APPENDIX H.
IMPACTS OF FLOODING ON THE KING COUNTY ECONOMY: A REVIEW OF PROMINENT LITERATURE SUMMARY REPORT

EXECUTIVE SUMMARY

A literature review was conducted to identify prominent studies that provide an understanding of how flooding and flood risk reduction measures can affect the economy of King County, Washington. Key findings of the studies collected through this review are summarized and compiled by topic below.

Avoided Cost Estimates

Avoided cost is a measure of the benefit provided by a project, program or policy that reduces or eliminates costs that would otherwise be expected. In the case of flood risk reduction activities, avoided cost commonly is estimated based on the cost of damage that would result from flooding if the activities were not implemented. Numerous studies were identified that present flood damage costs. Some present actual damage from previous floods; others estimate future costs of flood damage to people, structures or the economy based on computer modeling or other analysis techniques.

Previous King County Flood Damage History

Two studies identified through the literature review presented estimates of damage from past floods, as summarized in Table ES-1.

TABLE ES-1.
ESTIMATES OF DAMAGE FROM PREVIOUS FLOOD EVENTS

Flood	Damage to Public Facilities Only, from 2006 King County Flood Hazard Management Plan	Damage to Public and Private Property, from 2009 Regional Hazard Mitigation Plan
January 1990	$5.2 million	$17.8 million
November 1990	$3.7 million	$57 million
December 1990	$0.5 million	$5.1 million
November 1995	$3.0 million	$45.9 million
February 1996	$4.3 million	$113 million
December 1996	$3.6 million	$83 million
March 1997	$1.3 million	$6.5 million
November 2003	—	$30 million

Another study (Booth et al., 2006) estimated the total amount of flood insurance claim payments made in the Puget Sound region by the National Flood Insurance Program since 1978; the estimated total of $56 million does not include all flood losses borne by property owners, due disparities in insurance coverage.

Estimates of Potential Flood Damage to Property in King County

Three studies identified through the literature review used modeling to estimate the value of properties exposed to flood hazards and the potential damage to those properties from a future flood. Table ES-2 summarizes the estimates from these studies.

TABLE ES-2.
FLOOD EXPOSURE AND VULNERABILITY ESTIMATES

	Value of Properties in 100-Year Floodplain (millions)	Estimated Damage from 100-Year Flood (millions)
From 2006 King County Flood Hazard Management Plan (Unincorporated County Areas Only)	$2,708	$513
From 2009 Regional Hazard Mitigation Plan (Unincorporated County Areas Only)	$867	$302
From 2010 King County Flood Control District Hazard Mitigation Plan	$10,085	$2,031

Estimated Impacts on the King County Economy

One study (ECONorthwest, 2007) evaluated the level of economic activity in King County floodplains, the degree to which economic activity in the floodplains is connected to the greater King County economy, and the importance of economic activity in the floodplains to the county's economic vitality. Its key findings include the following:

- A one-day shutdown of economic activity in King County floodplains would result in at least $43 million in foregone economic output in the floodplains and $46 million countywide.
- 20 percent of the County's total manufacturing employment and 30 percent of the County's aerospace employment is located in floodplains.
- 6 percent of employed persons in King County work in floodplains and 2 percent of the total population lives in floodplains.
- A long-term 10-percent change in aerospace employment in the King County floodplains would lead to a $160 million change in personal income in the county.

Green River Flood Impact Studies

Four studies were identified that address economic impacts of flooding on the Green River rather than all of King County. Conclusions of these studies are as follows:

- Shannon & Wilson (2002) estimated an average annual damage cost due to Green River flooding of $65.73 million ($3.73 million to residential structures and $62 million to non-residential structures).
- The Federal Emergency Management Agency (FEMA, 2009) estimated damage costs and business impact losses for three scenarios of Green River flooding:
  - Base 100-Year Flood (12,800 cubic feet per second (cfs)) with some levee failures—Damage costs of $1.956 billion, business losses of $11 million
  - Flood of 17,600 cfs without levee failures—Damage costs of $1.324 billion, business losses of $22 million

  - Flood of 17,600 cfs with some levee failures—Damage costs of $3.710 billion, business losses of $38 million
- Goodwin (2010) estimated the following economic factors that would be affected by a Green River flood of 25,000 cfs with no levee failures
  - There are 100,000 jobs in the inundation area with a payroll of $16 million per day.
  - The total value of output in the inundation area is over $63 million per day.
  - There are 4,771 retail business sites in the inundation area.
  - Over $1.2 million per day in sales tax revenue would be lost during a flood event.
  - The assessed value of property in the inundation area was over $6.7 billion in 2008.
- The Department of Homeland Security's Dams Sector Exercise Series estimated the following impacts from a Green River flood exceeding the 100-year base flood, with one levee failure:
  - Damage to structures, contents, and automobiles of about $3.70 billion
  - Total economic losses up to $40 billion in the first year after the flood, or $16.7 billion if accounting for the positive offsetting effect of restoration investment.

Ecosystem Service Valuations

The relatively new field of ecosystem service valuation attempts to define monetary equivalent values for benefits provided by ecosystems. A standard set of such benefits commonly evaluated in studies includes "disturbance prevention," which includes the ability of natural systems to dampen the effects of flooding; for example, wetlands can naturally store floodwaters, helping to keep the waters from inundating developed areas. Ecosystem service valuation attempts to define the monetary value of that flood prevention benefit, as well as numerous other benefits that natural systems provide. The literature review collected three studies that estimate the flood-prevention value of ecosystems in parts of King County:

- Earth Economics (2007) performed case studies to estimate the value of all ecosystem services that would be generated by completing six projects along the Cedar River recommended in King County's 2006 Flood Hazard Management Plan. The study found that the projects would yield ecosystem services valued at $65,000 to $3.1 million per year, including a flood-prevention value of $10,000 to $2.7 million per year.
- Asia Pacific (2005) estimated the value of services provided by all existing ecosystems in the Green/Duwamish and Central Puget Sound watershed, which is designated Water Resource Inventory Area (WRIA) 9. The study estimated that existing systems in WRIA 9 provide a disturbance prevention benefit of $105 million to $758 million per year.
- Economics (2010) estimated the value of services provided by all existing ecosystems in the Snoqualmie River watershed. The study estimated that existing systems in the watershed provide a disturbance prevention benefit of $7.56 to $235.73 per acre per year. The study does not apply these unit values to the entire watershed to show a total estimated value for disturbance prevention, but a calculation described in this literature review summary report suggests the watershed-wide value may be $272,000 to $8.48 million per year.

Another study collected through the literature review (Leschine et al., 1997) estimated the flood-prevention benefit of wetlands throughout Western Washington. It concluded that the value of this benefit is in the range of $36,000 to $51,000 per acre.

A final ecosystems service study collected for the literature review (Costanza et al., 1997) does not address the King County or Puget Sound area, but it was included because it is one of the earliest and most comprehensive studies to gather together the large but scattered amount of information on ecosystem service valuations worldwide. The study provides a table giving average ecosystem service value in US$ per hectare per year for 17 ecosystem services provide by 21 vegetation-cover types (referred to in the study as "biomes"). It estimates a disturbance regulation benefit ranging from $2 to $7,240 per hectare per year ($0.8 to $2,930 per acre per year), depending on the biome.

Costs of Flood Risk Reduction Activities

Capital Project and Flood Control Program Costs

King County's 2006 Flood Hazard Management Plan shows that, from 1991 to 2005, King County's River and Floodplain management program spent $34 million in capital projects and technical studies to address flood risk; of that amount, $11 million was local funding and $23 million was state and federal funding. For the action plan presented in the plan, the estimated cost over 10 years (2007 – 2016) is $206 million; approximately $20 million each year.

Booth et al. (2006) evaluated expenditures on stormwater management programs throughout the Puget Sound region. It found that by Puget Sound cities and counties covered under National Pollutant Discharge Elimination System Phase 1 permits spend a combined $134 million per year on stormwater management programs. For eight specific jurisdictions surveyed (not including King County), the portion of these expenditures used for flood prevention ranged from about 25 percent to 100 percent; most were in the range of 40 to 60 percent.

Incidental Costs

One study identified through the literature review (Wood et al., 1997) examined the cost impact on road projects of a King County ordinance intended to reduce flood risks. The County's "zero-rise" ordinance of 1990 generally prohibited projects that would cause a rise in the base 100-year flood level at or near the project location. The study evaluated King County and Washington State Department of Transportation bridge projects in King County floodplains to determine the ordinance's impact on project costs. It concluded that affected road projects saw an average cost increase of 49 percent. The estimated increase was 66 percent for County road projects and 35 percent for state road projects. The study made no effort to estimate the value of avoided damage or other benefits resulting from the implementation of the ordinance.

