration, shrub sequestration values used here.	$6.20	$62.30	early pole
	Estimate based on Birdsey (1996) forest carbon sequestration and Chicago Climate Exchange.	$27.43	$623.33	mid-seral
	Estimate based on Birdsey (1996) forest carbon sequestration and Stern (2007) carbon values.	$99.00	$990.00	late seral
Water Regulation		***$9.61***	***$9.61***	
	Loomis, J.B.			$9.61
Pollination		***$31.49***	***$282.82***	
	Hougner, C.	$31.49	$282.82	
Habitat/Refugium		***$269.85***	***$500.24***	
	Kenyon, W. and Nevin, C.			$500.24
	Garber-Yontz et al. 2004	$269.85	$452.57	
Aesthetic and Recreational		***$4.89***	***$637.81***	
	Willis, K. G.	$104.04	$190.66	
	Willis, K. G.	$23.78	$40.76	
	Willis, K. G.	$4.89	$17.84	
	Willis, K. G.	$5.52	$5.94	
	Shafer, E. L., et. al.			$538.99
	Maxwell, S.			$11.78
	Bishop, K.			$637.81
	Bishop, K.			$569.01
	Bennett, R., et. al.			$169.13

Riparian Buffers*				
Gas and Climate Regulation		***$43.56***	***$990.00***	
	local estimate			$43.56
	local estimate			$990.00
Disturbance Prevention		***$7.56***	***$235.73***	
	Rein, F. A.	$53.39	$235.73	
	Rein, F. A.	$7.56	$115.84	
Water Supply		***$5.16***	***$13,015.08***	
	Mathews, L. G., Homans, F. R. and Easter, K. W.			$13,015.08
	Danielson, L., et. al.			$4,806.25
	Berrens, R. P., Ganderton, P. and Silva, C. L.			$2,105.11
Habitat/Refugium		***$58.89***	***$500.24***	
	Kenyon, W. and Nevin, C.			500.24
	Knowler, D. J. et. al.	$58.89	$269.91	
Aesthetic and Recreational		***$1043***	***$10,624.14***	
	Sanders, L. D., Walsh, R. G. and Loomis, J. B.			$2,297.39
	Duffield, J. W., Neher, C. J. and Brown, T. C.			$1,474.20
	Duffield, J. W., Neher, C. J. and Brown, T. C.			$1,043.00
	Bowker, J. M., English, D. and Donovan, J.	$4,420.54	$10,624.14	

Rivers and Lakes				
Water Supply		***$32.34***	***$834.44***	
	Ribaudo, M. and Epp, D. J.			$834.44
	Piper, S.			$32.34
	Henry, R., Ley, R. and Welle, P.			$429.30
	Croke, K., Fabian, R. and Brenniman, G.			$565.91

	Bouwes, N. W. and Scheider, R.			$617.46
Habitat/Refugium	***Subtotals***	***$17.13***	***$1,479.84***	
	Knowler, D. J. et. al.	$58.89	$269.91	
	Striner and Loomins 1996			$1,479.84
	Loomis 1996			$17.13
Aesthetic and Recreational	***Subtotals***	***$1.69***	***$19,699.00***	
	Young, C. E. and Shortle, J. S.			$81.85
	Young, C. E. and Shortle, J. S.			$81.85
	Ward, F. A., Roach, B. A. and Henderson, J. E.	$20.48	$1,918.61	
	Shafer, E. L. et. al.			$97.24
	Shafer, E. L. et. al.			$551.74
	Shafer, E. L. et. al.			$1,101.41
	Piper, S.			$240.20
	Patrick, R.,et. al.	$1.69	$25.56	
	Kreutzwiser, R.			$181.25
	Kealy, M. J. and Bishop, R. C.			$12.93
	Cordell, H. K. and Bergstrom, J. C.	$189.67	$796.50	
	Cordell, H. K. and Bergstrom, J. C.	$135.37	$283.79	
	Cordell, H. K. and Bergstrom, J. C.	$283.06	$800.69	
	Cordell, H. K. and Bergstrom, J. C.	$382.24	$1,419.65	
	Burt, O. R. and Brewer, D.			$461.82
	Loomis et al. 2002	$11,131.00	$19,699.00	
	TOTAL	$51.16	$22013.28	

Beach				
Disturbance Prevention		***$22,213.11***	***$36,006.72***	
	Pompe, J. J. and Rinehart, J. R.			$36,006.72
	Parsons, G. R. and Powell, M.			$22,213.11

Aesthetic and Recreational		***$140.21***	***$45,521.29***	
	Taylor, L. O. and Smith, V. K.	$418.61		
	Silberman, J., Gerlowski, D. A. and Williams, N. A.			$22,070.44
	Kline, J. D. and Swallow, S. K.	$35,273.49	$45,521.29	
	Edwards, S. F. and Gable, F. J.			$140.21
	TOTAL	22,353.32	81,528.01	

Estuary				
Water Supply		***$5.90***	***$127.84***	
	Whitehead, J. C., Hoban, T. L. and Clifford, W. B.			$5.90
	Leggett, C. G. and Bockstael, N. E.			$43.16
	Bocksteal, N. E., McConnell, K. E. and Strand, I. E.	$72.03	$127.84	
Habitat/Refugium		***$11.55***	***$1,385.51***	
	Johnston, R. J. et. al.			$439.73
	Johnston, R. J. et. al.			$1,385.51
	Johnston, R. J. et. al.			$87.16
	Farber, S. and Costanza, R.			$16.01
	Farber, S. and Costanza, R.			$11.55
	Armstrong, 2003	$22.18	$124.20	
Aesthetic and Recreational		***$1.17***	***$355.16***	
	Whitehead, J. C., Hoban, T. L. and Clifford, W. B.	$1.36	$9.22	
	Kahn, J. R. and Buerger, R. B.			$3.71
	Johnston, R. J. et. al.	$157.42	$355.16	
	Morrey, 2001	$1.17	$72.62	
	TOTAL	18.62	1,868.51	

Salt Marsh				
Disturbance Prevention		***$242.91***	***$95,951.00***	

	Costanza et al. 2007	$242.91	$95,951.00	
Habitat/Refugium		***$1.17***	***$1,017.08***	
	Lynne, G. D., Conroy, P. and Prochaska, F. J.			$1.17
	Farber, S. and Costanza, R.			$1.33
	Bell, F. W.	$154.19	$1,017.08	
	Batie, S. S. and Wilson, J. R.			$6.26
Water Flow Regulation		***$109.78***	***$17,673.84***	
	Breaux, A., Farber, S. and Day, J. 1995	$109.78	$17,673.84	
Aesthetic and Recreational		***$4.88***	***$97.56***	
	Farber, S.			$4.88
	Bergstrom, J. C., et. al.			$14.72
	Anderson, G. D. and Edwards, S. F.	$20.85	$97.56	
	TOTAL	$358.74	$114,739.48	

Agriculture				
Pollination		***$2.40***	***$12.10***	
	Southwick, E. E. and Southwick, L.			$2.40
	Robinson, W. S., Nowogrodzki, R. and Morse, R. A.			$12.10
Aesthetic and Recreational		***$27.50***	***$27.50***	
	Bergstrom, J., Dillman, B. L. and Stoll, J. R.			$27.50
	TOTAL	$29.9	$39.6	

Pasture				
Soil Formation		***$6.22***	***$6.22***	
	Pimentel, D.			$6.22
Aesthetic and Recreational		***$0.03***	***$0.03***	
	Boxall, P. C.			$0.03
	TOTAL	$6.25	$6.25	

Urban Green Space				
Gas and Climate regulation		***$26.81***	***$874.79***	
	American Forests			$203.44
	McPherson, E. G., Scott, K. I. and Simpson, J. R.			$26.81
	McPherson, E. G.	$175.37	$874.79	
Water Flow Regulation		***$5.72***	***$170.89***	
	American Forests			$170.89
	McPherson, E. G.			$5.72
Aesthetic and Recreational		***$1,261.31***	***$3,697.42***	
	Tyrvainen, L.	$1,261.31	$3,697.42	
	TOTAL	$1,293.84	$4,743.1	

Marine Waters				
Water Quality		***$259.34***	***$772.68***	
	Soderqvist, T. and Scharin, H.	$259.34	$431.16	
	Nunes, P and Van den Bergh, J.			
	Hanley, N., Bell, D. and Alvarez-Farizo, B.			
	TOTAL	$259.34	$772.68	

Grasslands/Herb				
Gas and Climate Regulation		***$3.85***	***$3.85***	
	Costanza et al. 1997			$3.85
Water Regulation		***$1.65***	***$1.65***	
	Costanza et al. 1997			$1.65
Soil Erosion Control		***$15.97***	***$15.97***	
	Costanza et al. 1997			$15.97

Soil Formation		***$0.54***	***$0.54***	
	Costanza et al. 1997			$0.54
Water Quality		***$47.91***	***$47.91***	
	Pimentel et al. 1995			$47.91
Pollination		***$13.77***	***$13.77***	
	Pimentel et al. 1995			$13.77
Biological Control		***$12.66***	***$12.66***	
	Pimentel et al. 1995			$12.66
Aesthetic and Recreational		***$1.01***	***$1.01***	
				$1.01
	TOTAL	$97.36	$97.36	

Eelgrass				
Nutrient Cycling		***$5,507***	***$15,421***	
	Costanza et al. 1997	$5,507	$15,421	
	TOTAL	$5,507	$15,421	

***** Estimates of forest and riparian carbon sequestration (climate stability) values are based on Birdsey (1996) for carbon sequestration estimates, these include timber values but not soil carbon. Low values were based on the low value of the Chicago Carbon Exchange (2007), high values are based on the Stern (2007) estimate. These forest and Riparian Buffer values are only used for mid, late/old growth forests. Early and pole forest values are not available. Shrub/scrub values were used as substitutes for early and pole forests.

Appendix D: Study Limitations

The results of this first attempt to assign monetary value to the ecosystem services rendered by the Chehalis River Basin have important and significant implications on the restoration and management of this natural capital. While valuation exercises have limitations that must be noted, they do not detract from the core finding that ecosystems produce significant economic value to society.

Transferred value analysis estimates the economic value of a given ecosystem (e.g., wetlands) from prior studies of that ecosystem. Like any economic analysis, this methodology has strengths and weaknesses. Because this is a meta-study, it has greater opportunity for error, and as the numbers show, a very wide range between low and high estimates. Some have objected to this approach on the grounds that:

1. Every ecosystem is unique; per acre values derived from another part of the world may be irrelevant to the ecosystems being studied.
2. Even within a single ecosystem, the value per acre depends on the size of the ecosystem; in most cases, as the size decreases, the per-acre value is expected to increase and vice versa. (In technical terms, the marginal cost per acre is generally expected to increase as the quantity supplied decreases; a single average value is not the same as a range of marginal values). This remains an important issue, even though this was partly addressed in the spatial modeling component of this project.
3. Gathering all the information needed to estimate the specific value for every ecosystem within the study area is not feasible. Hence the "true" value of all of the wetlands, forests, pastureland, etc. in a large geographic area cannot be ascertained. In technical terms, we have far too few data points to construct a realistic demand curve or estimate a demand function.
4. To value all, or a large proportion, of the ecosystems in a large geographic area is questionable in terms of the standard definition of "exchange" value; we cannot conceive of a transaction in which all or most of a large area's ecosystems would be bought and sold. This emphasizes the point that the value estimates for large areas (as opposed to the unit values per acre) are more comparable to national income accounts aggregates and not exchange values (Howarth & Farber, 2002). These aggregates (i.e. GDP) routinely impute values to public goods for which no conceivable market transaction is possible. The value of ecosystem services of large geographic areas is comparable to these kinds of aggregates (see below).

Proponents of the above arguments recommend an alternative that amounts to limiting valuation to a single ecosystem in a single location and only using data developed expressly for the unique ecosystem being studied, with no attempt to extrapolate from other ecosystems in other locations. An area with the size and landscape complexity of the Chehalis River Basin would make this approach to valuation extremely difficult and costly.