Cost-Benefit Analyses

The literature review identified two studies that provided comparisons of cost and benefit for specific flood-risk-reduction projects in King County:

- A loss avoidance study by Washington's Emergency Management Division (2010) compared the cost and benefit (estimated as the avoided cost of potential flood damage to structures) of elevating 11 homes in Snoqualmie above the base flood elevation. The study demonstrated a positive return on investment (as high as 132 percent) for all 11 homes. The report also provides a summary of a similar study by FEMA of 28 flood-proofed Snoqualmie homes. The FEMA study estimated a project benefit of $1.6 million from a single flood that occurred after the work was complete, compared to a project cost of $1.3 million.
- Tetra Tech (2011, DRAFT) estimated costs and benefits for several options of a levee replacement project along the Green River. Although the report does not give totals for costs and benefits (it presents ranges of values for components of both cost and benefit), it is

noteworthy for its approach to estimating benefit. The valuation of benefit uses both an modeling study to estimated avoided cost of flood damage and a literature review and analysis to estimate ecosystem services that would be enhanced by the project.

Qualitative Findings

Two studies that do not provide cost-specific evaluations or results were identified by the literature review because they discuss important general concepts related to the economic impacts of flooding:

- Critical Infrastructure Group (2009) summarizes presentations by local experts at a 2009 workshop addressing the likely impacts of a severe flood on the Green River. Impacts identified in this document could provide a framework for future cost evaluations of the economic impacts of flooding. The workshop identified the following critical infrastructure as susceptible to damage from an extreme flood:
  - Electric and gas service
  - The Olympic Pipeline, which supplies most of the fuel needs of Western Washington and all of the fuel needs of Sea-Tac Airport and the Port of Seattle.
  - Sea-Tac International Airport
  - Local and state highways
  - Phone service
  - Sewer systems
  - Potable water systems
  - Public health
- Rossi et al. (1978) is an early and influential study on the long-term impacts of disasters in the United States. The study performed modeling of Census data for communities affected by major disasters in the 1960s to evaluate whether such events had long-term effects on the communities' growth, as indicated by population and housing. The study concluded that natural disasters have no discernible effects on county or census tract population or housing trends that last beyond a few years after the event. It proposes the following policy considerations based on this conclusion:
  - For an "average" (rather than extreme) disaster, long-term post-disaster assistance may be more appropriate for individuals, families and businesses than for larger communities.
  - The most reasonable policy may be to admit that catastrophic (extreme) events cannot be prepared for and to expect that special measures would have to be taken ad hoc if such events occur. Disaster policy should be tuned to the needs associated with an average disaster and applied to those events alone.

1. INTRODUCTION

This report presents the results of a literature review conducted to identify prominent studies that provide an understanding of how flooding and flood risk reduction measures can affect the economy of King County, Washington. The review was performed by Tetra Tech at the request of King County's Water and Land Resources Division, as a work order under Tetra Tech's floodplain planning and management contract with the County.

Scope of Work

The work order for this project requests a literature review on the importance of flood risk reduction efforts in protecting the King County economy. Studies to be identified should cover the following topics, if available:

- Traditional economics including the economic disruption of a flood event (transportation, freight disruptions, etc.)
- Ecological economics associated with flooding ("ecological services," or the benefits provided to humans or the environment by a functioning ecosystem)
- Long-term impacts of a flood event, including timeframe of effects after a disaster (reduction of revenues, connections to other regions, etc.)
- Other economic data such as data from Hazus modeling (Hazus, or Hazards, U.S., is modeling software developed by the Federal Emergency Management Agency).

Methodology

Studies were identified for this literature review by the following methods:

- Two studies were provided by King County as part of the work order.
- Previous Tetra Tech documents related to the review topics were examined for potential relevance.
- Internet searches (using Google web search and Google scholar) were performed on the following sets of key words:
  - Flood economic impact King County
  - Flood economic impact risk reduction King County
  - Flood ecological services King County
  - Long-term flood impacts Washington.
- The reference lists of all studies collected in the first three steps were reviewed to identify additional relevant materials.

These review methods identified many hundreds of articles, studies, books and reports with potential relevance to the research topic. Given the limited scope and budget for this literature review, the selection of articles for inclusion in the final review was based on the following criteria:

- Only documents that were easily accessed in complete electronic form were obtained and reviewed.
- Studies were chosen based on specific geographic areas that they address, in the following order of preference:

  - Studies that address all of King County and only King County
  - Studies that address any of three larger areas that include King County: Washington State; Western Washington; Puget Sound
  - Studies that address an area that is completely or mostly within King County: Green River; Water Resource Inventory Area (WRIA) 9; Snoqualmie watershed
- Two studies that are not specific to the geographic areas listed above were collected because the search process indicated, based on frequent citation in other sources, that they are influential studies on a topic relevant to the literature review. These are included in this report in the section that summarizes larger-area studies.

This search methodology yielded 20 documents for review, totaling over 2,000 pages. The documents are summarized in the following sections, which are based on geographic area addressed. Within each area-based section, documents are listed chronologically.

Given the volume of material collected, the summaries are based on review of introductory or summary material in each document, along with review of specific sections or chapters of interest. Electronic copies of the complete documents in .pdf format are provided on a CD submitted with this report to allow for more in-depth review as appropriate.

2. SUMMARY OF DOCUMENTS SPECIFIC TO KING COUNTY

Wood et al. 1997—Assessment of Zero-Rise Ordinance

Citation

Wood, Andrew, Richard Palmer and Catherine Petroff. 1997. An Assessment of the Zero-Rise Ordinance in King County. Washington State Department of Transportation Publication WA-RD 426.1. Prepared for the Washington State Transportation Commission by Washington State Transportation Center. Seattle, Washington. 78 pp. December 1997.

Scope

This study assesses whether King County's 1990 zero-rise ordinance tightened floodplain regulations enough to hamper agencies responsible for maintaining bridges and roadways. The general purpose of the study was to evaluate the implications of the zero-rise regulation for bridge builders in the King County Roads Division and the Washington State Department of Transportation.

Methodology

This study does the following:

- Documents the development of the 1990 zero-rise regulation
- Compares the King County floodplain regulation to similar regulations in other states and counties and to other "absolute zero" regulations
- Assesses the costs of the ordinance for bridges designed since 1990
- Evaluates the effectiveness of procedures for obtaining variances from the zero-rise criterion.

Conclusions

Based on a review of water-crossing road projects underway from 1989 to 1995, this study developed estimates of the increased cost for roadwork affected by the County's zero-rise ordinance. It concluded

that affected County and state road projects saw an average cost increase of 49 percent. The estimated increase was 66 percent for County road projects only and 35 percent for state road projects only. The study makes no effort to estimate the value of avoided damage or other benefits resulting from the implementation of the ordinance. The study presents the following conclusions:

- King County has more restrictive floodplain regulations than other locales in which a zero-rise water surface constraint has been adopted. The report recommends that conflicts between the zero-rise regulation and Surface Water Design Manual constraints be resolved on the basis of the relative importance of each for preventing flood damage.
- The zero-rise ordinance has caused King County significant cost increases for bridge work, and the benefits of the ordinance have not been formally demonstrated.
- The zero-risk paradigm has been found to be unworkable in other examples of national environmental policy.
- The intended balancing of flood mitigation against increased bridge expense has not occurred.

King County 2006—King County Flood Hazard Management Plan

Citation

King County, 2006. Flood Hazard Management Plan: King County, Washington. King County Department of Natural Resources and Parks, Water and Land Resources Division. Seattle, Washington. 607 pp. Final, January 2007.

Scope

The King County Flood Hazard Management Plan provides a comprehensive review of flooding issues throughout King County, including a review of historical flooding and policies, an assessment of conditions in all major river basins, and an action plan for flood hazard mitigation measures. Chapter 3 of the plan provides an evaluation of the costs and impacts of flooding in King County. Section 7.2 provides cost estimates for the recommended action plan. The detailed action plan is presented in Appendix F.

Methodology

Key findings in the 2006 Flood Hazard Management Plan that are relative to this literature review were developed as follows:

- Section 3.2.3 summarizes historical flood damage costs for declared flood disaster events. The costs of damage to public facilities were taken from the County's 2003 Regional Hazard Mitigation Plan. Repair costs were obtained from the Washington Department of Emergency Management.
- Section 3.2.2 develops estimates of flood loss potential based on 100-year floodplain mapping at the time of the plan and Federal Emergency Management Agency (FEMA) methodologies for flood loss estimation.

Conclusions

Flood Damage Costs

The plan's review of previous federally declared flood disasters found public-facility damage estimates as follows for the seven events between January 1990 and March 1997.