Responses to these critiques can be summarized as follows (See Costanza et al 1998 and

Howarth and Farber 2002 for more detailed discussion):

- While every wetland, forest, or other ecosystem is unique in some way, ecosystems of a given type, by their definition, have many things in common. The use of average values in ecosystem valuation is no more and no less justified than their use in other "macroeconomic" contexts, for instance, developing economic statistics such as Gross Domestic or Gross State Product. This study's estimate of the aggregate value of the Chehalis River Basin ecosystem services is a valid and useful (albeit imperfect, as are all aggregated economic measures) basis for assessing and comparing these services with conventional economic goods and services.
- The results of the spatial modeling analyses that were described in other studies do not support an across-the-board claim that the per-acre value of forest or agricultural land depends on the size of the parcel. While the claim does appear to hold for nutrient cycling and other services, the opposite position holds up fairly well for what ecologists call "net primary productivity" or NPP, a major indicator of ecosystem health – and by implication of services tied to NPP – where each acre makes about the same contribution to the whole regardless of whether it is part of a large patch or a small one. This area of inquiry needs further research, but for the most part the assumption (that average value is a reasonable proxy for marginal value) seems appropriate as a first approximation.
- As employed here, the prior studies we analyzed encompass a wide variety of time periods, geographic areas, investigators, and analytic methods. Many of them provide a range of estimated values rather than single point estimates. The present study preserves this variance; no studies were removed from the database because their estimated values were deemed to be "too high" or "too low." Limited sensitivity analyses were performed. The approach is similar to determining an asking price for a piece of land based on the prices for "comparable" parcels; even though the property being sold is unique, realtors and lenders feel justified in following this procedure to the extent of publicizing a single asking price rather than a price range.
- The objection as to the absence of even an imaginary exchange transaction was made in response to the study by Costanza et al. (1997) of the value of *all* of the world's ecosystems. Leaving that debate aside, one can in fact conceive of an exchange transaction in which all or a large portion of, for example, a watershed were sold for development so that the basic technical requirement that economic value reflect exchange values could in principle be satisfied. Even this is not necessary if one recognizes the different purpose of valuation at this scale – a purpose more analogous to national income accounting than to estimating exchange values (cf. Howarth and Farber 2002).

In the last analysis, this report takes the position that "the proof of the pudding is in the eating", i.e., estimating the value of an area's ecosystem services is best demonstrated by presenting the results of an attempt to do so. In this report we have tried to display our results in a way that allows one to appreciate the range of values and their distribution. It is clear from inspection of the tables that the final estimates are not extremely precise. However, they are much better estimates than the alternative of assuming that ecosystem services have zero value, or alternatively, of assuming they have infinite value. Pragmatically, in estimating the value of ecosystem services, it seems better to be approximately right than precisely wrong.

The estimated value of the world's ecosystems presented in Costanza et al. (1997) has been criticized as both (1) "a serious underestimate of infinity" and (2) impossibly exceeding the entire Gross World Product. These objections seem to be difficult to reconcile but that may not be so. Just as a human life is "priceless" so are ecosystems--yet people are paid for the work they do. That the value ecosystems provide to people exceeds the gross world product should, perhaps, not be surprising. Costanza's estimate of the work that ecosystems do is an underestimate of their "infinite value" of "pricelessness"; but that is not what he sought to estimate. Consider the value of one ecosystem service, photosynthesis, and the ecosystem good it produces: atmospheric oxygen. Neither is valued in Costanza's study. Given the choice between breathable air and possessions, informal surveys have shown the choice of oxygen over stuff is unanimous. This indicates that the value of photosynthesis and atmospheric oxygen to people exceeds the value of the gross world product. That is only a single ecosystem service and good.

In terms of more specific concerns, the value transfer methodology introduces an unknown level of error, because with the exception of some studies that were conducted in this area, we usually do not know how well the original study site approximates conditions in the Chehalis River Basin. Other potential sources of error in this type of analysis have been identified (Costanza et al. 1997) as follows:

- Incomplete coverage – that not all ecosystem types and services have been valued or studied well is perhaps the most serious issue, since it results in a significant underestimate of the value of ecosystem services. More complete coverage would almost certainly increase the values shown in this report, since no known valuation studies have reported estimated values of less than zero.
- Distortions in current prices used to estimate ecosystem service values are carried through the analysis. These prices do not reflect environmental externalities and are therefore again likely to be underestimates of "true" values.
- Most estimates are based on current willingness-to-pay or proxies, which are limited by people's perceptions and knowledge base. Improving people's knowledge base about the contributions of ecosystem services to their welfare would almost certainly increase the values which are based on willingness-to-pay, as people would realize that ecosystems provided more services than they had previously known.
- The valuations probably underestimate shifts in the relevant demand curves as the sources of ecosystem services become more limited. If the Chehalis River Basin ecosystem services are scarcer than assumed here, their value has been underestimated

in this study. Such reductions in "supply" appear likely as land conversion and development proceed; climate change may also adversely affect the delta's ecosystems (e.g. through more intense hurricanes), although the precise impacts are more difficult to predict.

- The valuations assume smooth responses to changes in ecosystem quantity with no thresholds or discontinuities. Assuming (as seems likely) that such gaps or jumps in the demand curve would move demand to higher levels than a smooth curve, the presence of thresholds or discontinuities would likely produce higher values for affected services (Limburg et al. 2002).
- As noted above, the method used here assumes spatial homogeneity of services within ecosystems. The spatial modeling component of the project was intended to address this issue and showed that, indeed, the physical quantities of some services vary significantly with spatial patterns of land use and land cover. Whether this fact would increase or decrease valuations is unclear, and depends on the specific spatial patterns and services involved.
- Our analysis uses a static, partial equilibrium framework that ignores interdependencies and dynamics. More elaborate systems dynamics studies of ecosystem services have shown that including interdependencies and dynamics leads to significantly higher values (Boumans et al. 2002), as changes in ecosystem service levels ripple throughout the economy.
- The value estimates are not necessarily based on sustainable use levels. Limiting use to sustainable levels would imply higher values for ecosystem services as the effective supply of such services is reduced.
- The approach does not fully include the "infrastructure" or "existence" value of ecosystems. It is well known that people value the "existence" of certain ecosystems, even if they never plan to use or benefit from them in any direct way. Estimates of existence value are rare; including this service will obviously increase the total values.
- There are great difficulties and imprecision in making inter-country comparisons on a global level. This problem was of limited relevance to the current project, since the majority of value transfer estimates were from the U.S. or other developed countries.
- In the few cases where we needed to convert from stock values to annual flow values, the amortization procedure also creates significant uncertainty, both as to the method chosen and the specific amortization rate used. (In this context, amortization is the converse of discounting.)
- All of these valuation methods use static snapshots of ecosystems with no dynamic interactions. The effect of this omission on valuations is difficult to assess.
- Because the transferred value method is based on average rather than marginal cost, it cannot provide estimates in consumer surplus. However, this means that valuations based on averages are more likely to underestimate total value.

The result would most likely be significantly higher values if these problems and limitations were addressed. Unfortunately, it is impossible to know how much higher the values would be, though one example may be worth mentioning. Boumans et al. (2002) produced a dynamic global simulation model that estimated the value of global ecosystem services in a general equilibrium framework to be roughly twice what Costanza et al estimated, using a static, partial equilibrium analysis. It is impossible to say whether a similar result would be obtained for the Chehalis River Basin, but it does give an indication of the potential range of values.

Appendix E: ARIES (ARtificial Intelligence for Ecosystem Services)

Overview

ARIES (ARtificial Intelligence for Ecosystem Services) is a National Science Foundation funded project. Development was conducted by the University of Vermont, and the ARIES tool was applied regionally by Earth Economics (Western Washington and Puget Sound) and Conservation International (Madagascar). It is presently in a development/proof of concept stage, with full functionality planned to be in place by the end of 2010. Use of the ARIES tool is planned to be free for non-commercial use, with commercial users incurring a charge.

ARIES is a web-based technology intended to assist rapid ecosystem services (ES) assessment and valuation using an artificial intelligence approach. It is being developed in stages, and ultimately will be capable of assessing the spatial distribution and economic valuation of ES. It will determine optimization of PES (payments for environmental services), assess funding mechanisms, assist with conservation planning and forecasting change in ES provision. Utilizing Geographic Information System (GIS) data, ARIES can both produce models or use GIS input. ARIES also produces maps and quantitative data about ecosystem services.

Following is an overview of ARIES provided by Dr. Ferdinando Villa, Dr. Kenneth Bagstad and Dr. Tracy A. Farrell:

Key model reference: Villa, F., et al. 2009. ARIES (ARtificial Intelligence for Ecosystem Services): A new tool for ecosystem services assessment, planning, and valuation. Proceedings of the 11th Annual BIOECON Conference on Economic Instruments to Enhance the Conservation and Sustainable Use of Biodiversity, Venice, Italy, September 2009.

http://www.ucl.ac.uk/bioecon/11th_2009/Villa.pdf

Documentation (model equations) reference: None present. Bagstad, K. Villa, F. and Johnson, G.W. (2010) ARtificial Intelligence for Ecosystem Services (ARIES): A guide to probabilistic modeling and data. Ecoinformatics Collaboratory White Paper, University of Vermont (available as draft).

User guide reference: None present. Bagstad, K. Villa, F. and Johnson, G.W. (2010) ARtificial Intelligence for Ecosystem Services (ARIES): A guide to probabilistic modeling and data. Ecoinformatics Collaboratory White Paper, University of Vermont (available as draft).

Example applications: A series of case studies are described including ongoing work mapping flood protection benefits in Puget Sound, the economic benefits of protected areas in Romania, nutrient regulation functions of urban and suburban land covers, optimization of the design of PES schemes in Madagascar and flow of hydrological services in Mexico. The most developed applications are: Puget Sound, Washington State (focusing on aesthetic and carbon ES) and Madagascar (focusing on conservation and carbon).

Key users: University of Vermont, Conservation International, Earth Economics, United Nations Environment Program.

Number of citations: 4

Scales: The scale of an ARIES session varies from service to service and could occur at local to national scales for assessment of ES and economic valuation of ES, watershed to regional for optimization of PES and local to regional for conservation planning, spatial policy planning and forecasting of change in ES provision.

Poor data availability handling: How reliable and robust are modeling results? No modeling is without uncertainty. ARIES is specifically geared to provide information on how certain and reliable results are across a mapped area. Each analysis carries an uncertainty estimate with it, with data scarcity affecting the reliability of the results but not user's ability to access them. Unlike traditional deterministic models, ARIES tracks uncertainty of results through a probabilistic framework. All models applied are on a site basis, and versions of the models are currently parameterized for Madagascar and Puget Sound, Washington State. There is currently no ability to run models outside of these areas, although the ability to run models using global datasets should be incorporated in the near future.

Groundwater: ARIES does not consider groundwater at this time.

Operating system and software requirements: Web browser based, no local requirements, though data upload if/when implemented would require local GIS capacity to run a simulation outside of Puget Sound and Madagascar.

Technical capacity required for operation: None required for operation of web based tool, but provides access to GIS downloads for data upload and further analysis if GIS capacity is available.

ARIES is more fully described at *http://ecoinformatics.uvm.edu/aries/site/main.html*, and the ARIES white paper at *http://www.ucl.ac.uk/bioecon/11th_2009/Villa.pdf* provides further discussion about how ARIES works and can be used. Additionally, at the end of this appendix there are details describing the step-by-step process to login to the ARIES system and run a simulation.

How ARIES Works

ARIES simulates how ecosystem services are affected by different policy scenarios. This allows the user to understand the impacts of these scenarios on specific ecosystem values of interest. Rather than deterministic (physically based) models, probabilistic, Bayesian algorithms are used with appropriate input datasets and a set of rules or weights describing the user's understanding of the relevant processes. Moreover the user is also able to define the ways in which they value different ES, enabling ARIES to calculate the overall utility of ES against these values. ARIES can be adapted for use at a spatial scale of analysis relevant to the ES of interest. The user will be able to define a polygon or use an online gazetteer to select their region of interest. Data is automatically pulled from GIS databases and ARIES is then able to run an analysis, with the system returning a set of results.