- January 1990—$5.2 million

- November 1990—$3.7 million
- December 1990—$0.5 million
- November 1995—$3.0 million
- February 1996—$4.3 million
- December 1996—$3.6 million
- March 1997—$1.3 million

The estimated breakdown of repair costs for all of these events showed a federal share of $16 million, a state share of $3 million and a local share of $2 million.

Based on flood mapping at the time of the plan, King County assessor data for property values, and FEMA procedures for estimating flood loss, the plan estimated the property values in the 100-year floodplain and potential flood damage from 100-year floods unincorporated areas in the six major river basins in the county. This estimate does not account for damage potential outside the mapped floodplains. The risk assessment estimates are summarized in Table 1.

TABLE 1.
FLOOD EXPOSURE AND VULNERABILITY ESTIMATES FROM 2006 FLOOD PLAN

	Value of Properties in 100-Year Floodplain (millions)			Estimated Damage from 100-Year Flood (millions)
	Land	Structure	**Total**	
S. Fork Skykomish River	$1.8	$7.5	**$9.3**	$2.1
Snoqualmie River	$197.3	$258.9	**$456.2**	$101.7
Sammamish River	$276.3	$485.1	**$761.5**	$123.4
Cedar River	$102.5	$75.1	**$177.6**	$20.6
Green River	$388.7	$937.8	**$1,276.6**	$260.7
White River	$10.3	$15.0	**$25.3**	$4.1
Total	$927.0	$1,779.5	**$2,707.5**	$512.8

Flood Hazard Mitigation Expenditures

The plan shows that, from 1991 to 2005, King County's River and Floodplain management program spent $34 million in capital projects and technical studies to address flood risk; of that amount, $11 million was local funding and $23 million was state and federal funding. For the action plan presented in the plan, the estimated cost over 10 years (2007 – 2016) is $206 million; approximately $20 million each year.

Earth Economics 2007—Ecological Economic Assessment of Flood Hazard Plan

Citation

Earth Economics. 2007. An Ecological Economic Assessment of King County's Flood Hazard Management Plan. Prepared for King County Department of Natural Resources and Parks River and Floodplain Management Program by Paula Swedeen and James Pittman of Earth Economics. Seattle, Washington. 47 pp. August 10, 2007.

Scope

This report examines the value of ecological services that result when floodplain and river ecosystems are restored as a means of flood damage prevention. The first part of the report contains background information on an ecological economics approach to analyzing the benefits of flood protection programs, a general discussion of ecosystem services in King County floodplains, and the techniques used to determine their economic value. This sets up a case study, reported in Part 2 of this document, which analyzes the changes in value that would likely result from implementation of specific flood protection measures on six projects from the 2006 King County Flood Hazard Management Plant proposed for implementation in the Cedar River Watershed. The projects include home buyouts, levee setbacks, and bank stabilization. The results are intended to provide a general idea of what ecosystem service values can be gained with these strategies for flood hazard reduction in other watersheds in the county. The ecosystem services considered in this study listed in Table 2.

TABLE 2.
ECOSYSTEM SERVICES EVALUATED IN EARTH ECONOMICS 2007

Ecosystem Service	Description	Example of Benefit
Gas regulation	Role of ecosystems in biogeochemical cycles	Provides clean, breathable air, disease prevention, and a habitable planet
Climate regulation	Influence of land cover and biologically mediated processes on climate	Maintenance of a favorable climate promotes human health, crop productivity, recreation, and other services
Disturbance prevention	Influence of ecosystem structure on dampening environmental disturbances	Prevents and mitigates natural hazards and natural events, generally associated with storms and other severe weather
Water regulation	Role of land cover in regulating runoff and river discharge	Provides natural irrigation, drainage, channel flow regulation, and navigable transportation
Water supply	Filtering, retention and storage of fresh water (e.g. in aquifers and snow pack)	Provision of water for consumptive use, includes both quality and quantity
Soil retention	Role of vegetation root matrix and soil biota in soil retention	Maintains arable land and prevents damage from erosion, and promotes agricultural productivity
Soil formation	Weathering of rock, accumulation of organic matter	Promotes agricultural productivity, and the integrity of natural ecosystems
Nutrient regulation	Role of biota in storage and recycling of nutrients	Promotes healthy and productive soils and gas, climate, and water regulations
Waste treatment	Role of biota in removal or breakdown of nutrients and compounds	Pollution control/ detoxification and filtering of dust particles through canopy services
Pollination	Role of biota in movement of floral gametes	Pollination of wild plant species and harvested crops
Biological control	Population control through trophic-dynamic relations	Provides pest and disease control and reduces crop damage
Refuge function	Suitable living space for wild plants and animals	Maintenance of biological and genetic abundance and diversity
Nursery function	Suitable reproduction habitat	Maintenance of commercially harvested species
Food	Conversion of solar energy into edible plants and animals	Hunting, gathering of fish, game, fruits, etc. and small-scale subsistence farming and aquaculture

TABLE 2.
ECOSYSTEM SERVICES EVALUATED IN EARTH ECONOMICS 2007

Ecosystem Service	Description	Example of Benefit
Raw materials	Conversion of solar energy into biomass for human uses	Building and manufacturing, fuel and energy; and fodder and fertilizer
Genetic resources	Genetic material and evolution in wild plants and animals	Improve crop resistance to pathogens and pests
Medicinal resources	Variety of chemical substances in, and other medicinal uses of, natural biota	Drugs, pharmaceuticals, chemical models, tools, test and assay organisms
Ornamental resources	Variety of biota in natural ecosystems with potential ornamental use	Resources for fashion, handicraft, jewelry, pets, worship, decoration, and souvenirs
Aesthetic information	Attractive landscape features	Enjoyment of scenery
Recreation	Variety in landscapes with potential recreational uses	Travel to natural ecosystems for eco-tourism, outdoor sports, etc.
Cultural and artistic information	Variety in natural features with cultural and artistic value	Use of nature as motive in books, film, painting, folklore, national symbols, architecture, advertising, etc.
Spiritual and historic information	Variety in natural features with spiritual and historic value	Use of nature for religious or historic purposes (i.e., heritage value of natural ecosystems and features)
Science and education	Variety in natural features with scientific and educational value	Use of natural systems for school excursions, etc. Use of nature for scientific research

Methodology

The case study of six proposed projects in the Cedar River Watershed involves a “value-transfer” analysis of all ecosystem services except flood protection (flood protection is represented by the “disturbance prevention” ecosystem service). The value-transfer method uses existing economic estimates of the value of services and adapts the estimates to place value on those services as provided by functioning ecosystems. The critical assumption of this method is that the economic value of ecosystem services can be inferred with sufficient accuracy from analysis of existing valuation studies.

For flood protection, an original empirical estimate of value from the project was conducted based on avoided cost. In this approach, data is collected on as many of the following flood-related costs as possible: damage to homes, lost labor, insurance payouts, alternative housing, flood warnings, emergency response expenses, emergency repairs, and repair to public infrastructure. An estimate is then made as to how much less frequent and severe damage from flood events will be after proposed flood prevention measures are implemented. The costs avoided per flood event are then summed for the expected number of flood events that would cause damage over a 100-year period.

The flood protection values derived using the avoided-cost method are combined with the value-transfer data of other ecosystem services to get a full picture of all the ecosystem services gained by restoring floodplain habitats and functions.

Conclusions

The case study of six Cedar River projects from the 2006 Flood Plan estimates that the projects will yield a total ecosystem service benefit ranging from $65,000 to $3.1 million per year. This includes $55,000 to $400,000 per year for avoided flood damage costs and $10,000 to $2.7 million per year for all other ecosystem services.

An important result presented in the report is a table showing ranges of values per acre for each ecosystem service for which data was available from recent peer-reviewed studies. These values are given for six land-cover types typical of the project areas.

The report concludes the following major benefits of flood hazard reduction projects:

- Many costs are avoided from flood damage that would otherwise occur.
- By reconnecting the river to its natural floodplain, flood protection is accomplished naturally without recurring infrastructure costs to the county and the public.
- Other valuable ecosystem services are gained that will be delivered in perpetuity.

In order to apply the approach used in this study in a more formal cost-effectiveness framework, the report recommends the following:

- Comprehensive hydraulic modeling of the cumulative effects of flood hazard reduction in the subject watershed, to improve estimates of avoided costs and improved habitat-associated ecosystem services
- A centralized database of all components that go into avoided cost calculations (e.g., home damage, flood facilities damage, road and trail damage, emergency service costs, and lost work time)
- State funding of local and regional empirical studies of ecosystem services and their economic value.

ECONorthwest 2007—Floodplains and Greater King County Economy

Citation

ECONorthwest. 2007. Economic Connections Between the King County Floodplains and the Greater King County Economy. Prepared for King County Water and Land Resources Division by ECONorthwest. Eugene, Oregon. 35 pp. October 2007.

Scope

This study addresses the regional economic benefits related to implementing the 2006 King County Flood Hazard Management Plan. The analysis focuses on the level of economic activity in King County floodplains, the degree to which economic activity in the floodplains is connected to the greater King County economy, and the importance of economic activity in the floodplains to the county's economic vitality. The analysis consisted of sub-analyses examining the following topics:

- Employment and payroll in the floodplain areas
- The potential short-run impact on the countywide economy of a one-day work stoppage in the floodplain areas (as a proxy for a flood event)
- The long-run impact on the countywide economy of a permanent change in aerospace employment in the floodplain areas (the study assumes that implementing the flood hazard

management action plan, or failure to do so, could affect aerospace manufacturers' perception of safety in the floodplain and consequent decisions regarding investment in manufacturing capacity there).

The results of the three analyses are not cumulative. Rather, each provides a different view of the extent to which the economy of the floodplain areas is part of the larger King County economy and the extent to which a change in the level of economic activity in the floodplain would affect the countywide economy.

Methodology

The approach to the three sub-analyses was as follows:

- **Floodplain Employment and Payroll**—Using micro-level employment data for King County, the study examined employment and income by industry sector in the floodplain regions and compared them to the county as a whole. The study assessed the importance of business activity in the floodplains to the economic vitality of the rest of the county.
- **Impact of One-Day Work Stoppage**—Using an economic input-output model, the study estimated the direct and some of the indirect impacts associated with a major flood event.
- **Long-Term Effect of Change in Aerospace Employment**—Using a long-term economic and demographic forecasting model for the Puget Sound region, the study examined the impact that a small change in aerospace employment in the King County floodplains would have on the Puget Sound and King County economies.

Conclusions

The three sub-analyses indicate that there is substantial economic interaction between the floodplains and the rest of King County, and suggest that there are economic benefits to the County of protecting the floodplain. The following sections describe key findings.

Employment in the Floodplain

The floodplain region has many jobs but relatively few residents:

- Approximately 6 percent of the county's employment is located in the floodplain region (65,000 jobs).
- 20 percent of the County's total manufacturing employment and 30 percent of the County's aerospace employment is located in the floodplains.
- Manufacturing pays wages higher than the County average and aerospace pays the highest wages of any employment sector in King County.
- Nearly 7 percent of King County's total annual wage and salary income is generated within the floodplain ($3.7 billion).
- Approximately 2 percent of King County's population lives in the floodplain (32,000 persons). Most employees working in floodplain areas commute from other parts of King County or surrounding counties.

Because the floodplain region employs many people who live elsewhere in King County, the benefits of flood hazard management accrue beyond the floodplain to the entire County economy.

Effect of a One-Day Work Stoppage

A one-day shutdown of economic activity in the King County floodplain areas would result in at least $43 million in foregone economic output in the floodplains and $46 million countywide:

- Much of the effect of the stoppage would be felt in foregone wages to employees, most of whom live outside the floodplains in other King County communities.
- Business income and taxes paid to state and local governments throughout the County would be also be negatively impacted.
- The 10 King County industry sectors outside floodplains that would be most affected by a shutdown in the floodplain are oriented toward business services. They pay wages that are higher than the County average, and are predominately located in the County's major cities.

The estimated impact of the one-day work stoppage is conservative because it does not account for impacts on persons living in the floodplains who are unable to commute to jobs elsewhere, businesses outside that rely on goods and services produced by businesses inside floodplain areas, the value of damaged or destroyed property or equipment, or multi-day flood impacts.

Role of Aerospace Employment

A change in aerospace employment in the floodplain would have long-term impacts on employment and personal income growth in King County and the Puget Sound region:

- Public investment in flood hazard management would likely affect long-term business location decisions of aerospace manufacturers currently located in the floodplains.
- Thirty percent of King County's aerospace employment is located in the floodplains.
- Aerospace employment in the Puget Sound region has a positive causal relationship to employment in other sectors of the economy.
- A 10 percent change in aerospace employment in the King County floodplains would lead to a $160 million change in personal income in King County.

King County 2009—Regional Hazard Mitigation Plan

Citation

King County Office of Emergency Management. 2009. King County Regional Hazard Mitigation Plan, Phase 1. 288 pp. (without annexes) November 2009.

Scope

King County's Regional Hazard Mitigation Plan provides a risk assessment and hazard mitigation action plan for the major natural and human-caused hazards facing King County. It updates the County's previous plan, which was completed in 2004. The 2009 plan applies primarily to unincorporated county areas, though it provides for subsequent linking to the plan by incorporated jurisdictions and special purpose districts within the county.

The plan includes a hazard identification and vulnerability analysis for all hazards, including flooding, which it rates as a high-probability, high-impact hazard. The flooding section includes a review of damage from federally declared flood disasters in King County from January 1990 through November 2003. The plan also includes a risk assessment for the flooding hazard.

Methodology

Estimated damage to private and public property from past federally declared flood disasters was obtained for the hazard mitigation plan from the King County Flood Control District. The flooding risk assessment was completed using FEMA's Hazus risk assessment computer model to estimate the value of exposed and vulnerable properties in the 100-year floodplains of the six main river basins in King County.

Conclusions

The plan's review of previous federally declared flood disasters found private and public property damage estimates of $358.3 million from eight events between January 1990 and November 2003. Individual event damage estimates are as follows:

- January 1990—$17.8 million
- November 1990—$57 million
- December 1990—$5.1 million
- November 1995—$45.9 million
- February 1996—$113 million
- December 1996—$83 million
- March 1997—$6.5 million
- November 2003—$30 million.

The risk assessment estimated exposed and vulnerable property values in unincorporated areas of King County floodplains as summarized in Table 3.

TABLE 3.
FLOOD EXPOSURE AND VULNERABILITY ESTIMATES FROM 2009 HAZARD PLAN

	Value of Properties in 100-Year Floodplain (millions)			Estimated Damage from 100-Year Flood (millions)		
	Structure	Contents	**Total**	Structure	Contents	**Total**
S. Fork Skykomish River	$25.2	$13.6	**$38.9**	$5.3	$4.2	**$9.5**
Snoqualmie River	$282.7	$156.9	**$439.6**	$93.7	$68.2	**$161.9**
Sammamish River	$89.6	$58.0	**$147.6**	$8.3	$22.9	**$31.2**
Cedar River	$61.6	$30.4	**$92.0**	$11.7	$7.9	**$19.5**
Green River	$76.7	$39.6	**$116.3**	$32.4	$27.9	**$60.4**
White River	$21.8	$11.0	**$32.8**	$10.4	$9.4	**$19.8**
Total	**$ 558**	**$ 310**	**$ 867**	**$ 162**	**$ 141**	**$ 302**

King County Flood Control District 2010—Hazard Mitigation Plan

Citation

King County Flood Control District. 2010. Hazard Mitigation Plan. Prepared for the King County Flood Control District by Tetra Tech, Inc. Seattle, Washington. 176 pp. August 2010.

Scope

The King County Flood Control District's Hazard Mitigation Plan provides a risk assessment and hazard mitigation action plan for the major natural hazards facing all of King County. Flooding is one of seven natural hazards addressed

Methodology

Much of the flooding-related content in the Flood Control District's hazard mitigation plan was taken from the 2006 King County Flood Hazard Management Plan. New flood risk assessment analyses were performed using FEMA's Hazus model.

Conclusions

The flooding risk assessment in the District's hazard mitigation plant provides estimates of exposed and vulnerable properties throughout King County in the 100-year and 500-year floodplains, as well as estimates of potential damage to these properties from the 100-year and 500-year floods. Table 4 summarizes the results.

TABLE 4.
COUNTYWIDE FLOOD EXPOSURE AND VULNERABILITY ESTIMATES FROM 2010 FLOOD DISTRICT HAZARD PLAN

	Value of Properties in Floodplain (millions)			Estimated Damage from Flood Event (millions)		
	Structure	Contents	**Total**	Structure	Contents	**Total**
100-Year	$5,233.7	$4,851.9	**$10,085.6**	$716.7	$1,313.9	**$2,030.7**
500-Year	$5,883.6	$5,413.3	**$11,296.9**	$911.9	$1,610.9	**$2,522.8**

Tetra Tech 2012—King County Hazus Analysis

An updated analysis of King County flooding using FEMA's Hazus model is currently underway but was not completed in time for incorporation into this report.