ARIES currently provides a series of beta-level functions including CO_2 mitigation, initial flood protection, coastal protection, fisheries, aesthetics and economic valuation. The functions have limited coverage, including the Chehalis River Basin and Puget Sound in Washington State, and Madagascar as case studies. Further regional and global functionality is planned.

Currently ARIES has a working model for CO_2 mitigation, which returns a series of maps for carbon storage, sequestration and other values in Western Washington State and Madagascar. An aesthetics module computes source, use, sink and flow models for the aesthetic ecosystem service (views and proximity). Source, sink, and use values are available for flood regulation/mitigation but a spatial flow model to enable comparisons of scenarios is currently being developed. The system is in active development.

The main water related models of ARIES are the flood regulation model which focuses on the capacity of different land cover types to deliver reduction in flows (through infiltration and evapotranspiration), the coastal flooding model (focusing on coastal protection services against wind and waves) and the erosion and sedimentation module.

ARIES can rely on either prebuilt, peer-reviewed models or probabilistic models assembled by ARIES as appropriate for the ecosystem services and part of the world being mapped. A user workflow will eventually consist of seven phases:

1. The user enters information on the goals and policy objectives as well as the characteristics of the study area.

2. The system queries internal databases to develop an ES assets portfolio.

3. The user interactively refines this portfolio.

4. Economic valuation takes place, returning maps and summary statistics for economic value.

5. Different weights and priorities are defined.

6. Users perform scenario analysis.

7. Reports are produced including download of GIS maps.

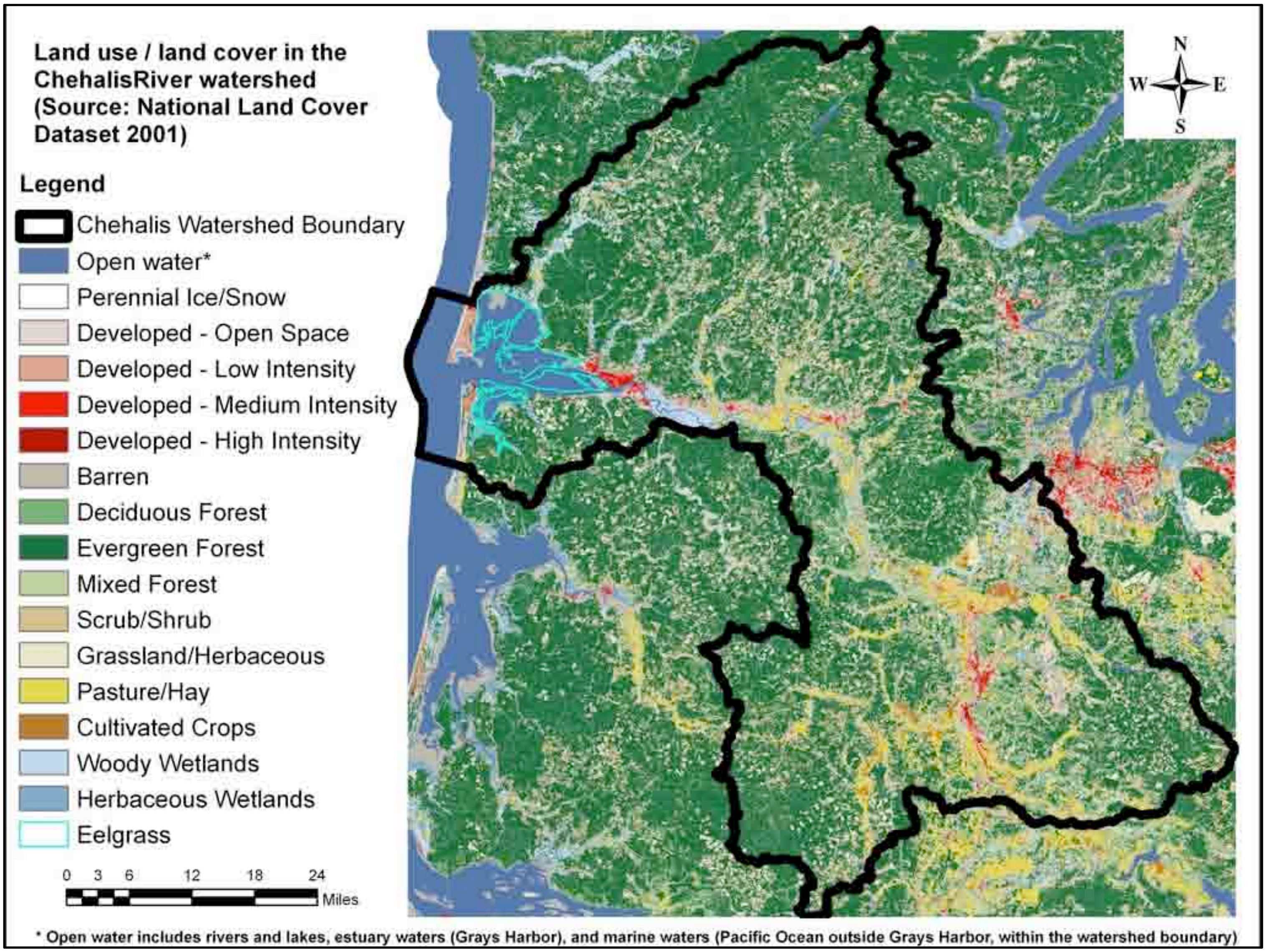
The model interface is available upon request. It is under development and often off-line as new components are added or tested weekly.

ARIES Mapping Results in the Chehalis Basin.

The next section discusses initial ARIES mapping and results for the Chehalis River Basin, excluding a complete hydrological model, but utilizing geographic information systems data specific to the

Chehalis River Basin. Much of this section is included in a condensed form in the section of this report titled **Modeling Flood Protection**. Mapping and understanding the beneficiaries, impairments and provisioning of flood events also sets in place the basis for a funding mechanism that can be developed for the Flood Authority.

Figure 1a. Land Use and Land Cover in the Chehalis River Basin



This is an initial analysis, and requires review and inputs from stakeholders, local governments, agencies, the State, and most significantly the Chehalis River Basin Flood Authority. The topography, vegetation, soils, hydrology, flood creating rain events, impermeable surfaces, levees, dams, locations of farms, residents, businesses, and public infrastructure are all important factors in flooding, safety, and flood protection.

The most important factors for the provisioning of ecosystem services is the vegetation cover, or land use type. The map in Figure 1a is a starting point, and shows the land cover/land use types in the Chehalis River Basin.

This map provides spatially specific data on the land cover type throughout the watershed. This spatial data, in the form of data pixels, is utilized within ARIES for modeling, as are many other GIS data. The information and the spatial specificity of each pixel is converted into a probability and retained. ARIES received the National Science Foundation Grant because of its capacity to combine vital GIS data with complex modeling, and account for uncertainty. This is very important for decision-makers who would like to understand the outcomes of different scenarios, and the reliability of these results (referred to as a "credible interval" in Bayesian statistics).

ARIES is built on basic science and our understanding of how natural systems work. The better the data on, and modeling of hydrology, topography, soils, and other determining factors are, the better ARIES can perform. Ecosystem services, such as flood protection are concerned with the way natural systems affect people. With this in mind, ARIES produces four types of meta-models, based on GIS and sub-models, such as hydrological models. The meta-models are: 1) Beneficiary models; 2) Provisioning (solution, flood protection provisioning) models; 3) Problem (sink or flood) models and 4) Critical vector models of how and from where benefits and damages are transferred from one area of the landscape to people (not yet fully developed).

In the case of the Chehalis River Basin and flood protection, the basic GIS data was first gathered. This data is referenced in Appendix F. Then, using mathematical procedures, the data was brought into compatibility (because rainfall data, slope, vegetation cover and other data are often assembled on different scales with different units across different intervals). Next, conceptual models for each of the beneficiary, provisioning and sink systems were constructed. Diagrams of the basic relationships and model frameworks are presented in this report. The Bayesian models that generated the outputs in this report are complex mathematical models, and are available upon request. Upon completion, ARIES will have available on the website all the data (currently available) and all of the mathematics (currently available upon request) for deriving all results. As ARIES is envisioned, all data, models and applications will be publically available on the web (they are currently available by request) providing full transparency.

These models are currently based on many assumptions. To fully develop them would require close collaboration with the Flood Authority and with the Army Corps of Engineers, utilizing the best available data, LIDAR and hydrological models. The ARIES maps produced for the Chehalis River Basin are real results using real data from, and models specifically constructed for, the Chehalis River Basin to examine flood protection. The beneficiary maps are more accurate than the final flood protection maps because the hydrology is not fully included (or understood), and these models require further refining. The provisioning maps in particular should be seen as a very preliminary and an incomplete rendition of what could be produced with further work.

Beneficiary Group Mapping and Modeling

The beneficiaries of flood protection are the people who reside, work, own or otherwise gain from reductions in flood damage and hazards.

In the case of floods, beneficiary models are not complicated (as opposed to salmon or recreation). The floodplain and inundated areas can mark out the physical boundary of flooding. However, people outside the watershed also benefit from flood protection. The following two maps are illustrative of local beneficiaries of flood protection. The full set of beneficiary maps not produced here (due to scope and budget limitations) would map the beneficiaries of flood protection in all the affected counties, along with people living outside the Chehalis River Basin, such as those who benefit from the I-5 corridor, rail lines, and recreational areas. These beneficiaries would be mapped from Vancouver, BC to Los Angeles, and based on the traffic and value of transported goods, could be graded according to the size of economic benefits they receive.

Three basic beneficiary groups were identified in the Chehalis River Basin: residential owners, private owners (not including residential owners) and public owners, such as public schools, utilities and governments. Figure 2a shows the basic modeling relationship structures for three sets of beneficiaries. These results could be strengthened further if the location of each house, building and asset were specifically identified within the property where it occurs. The GIS data for the Chehalis Basin does not show the exact locations of structures within property boundaries. Because properties have different elevations, knowing where assets are on the property provides even more specific data than shown in these GIS examples and would eventually enable scenario planning that could provide detail including partially flooded properties. This would enable more accurate consideration of actions and scenarios that would modify/move buildings and other assets within property boundaries to avoid flood damage.

Figure 2a. Modeling Relationship Structures for Beneficiaries

Draft Beneficiaries Flood Model Framework of ARIES

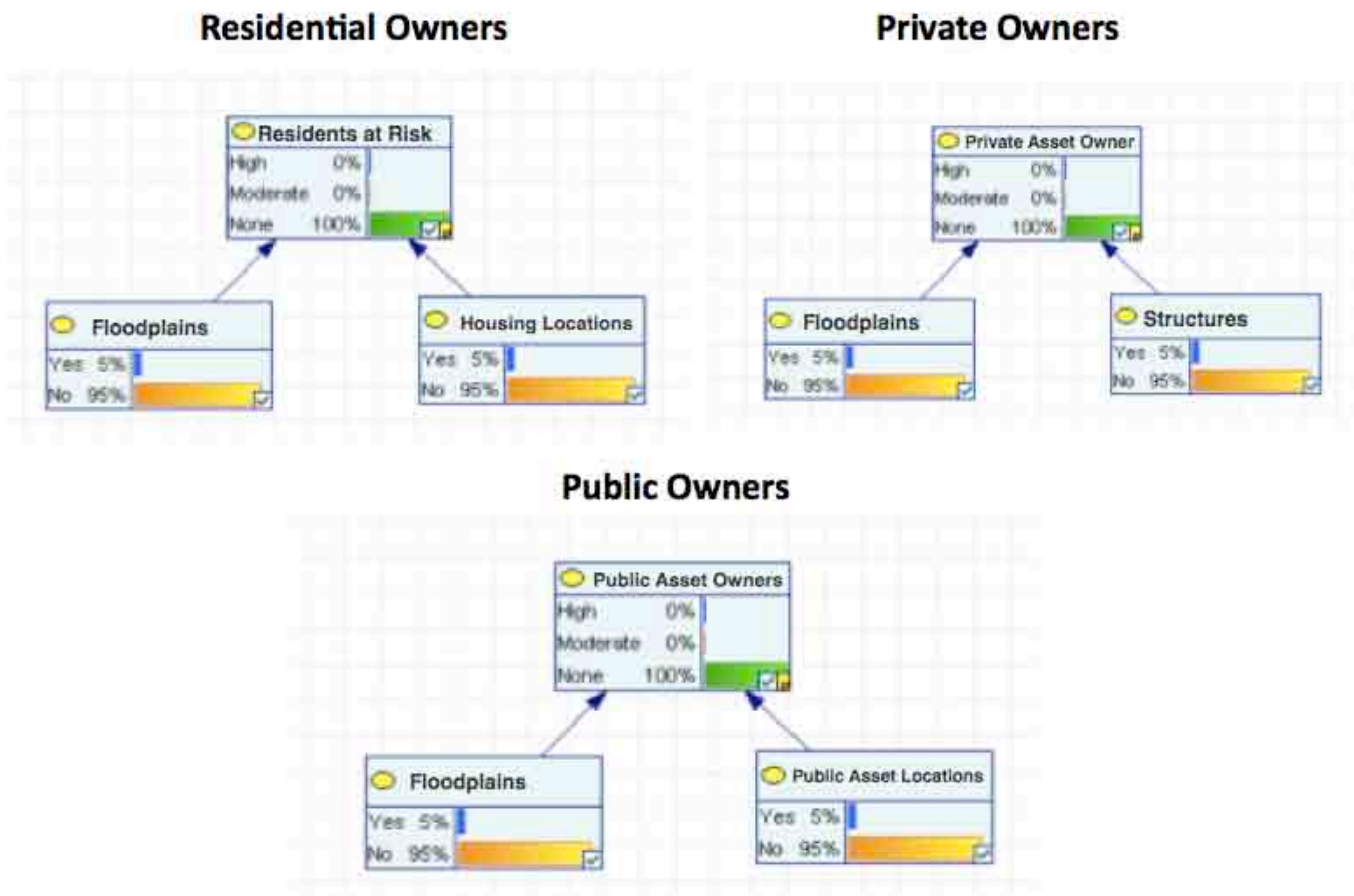


Figure 3a. Grays Harbor Residents at Risk

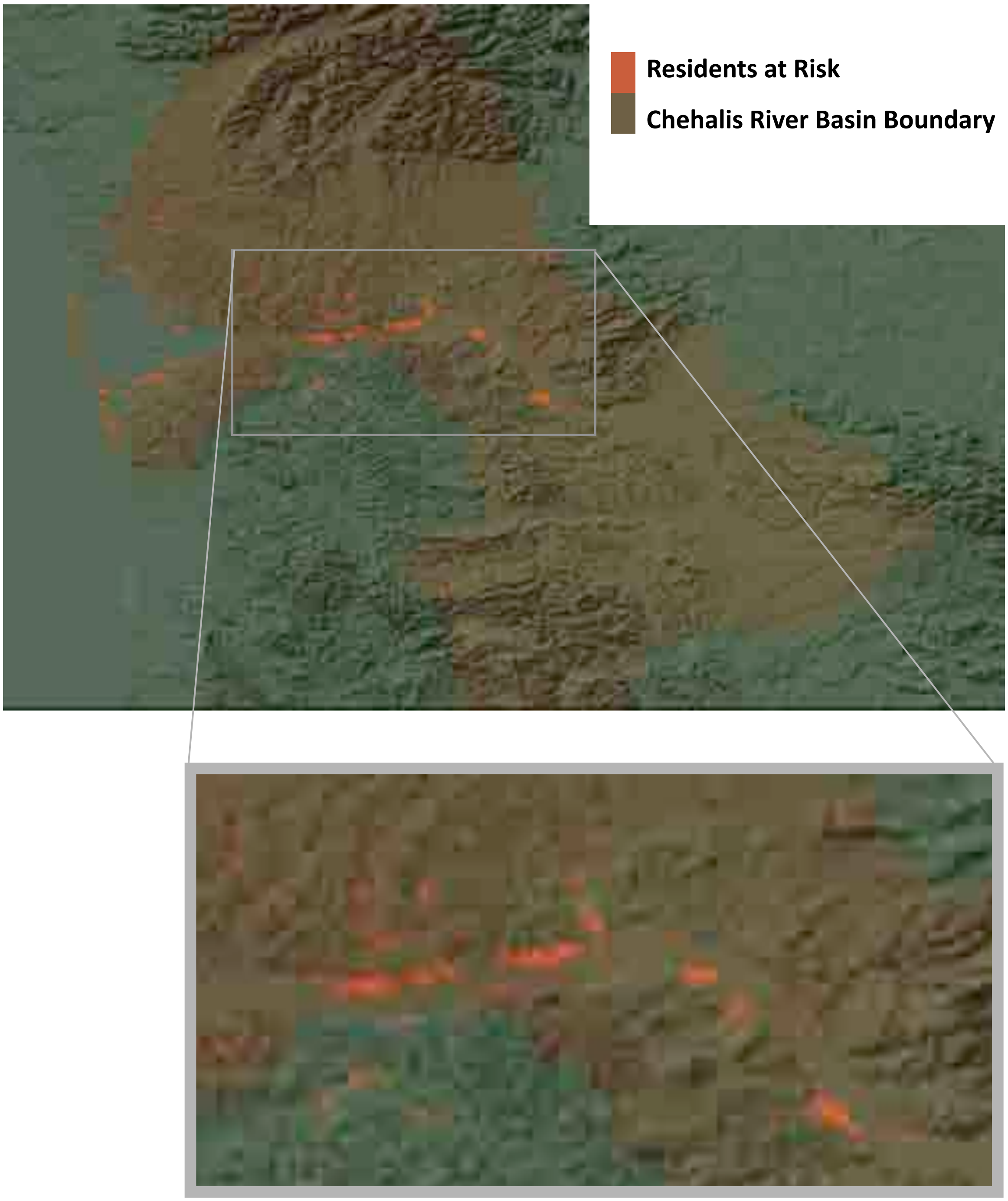
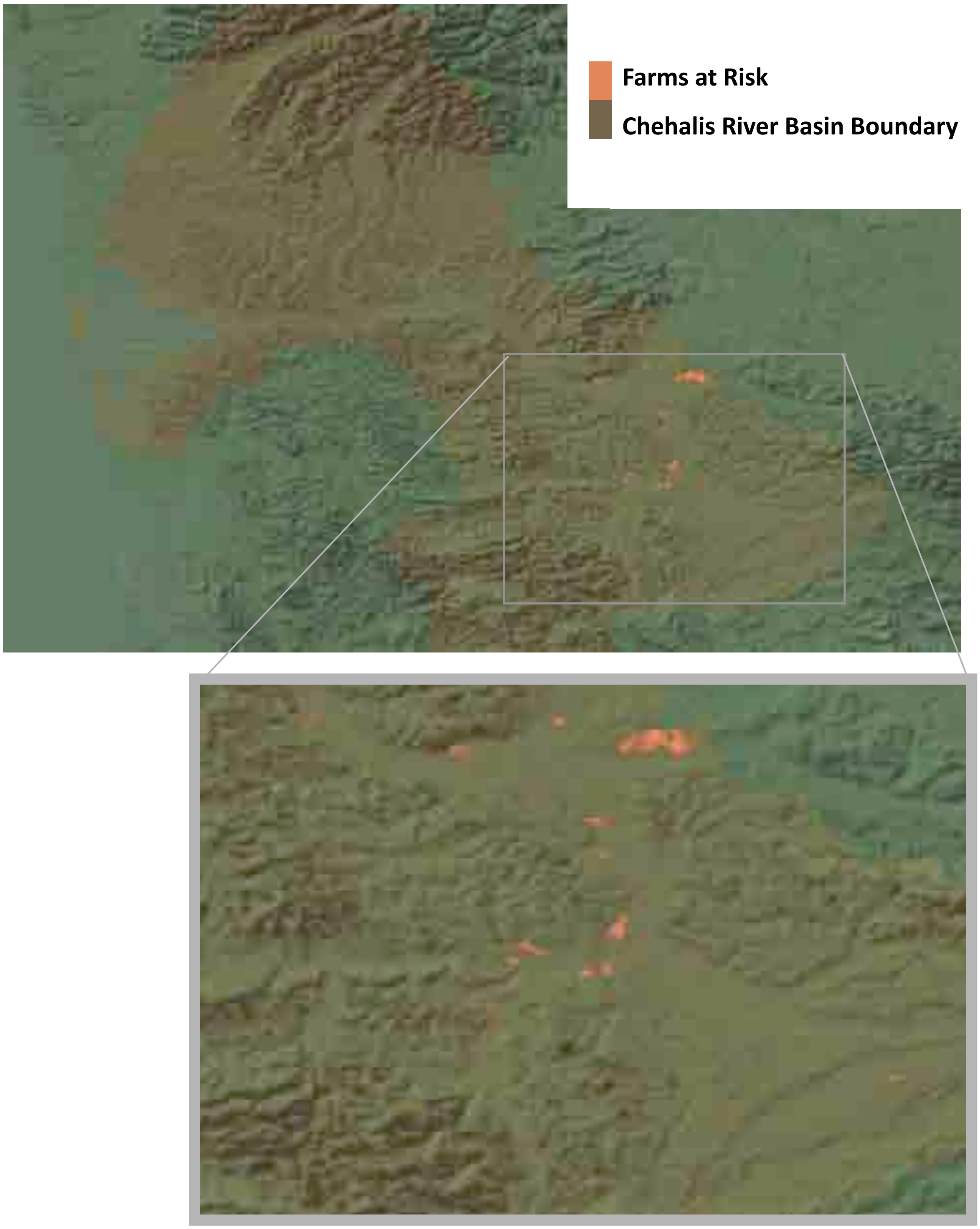


Figure 4a. Farms at Risk



Farms, residents and businesses at risk depend on where and how much rainfall takes place, thus the actual farms or residents harmed by flooding vary in every flood or flood scenario. All GIS data used in this ARIES analysis are listed and referenced in Appendix F.

The above maps show Grays Harbor residents and farms that are at risk of flooding. These maps are scaled out; it is possible to zoom into a specific area with the web-based tool and see individual properties. Changes in conditions change these maps, for example, residents on the western end of Grays Harbor will not be flooded during a low tide when floodwaters drain well. How many residents will be at risk of flooding during a high tide depends greatly on the timing and elevation of the high tide with peak floodwaters as they reach the mouth of the Chehalis River as high tide causes backing up into tributary areas. Figure 3a shows a map of the residents at risk of flooding in Grays Harbor. Figure 4a shows a map of the farms at risk of flooding in Lewis County.

The beneficiary model and mapping is detailed. Were information on house locations known, ARIES could identify houses, which could be elevated by moving them to different areas of the property.

Flood Source and Protection Modeling Structures, Data and Mapping

Once the beneficiary maps were developed, draft flood model structures were created. These are not complete at this point; they are simple conceptual models of how flooding is created in the Chehalis River Basin. These were used to generate mathematical Bayesian models, which derived flood source and flood protection models and output maps using Chehalis GIS data. ARIES will have the capacity to "bolt" hydrological models developed by the US Army Corps of Engineers or others into ARIES models. In addition, GIS data formatted for different rainfall scenarios can currently be read and used by ARIES and will provide the basis for scenario planning. This work needs further scientific data, likely garnered in the Chehalis Basin general investigation.

This basic modeling is still in a testing phase. However, ARIES reads current, accurate GIS data from the Chehalis River Basin such as land use type, forest successional stages, average rainfall, and the position of levee structures in Lewis County (other data on existing levees in Thurston and Grays Harbor Counties and illegal levees have not yet been obtained and included). Each of the identified factors has a different degree of importance depending on its relation with other factors. For example, successional stages of forests are generally important to flood protection, and even more important on steeper slopes. Areas with large trees and thick foliage tend to break up rainfall, slow peak flows and increase ground infiltration. Areas with no trees or very young trees tend have greater surface runoff (in both speed and quantity), and contribute disproportionately to higher peak flows, potential landslides, and erosion.

The flood model framework includes modeling factors contributing to flooding including rainfall, temperature, snow pack, run-off, ground water levels, soil saturation and other data to form a very simple hydrological model.