3. SUMMARY OF DOCUMENTS ADDRESSING A BROADER REGION

Leschine et al. 1997—Wetlands and Western Washington Flooding

Citation

Leschine, Thomas M., Katharine F. Wellman and Thomas H. green. 1997. The Economic value of Wetlands: Wetlands' Role in Flood Protection in Western Washington. Ecology Publication No. 97-100. Prepared for Washington State Department of Ecology Northwest Regional Office. Bellevue, Washington. 68 pp. October 1997.

Scope

This report argues that economic valuation of wetlands' flood protection services can provide a strong rationale for Western Washington communities to protect remaining wetlands. After describing an economic rationale for pricing non-marketed natural resource services such as flood protection and outlining the approaches economists use to establish such values, the study assesses how the "alternative/substitute cost" method can be used to produce a proxy for the value of the flood protection services that many wetlands currently provide. Illustrations of the study's argument are provided by

estimating the dollar-per-acre values of wetlands systems for flood protection in two Western Washington communities experiencing frequent flooding—Renton in King County and Lynnwood in Snohomish County.

Methodology

Cost estimates for engineered hydrologic enhancements to wetlands currently providing flood protection are used to establish proxies for the value of the flood protection these wetlands provide. A "ratio analysis" scheme is employed, making the method transferable to other communities seeking ways to enhance the flood protection that remaining wetlands provide.

The economic analysis of the value of flood protection provided by wetlands used data on projected flood benefit (reduced flow or increased storage) that would result from proposed engineered flood-mitigation projects. The analysis assumed that the willingness of a jurisdiction to pay the estimated costs of the proposed enhancements is an accurate reflection of the value to residents of the ability of wetlands to provide an equivalent flood benefit. Ratios were calculated of the costs of the proposed enhancements to the flood benefit they would achieve, and of existing wetlands acreage to the flood benefit it achieves. These ratios were then combined mathematically to produce a dollars-per-acre estimate of the value of flood protection provided by wetlands.

Conclusions

The results of the analysis, when annualized to dollars per acre per year, are comparable to values found in other economic studies that have been done of the value of wetlands for flood protection. The study's estimates of "whole system" wetlands value for flood protection range from about $36,000 per acre to about $51,000 per acre.

The broader lesson of the analysis is that the per-acre value estimates appear to increase rapidly as the cost inefficiency of enhancing wetlands also increases; this happens as wetland systems become increasingly fragmented and degraded. This suggests that policies allowing the removal of wetlands that are presently contributing little to flood protection but that have the potential to do so in the future, could lead to rapidly rising flood-protection values for remaining wetlands, as increasingly marginal wetlands are called into service. At some point the "next best" alternatives to enhanced flood protection will not involve wetlands at all, and the purely engineered systems that might have to be built could prove very expensive. These results suggest that price-sensitive market signals do exist that provide a strong economic rationale for communities in Western Washington to protect wetlands today in order to avoid what are likely to be much higher costs of flood protection in the future.

Booth et al. 2006—Puget Sound Stormwater Runoff Costs

Citation

Booth, Derek B., Bernadette Visitacion and Anne C. Steinemann. 2006. Damages and Costs of Stormwater Runoff in the Puget Sound Region. Prepared for Puget Sound Action Team, Office of the Governor by University of Washington Department of Civil and Environmental Engineering Water Center. Seattle, Washington. 22 pp. August 30, 2006.

Scope

This report describes the costs of stormwater damage within the Puget Sound region, documents the costs of stormwater mitigation, and presents some of economic benefits of stormwater management. The stormwater impacts assessed include flooding, landsliding and property damage; a decline in drinking-

water and surface-water quality; habitat degradation; and contamination of shellfish growing areas. The study groups these impacts into categories of stormwater-related costs:

- Direct damage caused by stormwater
- Cost of government and/or private actions and programs to reduce the effects of stormwater
- Indirect damage caused by stormwater
- Unquantified costs caused by stormwater.

This report presents examples of economic costs associated with the first two categories. The last two categories are difficult to quantify in economic terms and therefore are addressed separately.

Methodology

Findings of this study were drawn from interviews with city and county officials and review of public records and previous studies.

Conclusions

Key findings of the study related to flood impacts are as follows:

- The total amount of flood insurance claim payments made in the Puget Sound region by the National Flood Insurance Program has totaled $56 million since 1978. This does not include all flood losses borne by property owners, due disparities in insurance coverage.
- The annual budget of stormwater and flood management programs can be on the order of hundreds of thousands to millions of dollars, depending on size and population of the jurisdiction. The largest Puget Sound jurisdictions (namely, cities and counties covered under National Pollutant Discharge Elimination System Phase 1 permits) reported expenditures of $134 million. When stormwater management costs are expressed per capita, typical management costs are on the order of $100/person/year, exclusive of episodic damage costs.
- Efforts to reduce flooding and drainage problems are the largest capital project costs among all jurisdictions, regardless of size, as shown in Figure 1.

Washington Emergency Management 2010—Loss Avoidance Study

Citation

Washington State Emergency Management Division. 2010. Loss Avoidance Study *in* Washington State Enhanced Hazard Mitigation Plan. Olympia, Washington. 33 pp. October 2010.

Scope

This study evaluates the cost-effectiveness of 20 flood mitigation projects and four earthquake mitigation projects completed in Washington and funded through various disaster declarations. Of the flood mitigation projects, 12 were in King County (11 in the City of Snoqualmie and one near Issaquah); the rest were in Pierce or Snohomish County. The Snoqualmie projects were all for elevations of existing flood-prone homes.

The study also summarizes the findings of FEMA loss avoidance studies for the City of Snoqualmie, a mobile-home park in Sumner, and the City of Centralia.

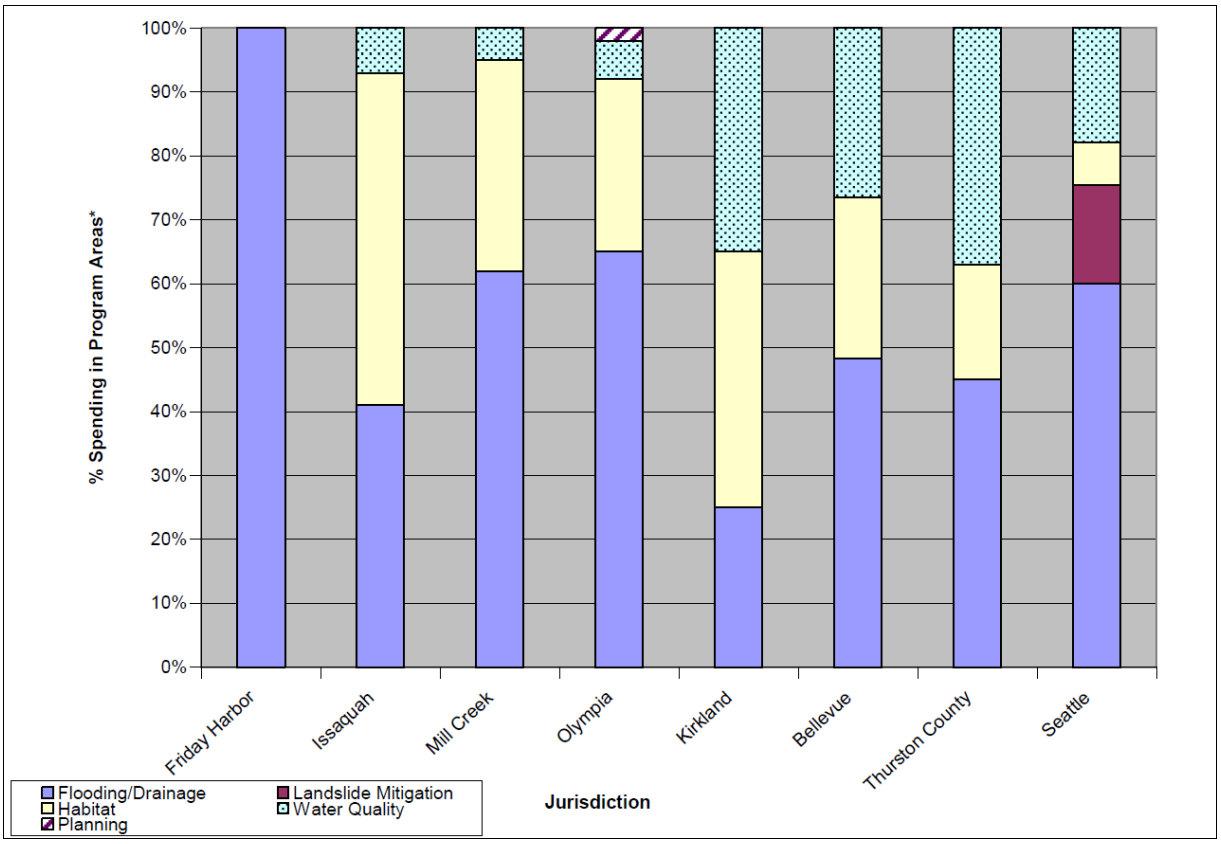

Figure 1. Division of Capital Improvement Project Costs for Various Puget Sound Stormwater Programs

Methodology

This study used a FEMA loss avoidance study methodology that evaluates cost-effectiveness based on an actual hazard event that has occurred at a mitigation project site prior to completion of the project. The methodology determines actual damage cost from the event and compares that value to estimates of damage that would be expected with the mitigation project completed. For the 11 Snoqualmie home elevation projects (the bulk of flood projects evaluated that are in King County), three calculations of avoided cost were made:

- The difference between Hazus modeling of damage from the 100-year flood with and without the project
- The difference between Hazus modeling of damage from the 100-year flood with the project and actual damage from a flood in 2006 (before the project)
- The difference between Hazus modeling of damage from the 100-year flood with the project and actual damage from a flood in 2009 (before the project).