The flood source structure shows the causes of flooding. To provide the data for modelling, many data layers are automatically extracted from the ARIES GIS database constructed from actual Chehalis Basin GIS maps (see Appendix F). Among these factors are precipitation, snow, slope, soils, vegetation cover, forest successional stage and more. Rainfall is a crucial input; currently the modeling uses only monthly averages, but it has the capacity to include high rainfall events and take into account the distribution of this rain across the landscape to create different levels of flooding. Flood rainfall data by inches, temperature and location can be entered at present. Figure 5a is the modeling framework for the sources of flooding.

Spatially specific data and maps used to model floods are shown below including an image of monthly rainfall as measured across the Chehalis River Basin. Built capital, such as levees, bridges and dams can also be mapped, and their hydrological properties included. Existing levees in Lewis County have been mapped and included in ARIES.

Finally, with input data spatially specific to the Chehalis Basin, and modeling of how floodwaters move across the landscape flood source maps can be produced. The Floodwater source map is shown below in Figure 6a.

This map shows the areas most likely to produce floodwaters under average rainfall patterns. Any rainfall pattern created in a GIS format for the Chehalis River Basin can entered into ARIES for testing.

All flood protection modeling entails uncertainty. What level of confidence is there in the results of modeling? Most models fall short of describing uncertainty inherent in their results. ARIES estimates the levels of uncertainty in data, modeling and results. How well will a levee perform with different levels of rainfall in different places? If rainfall is low and distributed in one way, there may be a great deal of certainty that a levee will provide flood protection. However, if rainfall is concentrated in a particular subwatershed, the certainty of levee performance may be low. The same is true of natural capital. As soil becomes increasingly saturated on steep slopes, slope stability becomes less certain.

Decisions about flood protection projects and actions should be informed by uncertainty analysis. ARIES results are accompanied by estimates of uncertainty and these estimates can be shown in a GIS map form. Figure 7a provides an uncertainty map of the floodwater source data.

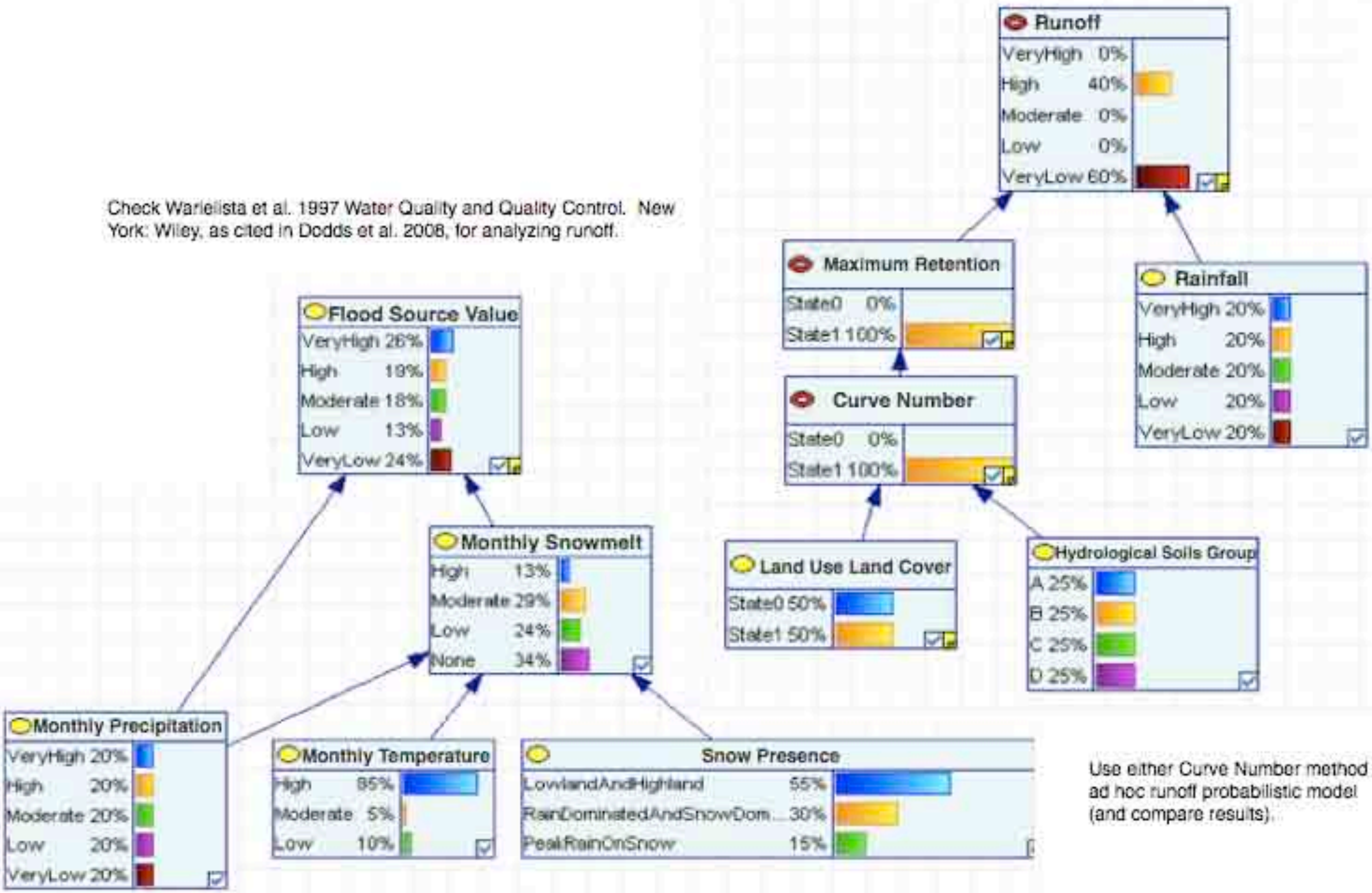
Input GIS data and maps for the rudimentary hydrological functions and flood source models are included in the following figures and can be viewed on the ARIES website.

Figure 5a. Flood Source Model Structure

Draft Flood Source Model Framework of ARIES

http://www.ecn.purdue.edu/runoff/documentation/scs.htm

Check Warielista et al. 1997 Water Quality and Quality Control. New York: Wiley, as cited in Dodds et al. 2008, for analyzing runoff.



Use either Curve Number method or ad hoc runoff probabilistic model (and compare results).

Figure 6a. Floodwater Source

This map is derived by a combination of snowmelt and precipitation data.

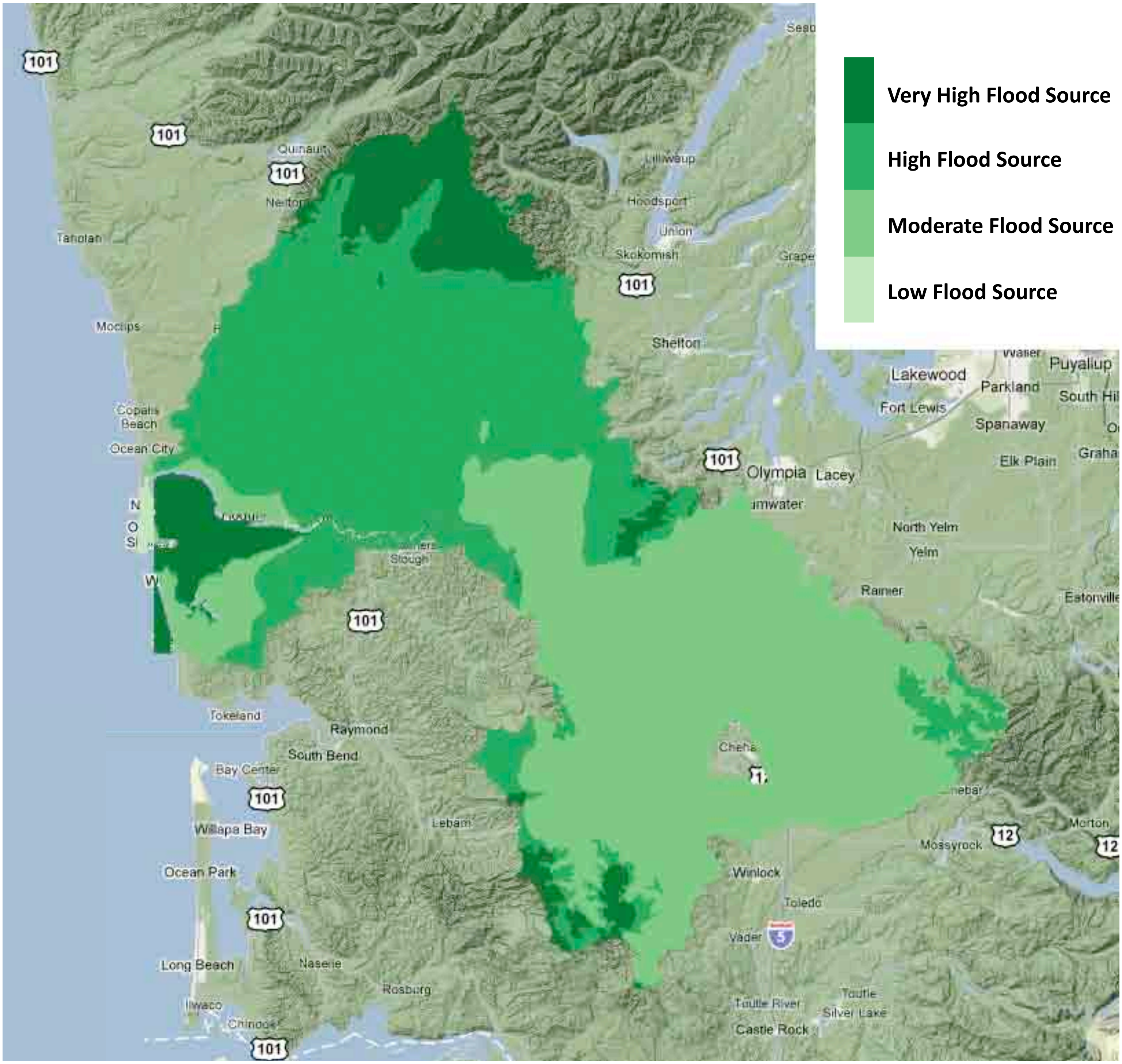
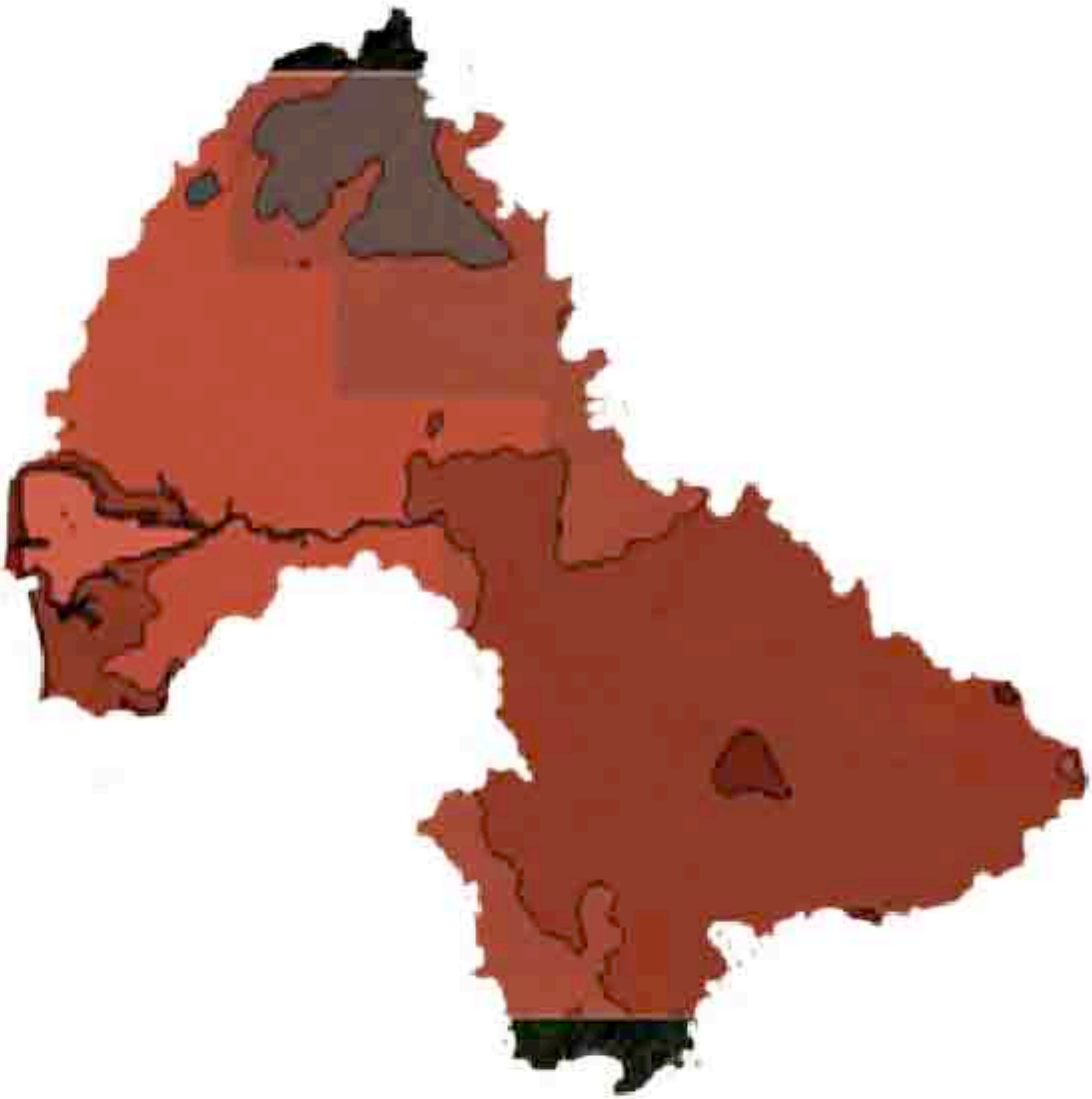


Figure 7a. Flood Source Map with Superimposed Uncertainty Map

Redder areas contain the least reliable predictions.



The distribution of average monthly precipitation is shown in Figure 8a. With rain gage information and the construction of rainfall scenarios, such as the 2007 and 2009 flood related rains, other scenarios could be mapped on the landscape to show the highest contributing areas to flooding under those conditions.

Depending on the location of heavy rainfall, the flood protection value of both natural and built flood protection infrastructure can shift dramatically. In addition, warm heavy rain on snow will cause high elevations to become larger sources of floodwaters. All land and snow pack above the snowline provides flood protection. If heavy precipitation occurs with low temperatures, greater areas of high elevation would provide flood protection as snow pack. If a warm heavy rainfall arrives, raising the snow line, snow pack below the freezing elevation will flip to become a source area of floodwaters.

Understanding the hydrology, environment and land use of how floods are created is critical for testing different options of provisioning flood protection.

The provisioning of flood protection is also a critical set of models for generating scenarios and helping inform decisions on where to invest in flood protection projects. Mapping the contributing assets to flood protection includes both built and natural capital flood protection assets.

The provisioning of flood protection includes built capital, natural and social capital. Built capital infrastructure, such as dams and levees are included in flood protection modeling. Natural infrastructure, such as forests, wetlands, soils, impermeable surfaces, and groundwater recharge/ flows are also included in flood protection modeling. Social actions, such as raising structures or early warning systems have not yet been included in ARIES modeling. From this built and natural flood protection framework a model is constructed and protection values calculated across the landscape. The modeling framework is shown in Figure 9a.

Figure 8a. Monthly Precipitation

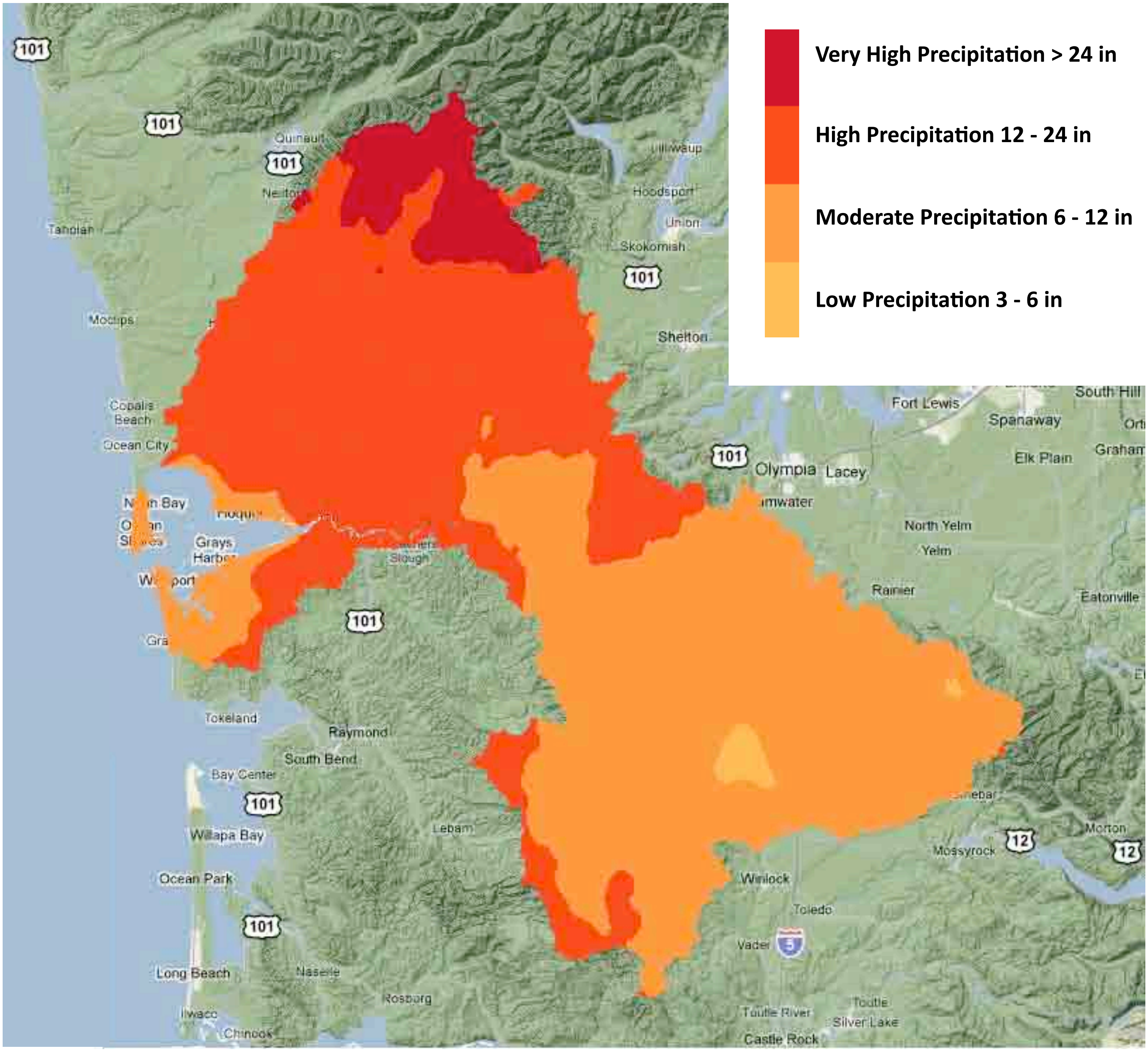
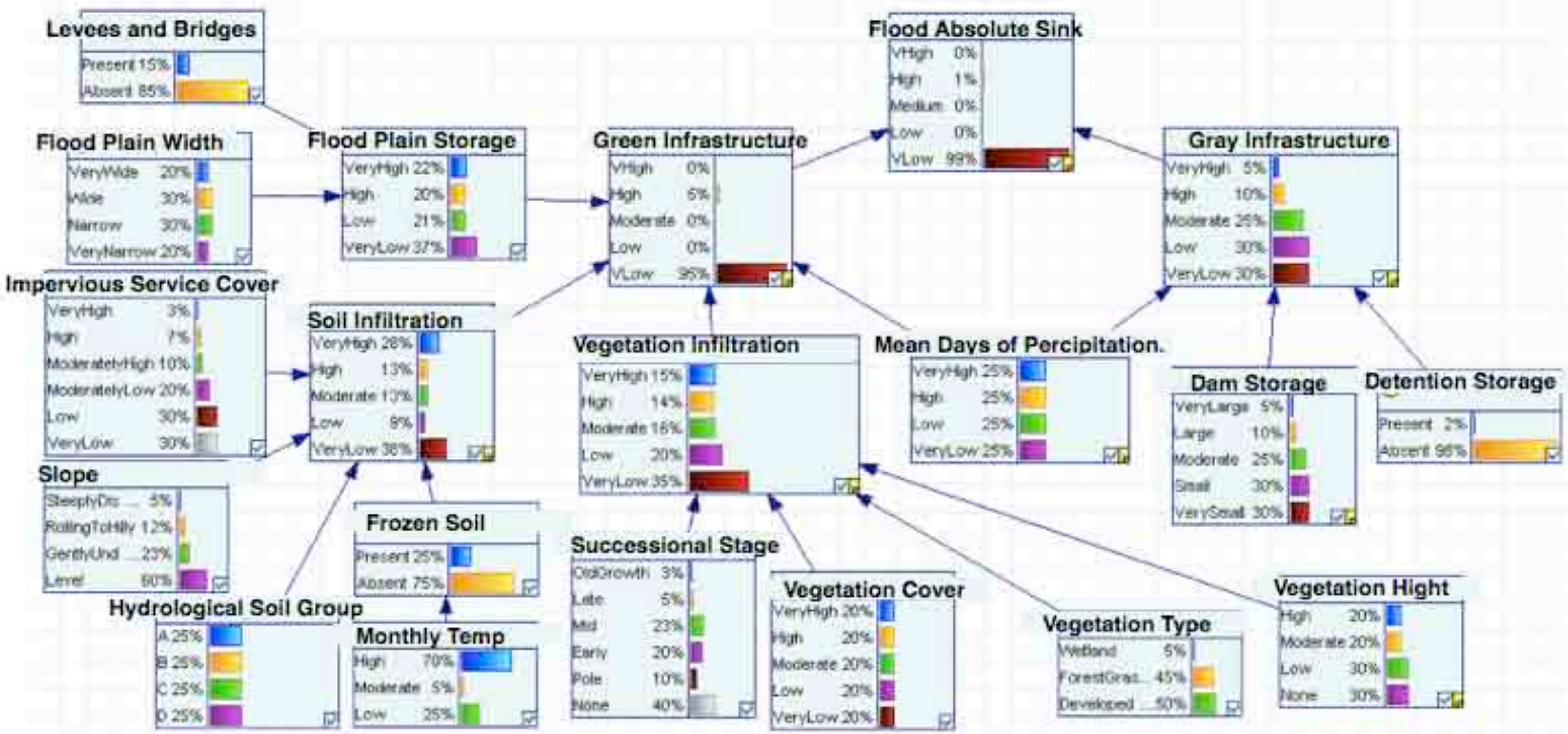


Figure 9a. Flood Protection Structure

Draft Flood Protection Model Framework of ARIES



As GIS data is entered, a simplified hydrological model is applied. With modeling based on the above framework, flood protection values for natural and built capital can then be derived. One output provided is an illustrative map of flood protection green infrastructure from natural capital in the Chehalis Basin shown in Figure 10a.

GIS information entered into the flood protection modeling includes slope. In the Chehalis Basin, slope, soil types, saturation, rainfall and vegetation cover combine to determine whether steeply sloped areas will break up and attenuate peak flows, result in land slides or behaviors under flood conditions. Figure 11a shows slope in the Chehalis River Basin.

Another important factor is successional stages. Here successional stages refer to the diameter of timber. Larger, older timber tends to break up rainfall and developed root structures and humus both absorb and conduct water into groundwater. Larger trees do this more effectively than lands which have been recently cut and planted with small trees where there is little root structure and simplified soils. Figure 12a shows the forest successional stages in the Chehalis River Basin.

With further development in 2010, ARIES is expected to better calculate the distribution of floodwaters and flood protection capacity across the Chehalis Basin. With calibration of the basic modeling, flood scenarios with different rainfall patterns, temperatures and other variables can be conducted. At the same time scenarios of different flood protection actions can be run.