For each of these values, return on investment was calculated as the avoided cost divided by the home elevation project cost.

This study does not calculate loss avoidance associated with social impacts, such as economic impact, loss of use, displacement, employment impact, or environmental impact. The software used to conduct this study (Hazus) does not allow for inclusion of these impacts. The study considers only structural losses and recovery. It also presents a qualitative review of regulatory authority in place to strengthen mitigation.

Conclusions

The study demonstrated a positive return on investment for each project, based on the comparison of awarded funding for the project to avoided losses in subsequent events. Table 5 summarizes the return on investment calculated for the 11 Snoqualmie properties. If various other elements of loss were to be included, such as the social impact, displacement of residents, potential impact on the environment, etc., the return on investment would be greater still.

This report also presents a review of a FEMA loss avoidance study of flood mitigation projects in the City of Snoqualmie. The city, King County, Washington State and FEMA committed millions of dollars to relocating or elevating more than 100 residential properties in the Snoqualmie River floodplain over a period of about 30 years. The FEMA loss avoidance study evaluated 28 of these structures for which all necessary data was available. The study calculated a total project cost for the 28 structures of $1.3 million and estimated total avoided losses of $1.6 million during the flood of November 2006. FEMA noted that the avoided losses would likely have been greater had the U.S. Army Corps of Engineers not removed a constriction in the Snoqualmie River downstream of the City that had caused backwater in the study region during previous flood events.

TABLE 5.
RETURN ON INVESTMENT FOR 11 ELEVATED HOMES IN SNOQUALMIE FROM 2010 LOSS AVOIDANCE STUDY

	Return on Investment (Avoided Cost as Percent of Project Cost)		
Property #	Hazus Model Avoided Cost	2006 Flood Avoided Cost	2009 Flood Avoided Cost
1	65.38%	29.74%	41.48%
2	79.31%	14.69%	10.95%
3	56.33%	12.33%	2.43%
4	56.32%	2.03%	11.46%
5	121.60%	44.41%	53.75%
6	85.71%	53.90%	65.57%
7	63.61%	35.08%	—
8	84.76%	102.35%	132.56%
9	59.71%	109.72%	52.40%
10	80.13%	94.84%	94.39%
11	69.87%	35.76%	57.82%

Rossi et al. 1978—Long Term Effects of Natural Disasters

This study is not specific to the King County or Washington State area. Its study area is the United States. However, it was included in this literature review because it was deemed to be influential, based on frequent references to it in other literature. Its conclusions regarding disaster policy and assistance programs are meaningful for King County as for anywhere else in the United States.

Citation

Rossi, Peter H., James D. Wright, Sonia R. Wright and Eleanor Weber-Burdin. 1978. Are There Long Term Effects of American Natural Disasters? Estimations of Effects of Floods, Hurricanes, and Tornados Occurring 1960 to 1970 on U.S. Counties and Census Tracts in 1970. Social and Demographic Research

Institute, University of Massachusetts. Amherst, Massachusetts. 16 pp. *In* Mass Emergencies 3 (1978) 117 – 132.

Scope

This paper was among the first to systematically evaluate how natural disasters have long-term impacts beyond the timeframe immediately after their occurrence. Most previous studies on long-term disaster impacts were case studies looking at individual events that may or may not have been typical. This study evaluated all major floods, tornadoes and hurricanes in the U.S. between 1960 and 1970. To better identify the impacts of these disasters, the study includes estimates of how communities would have developed had the disasters not occurred.

The destruction of homes, stores, factories, public utilities and public facilities, as well as injuries and deaths inflicted upon inhabitants, constitute the direct impacts of a natural disaster. Consequently, it is reasonable to expect that a major indicator of long-term disaster effects would be alterations in the growth patterns of an area's housing and population. This study examines U.S. Census data for areas affected by disasters to identify any such alterations in growth patterns. It assesses whether Census tracts that were subject to tornado, flood or hurricane events showed growth trends in the period between 1960 and 1970 that were more, less or the same as tracts that did not suffer such incidents

Methodology

This study used U.S. Census demographic, housing and economic data to model changes in these characteristics over a decade's time. The model was applied to 1960 Census data in order to project conditions in 1970. Actual 1970 Census data for areas affected by disasters was then compared to the projections to estimate the disaster's impact. This approach was applied to all U.S. counties or metropolitan tracts that experienced a major disaster in the decade and to a control sample of areas that experienced no disaster.

The models were not able to separate the effects of disasters from the effects of public policies implemented in response to the disaster, so study results indicate the impacts of disasters and of recovery efforts, aid contributions, and housing market reactions to disasters.

Conclusions

This study found that natural disasters have no discernible effects on county or census tract population or housing trends that last for an appreciable period of time. Based on its findings, it presents the following key conclusions:

- Assessments of the likely effects of natural disasters must take into account the magnitude of the losses involved against the resources at the command of the unit in question (e.g., a household or a county). The larger the impact ratio (ratio of loss to available resources), the larger the need for outside help. Post-disaster long-term assistance may be more appropriate for individuals, families and businesses than for the larger community. More extreme disaster events are likely to have higher impact ratios than an "average" disaster.
- In an ideal case of unlimited resources, policies based on the worst imaginable disasters are reasonable and defensible. In such a world, every city could be prepared for a 1,000-year flood. However, given other demands on resources, it is reasonable to question how big a disaster it is rational and efficient to prepare for. The most reasonable policy may be to admit that catastrophic events cannot be prepared for and to expect that special measures would have to be taken *ad hoc* if such events occur. Disaster policy should be tuned to the needs associated with an average disaster and applied to those events alone.

Costanza et al. 1997—Value of Ecosystem Services

This study is not specific to the King County or Washington State area. Its study area is the world. However, it was included in this literature review because it was deemed to be influential, based on frequent references to it in other literature. Its conclusions findings on average unit values for ecosystem services are meaningful for King County as for anywhere else in the world.

Citation

Costanza, Robert, Ralph d'Arge, Rudolf de Groot, Stephen Farberk, Monica Grasso, Bruce Hannon, Karin Limburg, Shahid Naeem, Robert V. O'Neill, Jose Paruelo, Robert G. Raskin, Paul Sutton and Marjan van den Belt. 1997. The Value of the World's Ecosystem Services and Natural Capital. 8 pp. *In* Nature, Vol. 387. May 15, 1997.

Scope

This study's goal was to estimate the incremental value of ecosystem services (the estimated rate of change of value compared with changes in ecosystem services from their current levels). Many previous studies had estimated the value of a wide variety of individual ecosystem services. This is one of the earliest and most comprehensive studies to gather together this large but scattered amount of information and present it in a form useful for ecologists, economists, policy makers and the general public. From this synthesis, the study estimated values for ecosystem services per unit area by biome (vegetation cover type), and then multiplied by the total area of each biome for a global estimate of the value of ecosystem services.

Methodology

The study methodology involved a literature review and a few original calculations. The literature review recorded valuation methods, location and stated value from over 100 studies. Many of the valuation techniques used in the studies are based, directly or indirectly, on attempts to estimate individuals' "willingness-to-pay" for ecosystem services. Each estimate was converted to US$ (1994) per hectare per year using the USA consumer price index and other conversion factors as needed. To adjust for income effects for some estimates, service estimates were converted into US$ using the ratio of purchasing power GNP per capita for the country of origin to that of the USA. Where possible, estimates were stated as a range, based on high and low values found in the literature, and an average value. Some estimates from the literature on 'total ecosystem value' were recorded for comparison with totals from the other techniques.