Figure 10a. Green Infrastructure Map

Absorption, infiltration, and/or detention of floodwater provided by green infrastructure.

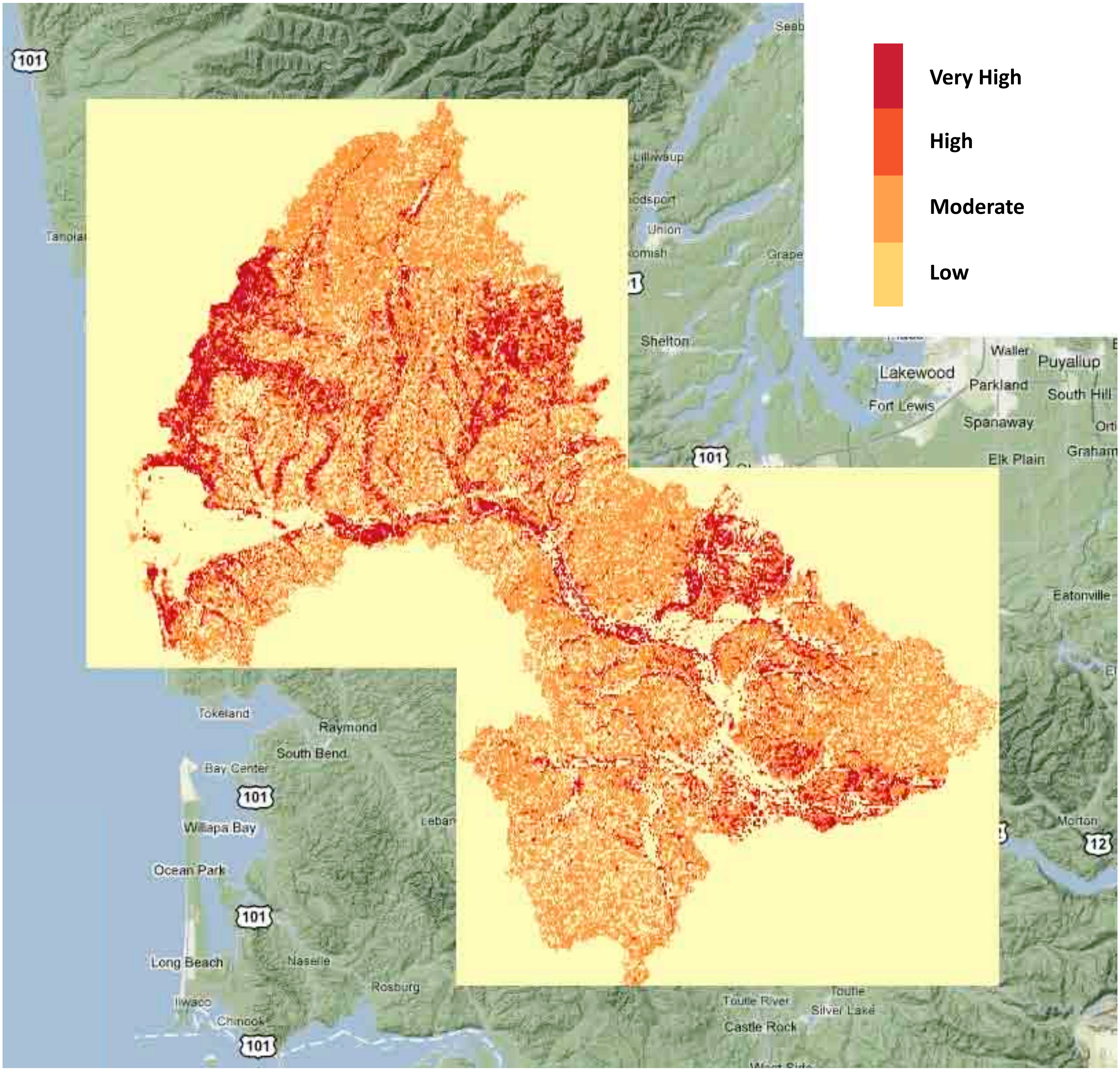


Figure 11a. Slope Map

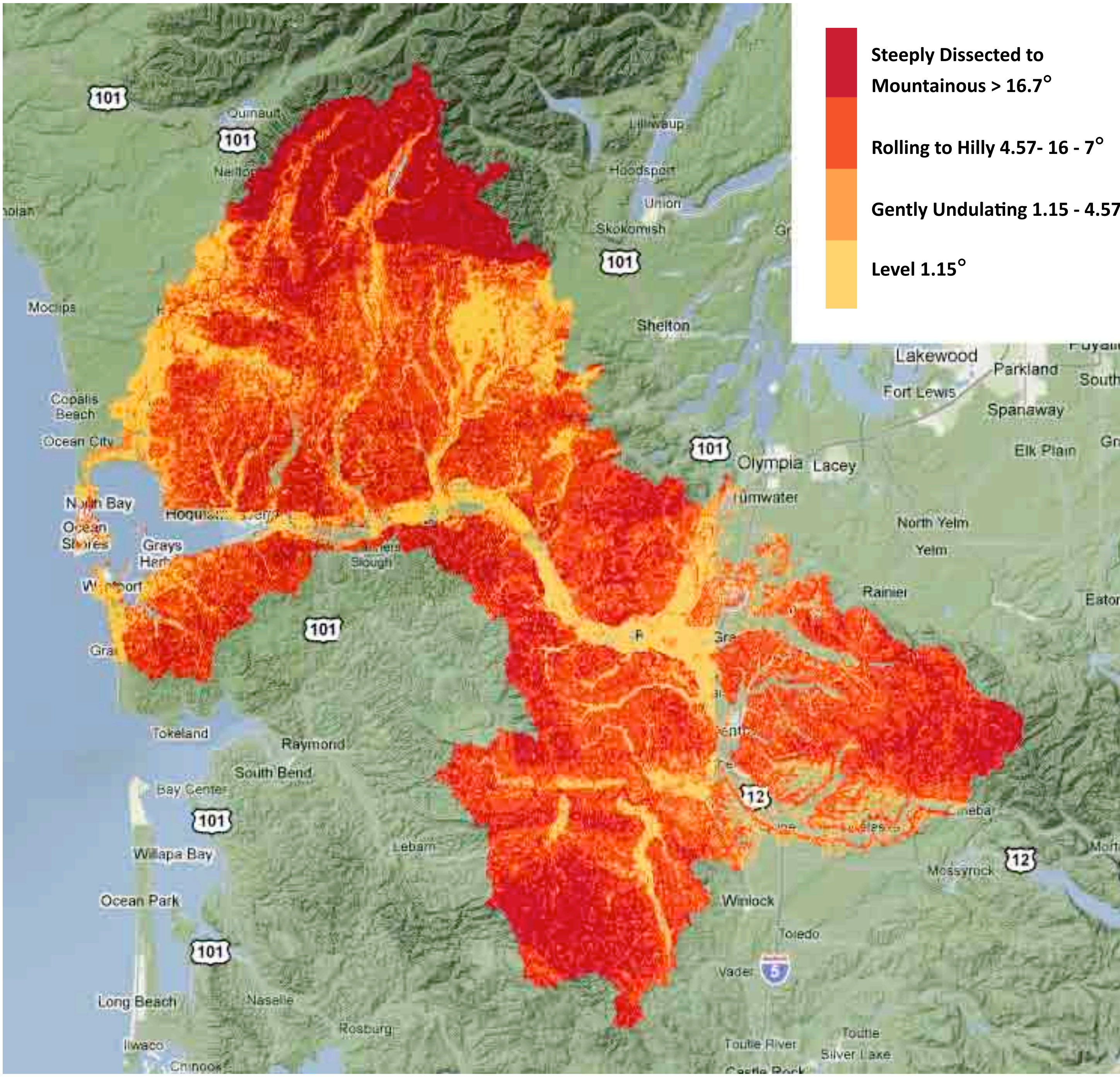
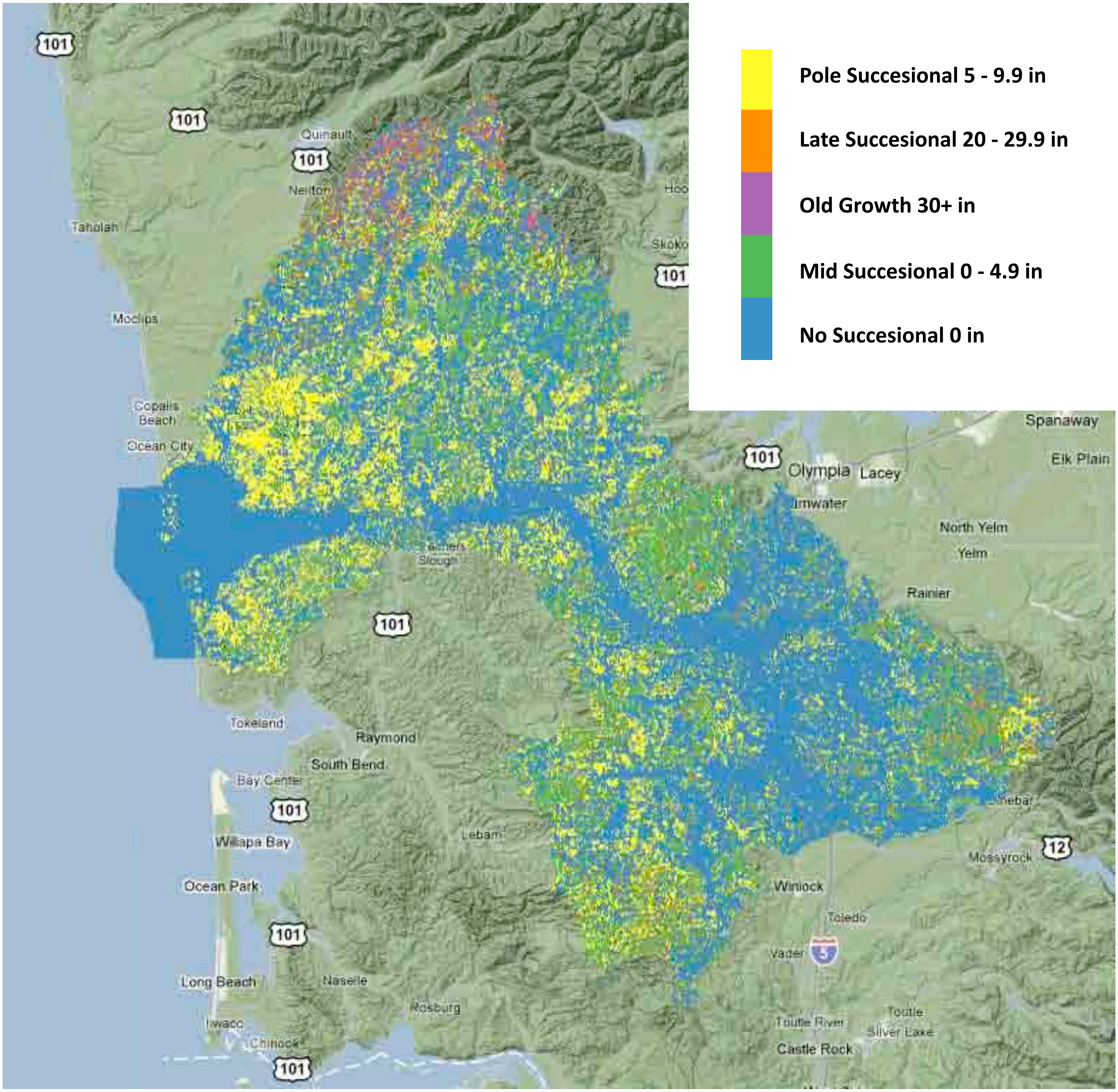


Figure 12a. Forest Successional Stages



Additional Modeling Scenarios

Understanding the goals for salmon restoration, drinking and irrigation water, and carbon sequestration can increase co-funding for flood protection and enhance these ecosystem services. For example, levee setbacks benefit salmon and widen the floodway providing greater floodwater conveyance. Longer forest rotations can increase the vertical and subsurface structure of forests, promoting greater slope stability, transpiration and groundwater infiltration. These functions help attenuate peak flows. Longer forest rotations also increase carbon sequestration in timber and soils, contributing to climate stability.

Legislation to create a carbon trading system in the United States was proposed in 2010. This would create an income stream for rural carbon sequestering areas, such as the Chehalis Basin, and would be a potential income source from outside the watershed. A carbon trading market mechanism could bring significant income into the Chehalis Watershed for activities such as flood protection. The following map is an initial analysis of the carbon sequestration potential in the Chehalis River Basin.

Figure 13a shows carbon sequestration in forests and soils in the Chehalis Basin. Darker green shows greater carbon storage. Data is presented in tons of carbon stored. Much of the timber is relatively young and is increasing in value as timber, carbon sequestration and flood protection.

Map 14a shows the release of carbon in the Chehalis Basin. The Chehalis Basin has a positive net sequestration of carbon. This implies that a carbon trading or offset mechanism would bring funding into the Basin. This could complement a flood district funding mechanism as a longer timber rotation would provide greater flood protection value from natural capital, and it would bring carbon credits and income into the Basin. Depending on the structure of the carbon scheme, either governments or landowners could receive carbon sequestration payments.

Figure 13a. Carbon Sequestered and Stored by Vegetation

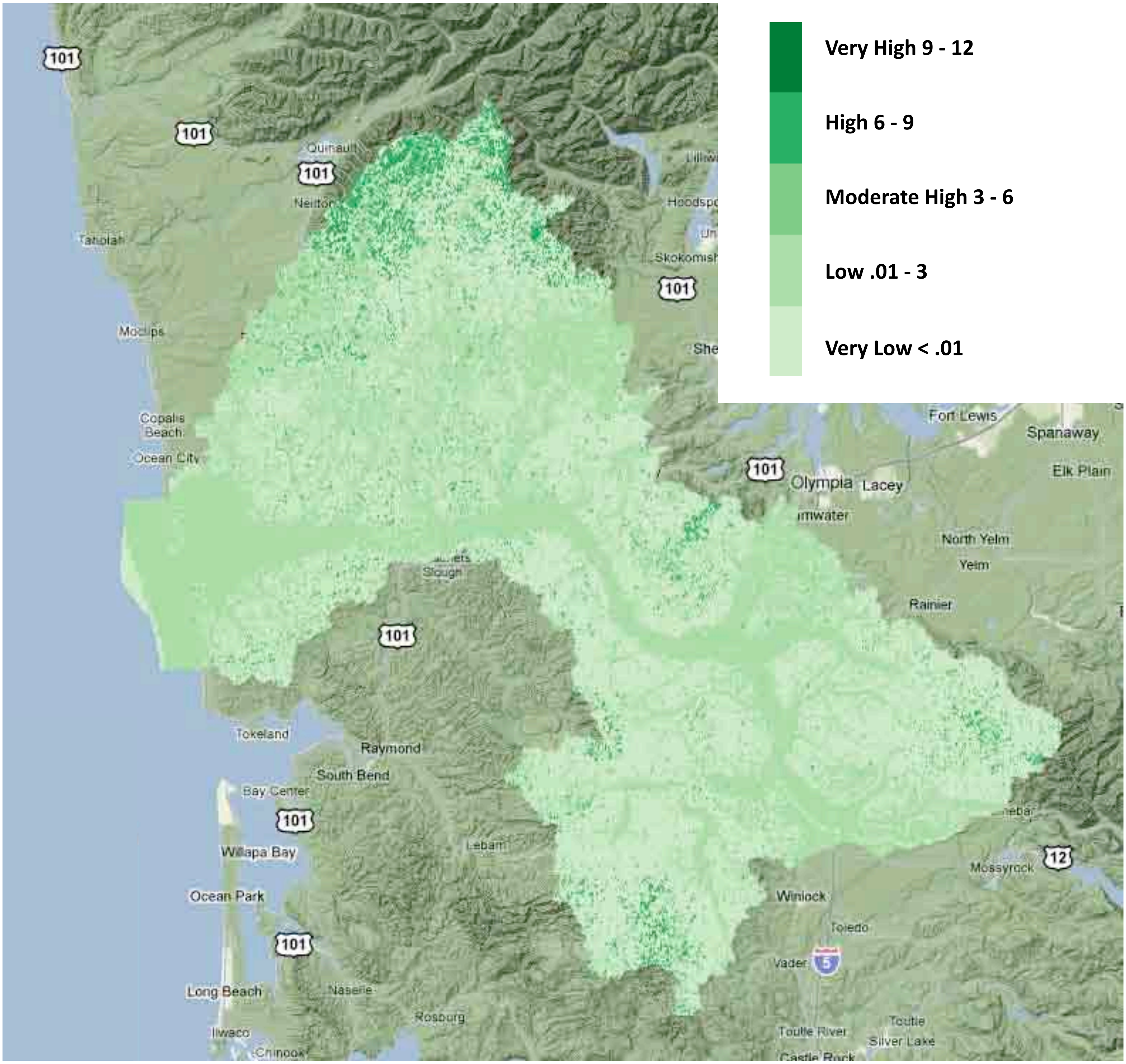
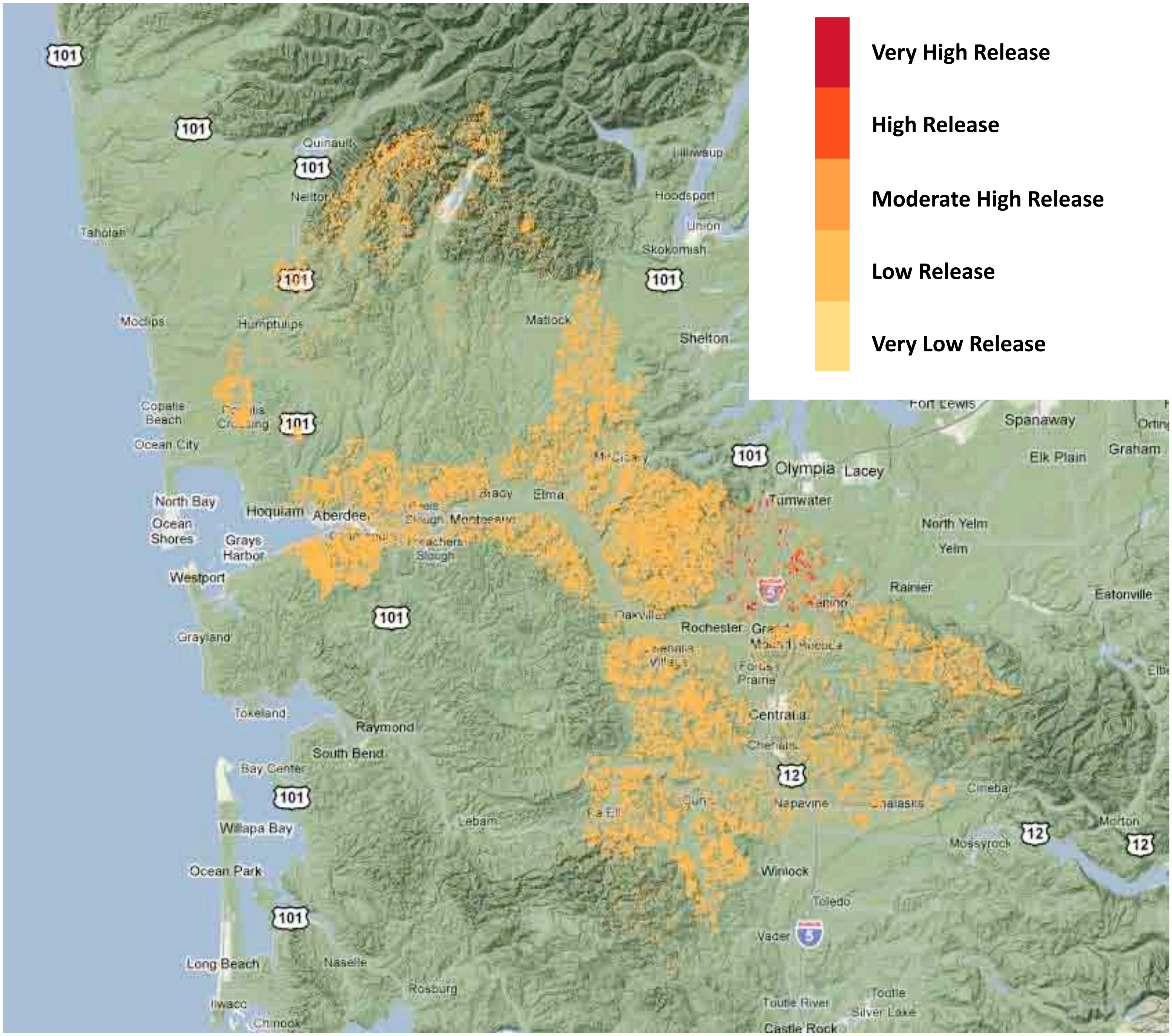


Figure 14a. Release of Carbon Stored in Chehalis



For more information and references to technical papers as well as limitations please see the ARIES website. The ARIES tool is available online for Chehalis analysis today.

Instructions to run the ARIES Online Toolkit for Chehalis:

1. Go to http://ecoinformatics.uvm.edu/aries and click on "Start Application".
2. Type "chehalis" (lower case c in chehalis) in the box and press return; when the arrow on top right turns green, click it.
3. Expand "Flood Mitigation" and click the green button.
4. Expand "CO_2 mitigation" and click the green button.
5. Expand "Aesthetics" and click the green button.
6. Wait for the tab titles to turn yellow (it will take awhile but you can view data as they become available).
7. Click on the checkboxes to see data. You can see each map as contours by clicking the rainbow button, and go back to rasters clicking the button on its left.
8. You can export to images, GIS files, or open all data in Google Earth with the buttons to the left of the colormap. Colors may require adjustment (e.g. the flood sink is still yellow instead of green) but in those cases, you can use the contour display or GIS outputs: for example, contours on the flood sink are more readable than rasters.
9. You can experiment with uncertainties, which are superimposed as a pink "mask" by clicking on the triangular "warning sign" icon. Clicking it again causes them to disappear. For example look at the Stored Carbon Release in CO_2 mitigation, with uncertainty ON.
10. Flow data (in Aesthetics only) are shown as contours by default, and several kinds of diagrams (actual, possible, blocked flows) are available using buttons at the left end of the top right button row.
11. The valuation maps are the result of applying the valuation toolkit using spatial context with automatic mapping of land cover type.

Appendix F: References for GIS Data Sources for ARIES Chehalis Basin Modeling

Booth, D.B. and C.R. Jackson. 1997. Urbanization of aquatic systems: Degradation thresholds, stormwater detection, and the limits of mitigation. Journal of the American Water Resources Assocation 33 (5): 1077-1090.

Boyd, J and L. Wainger. 2003. Measuring ecosystem service benefits: The use of landscape analysis to evaluate environmental trades and compensation. Discussion Paper 02-63, Resources for the Future: Washington, DC.

Chan, K.M.A., M.R. Shaw, D.R. Cameron, E.C. Underwood, and G.C. Daily. 2006. Conservation planning for ecosystem services. PLOS Biology 4 (11): 2138-2152.

de Groot, R.S., Wilson, M.A., and Boumans, R.M.J. 2002. A typology for the classification, description, and valuation of ecosystem functions, goods, and services. Ecological Economics 41: 393-408.

Eade, J.D.O. and D. Moran. 1996. Spatial economic valuation: Benefits transfer using geographical information systems. Journal of Environmental Management 48: 97-110.

Lehner, B., K. Verdin, and A. Jarvis. 2008. HydroSHEDS Technical Documentation, Version 1.1. Accessed March 3, 2010 from: http://hydrosheds.cr.usgs.gov/references.php.

Millennium Ecosystem Assessment (MA). 2005. Millennium Ecosystem Assessment: Living beyond our means - Natural assets and human well-being. Washington, D.C.: World Resources Institute.

Opperman, J.J., G.E. Galloway, J. Fargione, J.F. Mount, B.D. Richter, and S. Secchi. 2009. Sustainable floodplains through large-scale reconnection to rivers. Science 326: 1487-1488.

Soil Conservation Service (SCS). 1972. National Engineering Handbook, Section 4, Hydrology, SCS.

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