To estimate the total global extent of each ecosystems, the study used an aggregated classification scheme with 16 primary categories to represent global land use. The major division is between marine and terrestrial systems. Marine was further subdivided into open ocean and coastal, and coastal was subdivided into estuaries, seagrass/algae beds, coral reefs, and shelf systems. Terrestrial systems were broken into two types of forest (tropical and temperate/boreal), grasslands/rangelands, wetlands, lakes/rivers, desert, tundra, ice/rock, cropland, and urban.

Conclusions

The study provides a table giving average ecosystem service value in US$ per hectare per year for 17 ecosystem services and 21 biomes. These estimates represent worldwide unit values, and estimates are also provided for total worldwide value by ecosystem service and by biome. A world map of total ecosystem service value per hectare per year is also presented.

The study estimates that the average annual value of ecosystem services is US$33 trillion—1.8 times the global gross national product. One practical use of the estimates presented is to help modify systems of national accounting to better reflect the value of ecosystem services and natural capital. A second important use of the estimates is for project appraisal, where ecosystem services lost must be weighed against the benefits of a specific project. Because ecosystem services are largely outside the market and uncertain, they are often ignored or undervalued, leading to the error of constructing projects whose social costs outweigh their benefits.

4. SUMMARY OF DOCUMENTS ADDRESSING PART OF KING COUNTY

Shannon & Wilson 2002—Green River Flood Damage Analysis

Citation

Shannon & Wilson. 2002. Preliminary Risk-Based Flood Damage Analysis: Green River Flood Control Zone District, King County, Washington. Prepared for King County Water and Land Resources Division by Shannon & Wilson, Inc. Seattle, Washington. 41 pp. January 2002.

Scope

A risk-based analysis was performed to determine flooding-related damage that could occur as a result of levee and revetment instability in the Green River Flood Control Zone District (which has since been replaced by the King County Flood Control Zone District). The objective of the study was to develop a preliminary estimate of the expected annual damage to structures and contents within the District's floodplain. This risk-based analysis accounted for uncertainty in available data associated with the complexity of systems such as rivers, levees and floodplains and their uses. Risk-based analysis identifies and quantifies the effects of uncertainty. The results were intended to provide an initial basis for developing a long-term levee- and revetment-maintenance and repair funding plan and to identify elements of the risk-based analysis that may require a more thorough evaluation.

Methodology

The analysis used the U.S. Army Corps of Engineers' Hydrologic Engineering Center Flood Damage Analysis (HEC-FDA) software to estimate expected annual damage. The study used a simplified model of the river, levees and economic impacts of flooding:

- The river is represented by a **discharge-probability function** and a **stage-discharge function**, obtained from single locations.
- Modes of levee failure evaluated in the study included under-seepage, through-seepage, slope stability of the levee on the riverside under static conditions, slope stability of the levee on the landside under static conditions, slope stability of the levee on the riverside during rapid drawdown, and scour due to river flow. These failure modes were evaluated separately and then combined to determine a composite **river-stage/levee-failure-probability function**.
- Historical flood damage data was used to establish the **stage-damage function**, which expresses the relationship between water level and the cost of damage incurred.

Conclusions

The estimated damage per year in the Green River Flood Control Zone District determined by the study for existing conditions is $65,730,000, with a standard deviation equal to $330,000. The estimated annual damage to residential structures and contents is $3,730,000 (3.4 percent of the total assessed value of

improvements and contents for these structures). The estimated annual damage to non-residential structures and contents is $62,000,000 (1.1 percent of the total assessed value of improvements and contents for these structures).

This estimate could be more accurately defined given a larger scope, including further investigation and exploration of the river, levees, floodplain characteristics, and adjacent land use. The study recommends a detailed survey of the levee, river and floodplain, including visual reconnaissance and inspection, photogrammetry, topographic surveys, subsurface exploration, and soil testing.

Asia Pacific 2005—WRIA 9 Ecosystem Services and Conservation

Citation

Asia-Pacific Environmental Exchange. 2005. Ecosystem Services Enhanced by Salmon Habitat Conservation in the Green/Duwamish and Central Puget Sound Watershed. Final Report. Prepared for WRIA 9 Steering Committee and King County and King County Water and Land Resources Division by David Batker, Elizabeth Barclay, Roelof Boumans and Terri Hathaway of Asia Pacific Environmental Exchange. 93 pp. February 2005.

Scope

This study estimated the value of ecosystem goods and services—including flood prevention—produced within the Green/Duwamish and Central Puget Sound Watershed, which is designated Water Resource Inventory Area (WRIA) 9. WRIA 9 lies completely within King County; it covers 664 square miles in the southern portion of the county—29 percent of the total county area of 2,307 square miles.

The study was conducted as part of the effort of preparing the WRIA 9 Salmon Habitat Plan (*Salmon Habitat Plan – Making Our Watershed Fit for a King*, Green/Duwamish and Central Puget Sound Watershed WRIA 9 Steering Committee, August 2005). It identifies ecosystem goods and services that would be enhanced by implementing the WRIA 9 Habitat Plan and examines two case studies for salmon restoration actions. The study's methodology, results and conclusions are summarized in Chapter 6 of the Habitat Plan.

Methodology

Taking the lowest and highest dollar value range per acre for each vegetation type established in academic literature (forest, wetland, etc.) and multiplying that range by the acreage of that vegetation type in the study area provides a rough range of estimates for the value of ecological services provided by the subject ecosystem. Using geographic information system (GIS) data for WRIA 9, the acreages of forest, grass and shrublands, agriculture and pasturelands, wetlands, urban areas, lakes, ponds, rivers and streams, and rock were multiplied by the estimated value per acre for each identified ecosystem service. Peer reviewed journal articles were reviewed for each GIS classification and the values associated with each of 23 ecological services. The high and low values for each ecosystem type and ecological service were selected to provide the high and low range estimates. A value-transfer methodology was then used to calculate a range of dollar values for ecosystem services provided annually in WRIA 9.

The study categorizes ecosystem services into the same groupings used in Earth Economics 2007, as listed in Table 2 of this summary report. In that framework, flood protection is included in the category referred to as "disturbance prevention."

Conclusions

The study estimates the value of the disturbance-prevention ecosystem service for all of WRIA 9 based on land cover type, as summarized in Table 6.

TABLE 6.
RANGE OF DISTURBANCE-PREVENTION ECOSYSTEM SERVICE VALUES FOR WRIA 9 FROM ASIA PACIFIC 2005

	Range of Annual Value of Disturbance Prevention Ecosystem Service	
Land Cover	Low	High
Forest	$78,999,560	$571,956,814
Grasslands and Shrubs	$22,311,072	$161,532,161
Agriculture and Pasture	$349,977	$2,533,615
Urban	$0	$0
Lakes, Rivers, Ponds, Reservoirs	$0	$0
Wetlands	$1,579,001	$11,431,965
Coastal	$1,484,084	$10,744,768
Rock	$0	$0
Total	**$104,723,694**	**$758,199,323**

FEMA 2009—Green River Hazus Analysis

Citation

FEMA. 2009. Hazus Analysis for the Green River Valley. Prepared by Federal Emergency Management Agency Region X. Seattle, Washington. 50 pp. October 6, 2009.

Scope

Green River flows are controlled by the Howard Hanson Dam, which is owned by the Army Corps of Engineers. Following a record high level of water behind the dam in January 2009, the Corps discovered two depressions on the right abutment, increased water levels in groundwater monitoring wells, and silty water entering the abutment drainage tunnel. The Corps then installed additional monitoring equipment and conducted tests to determine the elevation to which the pool behind the dam can be raised without significant adverse impact on the abutment. Potential impacts of dam operation restrictions included increased flood risk to the Green River valley below the dam.

In June 2009, King County Emergency Management requested support from FEMA Region X in assessing risk to communities potentially affected by the dam restrictions. FEMA evaluated the impacts and effects of three flooding scenarios on the Green River using Hazus-MH and incorporating depth grids developed by King County and the Corps, planning and infrastructure data from local communities, and default Hazus information where no more accurate data exists. Each scenario represents a situation whereby flooding occurs downstream of Auburn that is beyond the capability of the existing levee system. The results of this study provide estimates of loss and damage that are likely to occur given the data modeled.

Methodology

Hazus requires the following information about the built environment to calculate loss due to flooding:

- Structure location
- Occupancy type
- Square footage
- First floor height above grade
- Replacement and content values.

All but content value and first floor height above grade were available in King County's April 2009 GIS data package, which includes parcels, assessment information, and essential facilities. Improvement values from King County's Assessor were used for replacement values. Content value and first floor height above grade were calculated using Hazus default methodologies. Hazus also requires flood depth grids, which are created from hydrologic and hydraulic modeling to show flood depth in feet. For this study, three depth grids were used:

- Scenario 1, the Corps' depth grid for a flow of 17,600 cubic feet per second (cfs)—The key assumption in this scenario is that the levees remain intact (i.e. the channel and levees contain 12,800 cfs while 4,800 cfs overtops the levees and floods the overbank areas).
- Scenario 2, the King County 100-year base flood study—The key assumptions in Scenario 2 are a base (1-percent annual chance) flood event with a volume of 12,800 cfs and a combination of six "with and without" levee scenarios modeled to simulate levee failure.
- Scenario 3, a combination of the two studies, with 17,600 cfs and levee removals—The depth grids imported into Hazus for this scenario are the result of applying the levee modeling assumptions from Scenario 2 with the water volume (17,600 cfs) used in Scenario 1.

Using the combination of the depth grid and the local data, Hazus calculates economic losses, shelter requirements, and debris. A comparison was also completed between each flood scenario. Economic loss is calculated as building, content, and inventory (business) loss as well as business interruption costs.

Conclusions

Estimated losses for the three scenarios modeled are summarized in Table 7.

TABLE 7.
HAZUS-ESTIMATED FLOOD LOSSES DUE TO GREEN RIVER FLOODING FROM FEMA 2009

	Hazus-Estimated Flood Loss Value (millions)		
	Scenario 1—17,600-cfs Flood Flow	Scenario 2—100-Year Flood with Some Levees Removed	Scenario 3—17,600 cfs Flood Flow and Some Levees Removed
Building Losses			
Structure	$340.28	$508.00	$977.70
Content	$725.84	$1,048.05	$2,038.26
Inventory	$257.99	$400.52	$694.35
Building Subtotal	***$1,324.11***	***$1,956.57***	***$3,710.31***
Business Losses			
Income	$2.39	$2.88	$6.03
Relocation	$1.53	$1.73	$3.15
Rental Income	$1.23	$1.45	$2.76
Wages	$17.13	$4.79	$26.15
Business Subtotal	***$22.28***	***$10.86***	***$38.09***
Total	**$1,346.39**	**$1,967.43**	**$3,748.39**

Critical Infrastructure Group 2009—Green River Flood Impacts Workshop

Citation

Critical Infrastructure Protection Working Group 2009. Summary Report on the Critical Infrastructure Interdependencies Workshop; Focus: Potential Flood Impacts and Short and Longer Term Regional Risk Mitigation Associated with the Green River; Held November 12, 2009 in Seattle, Washington. Workshop conducted by the Washington Homeland Security Region 6 Critical Infrastructure Protection Working Group, the Pacific Northwest Economic Region Center for Regional Disaster Resilience, and the Puget Sound Partnership for Infrastructure Security and Resilience, in cooperation with the City of Tukwila and King County Office of Emergency Management. 31 pp. November 12, 2009.

Scope

Local government agencies, private stakeholders and other key organizations convened on November 12, 2009 in Seattle to discuss potential impacts from a major flood in the Green River Valley and identify ways to mitigate consequences for public health and safety and the region's economy. The workshop was designed to highlight key infrastructure dependencies and to facilitate discussion among critical infrastructure owners on preparedness, response, recovery and long-term restoration.

The first session presented background on the Howard Hanson Dam, a status report on repairs associated with the dam and downstream levees, and an overview on infrastructure dependencies and types of vulnerabilities and impacts. The second session presented "snapshots" of critical infrastructure sectors in the region and issues involved in developing a flood mitigation and restoration plan. The workshop concluded with discussion of additional short-term mitigation measures that could be undertaken and development of a longer-term regional mitigation strategy to deal with potential flood impacts.

Methodology

This report is a workshop summary. The workshop consisted of presentations by government and business officials. Workshop results are based on participant comments and feedback forms.

Conclusions

Economic impacts of flooding were not presented as cost estimates at this workshop, but the types of economic disruptions that could occur were outlined, as follows:

- Electric and gas service disruptions could be of significant duration. Utilities will not be able to restore power until all floodwaters have subsided and equipment is dried out. Customers may be required to have service inspections.
- The Olympic Pipeline running through the Green River Valley supplies most of the fuel needs of Western Washington and all of the fuel needs of Sea-Tac Airport and the Port of Seattle. Potential flood impacts on this operation are as follows:
  - The main hub for pipeline operations is in Renton and could be forced to shut down during a flood. An alternate command center in Tacoma can run the pipeline should this happen. Without the Renton hub, operations would be down to 70 percent.
  - Affected fuel companies typically maintain a three-day supply of product. After three days, there would be a need to transport fuel by means other than through the pipeline, using trucks and barges.
  - Sea-Tac Airport keeps enough fuel on hand for three days; distribution disruption for longer than that would have far-reaching effects. Should the pipeline segment to Sea-Tac be shut down when transporting product other than jet fuel, the line would have to be cleared once operations were running again, causing further delay in providing jet fuel. If there were significant flooding, it could take several weeks to months to get facilities repaired, rebuilt, and back on-line.
- A one-day shutdown of the airport (due to flood impacts on the pipeline supplying jet fuel) would take three days to get air flights back to normal. Also, the airport is the major hub for the State of Alaska, which is dependent on air cargo supply chains.
- Many transportation routes would be impassable. Debris traveling down the river could damage bridges. Thirty transit routes would be affected. State Route 18 would probably remain open, but State Route 167 would be impacted. There would be high volume on I-5. This, in conjunction with an evacuation, would cause major traffic disruptions and interrupt the trucking industry.
- Qwest (the local phone service provider at the time of the workshop) has five central offices in the region, including a cyber-center in Tukwila, a warehouse in Kent, and cables, equipment, garages, and controlled environmental vaults. Qwest serves the FAA, 911, local emergency services and law enforcement, schools, and hospitals. If the company's assets were inundated, telephone service would be disrupted to Qwest customers. Restoration of telecommunications services could take weeks in the event of major flooding and would follow power restoration.
- The King County sewer system in the Green River valley is only capable of handling routine wastewater flows and would not be able to handle additional flows that would come from the interior drains of inundated homes and businesses. The conveyance system in the area of concern is a gravity system that flows to the King County South Treatment Plant, and the system in essence would become a sump for the inundated areas and would quickly be

overwhelmed. Wastewater systems in the inundation area would not be fully operational for some time because of contamination, lack of power for pumps, and the need to drain, flush, and test the system.

- In the event of major flooding, each city in the flooded area would need to test its potable water to ensure that it was not being contaminated.
- Public health concerns associated with flooding include hazardous materials co-mingling with floodwaters, sewage overflows, drinking water system integrity, solid waste/debris management, rodents/vectors, dead animals, household chemicals, food safety and sanitation, food warehousing and distribution, and mass care sheltering.

Earth Economics 2010—Snoqualmie Watershed Valuation

Citation

Earth Economics. 2010. A New View of Our Economy: Nature's Value in the Snoqualmie Watershed. Prepared by Earth Economics. Tacoma, Washington. 89 pp. June 2010.

Scope

This study estimated the value of ecosystem goods and services—including flood prevention—produced within the Snoqualmie Watershed. The Snoqualmie watershed covers 692 square miles, largely in King County but with a small portion in Snohomish County. It represents over a quarter of the total county area of 2,307 square miles.

Methodology

The methodology used to conduct this economic valuation was the technique called benefit-transfer or value-transfer, wherein the estimated economic value of an ecological service is determined by examining previous valuation studies of similar services in comparable locations. Additive values provide different services and contribute to the total value of an ecosystem. An acre of forestland provides water regulation and filtration, aesthetics, flood protection and habitat. One study may establish the value per acre of watersheds for drinking water filtration. Another study may examine the value per acre of wildlife habitat. To determine the full per acre value provided by a vegetation type, ecosystem service values are summed up and multiplied by the acreage. The Snoqualmie Watershed was divided into 15 vegetative land cover types, and the ecosystem service valuation was performed for each type.

The study categorizes ecosystem services into the roughly same groupings used in Earth Economics 2007, as listed in Table 2 of this summary report, although a few services have been combined or omitted. In the framework for this study, flood protection is included in the category referred to as "disturbance regulation."

Conclusions

Of the 15 vegetative land cover types identified in the Snoqualmie Watershed, this study found ecosystem services and any kind provided in only 11 land cover types, and estimated the value of flood protection (disturbance regulation) provided only for the riparian buffer land cover type. The estimated range of disturbance regulation value for this cover type is $7.56 per acre per year to $235.73 per acre per year.

This study does not show an acreage of riparian buffer in the Snoqualmie Watershed to which these unit estimates of flood protection service values can be applied. However, comparison of total ecosystem service unit value estimates in two tables (Table 8 and an un-numbered table on page 58) suggest that the riparian buffer designation is the same as the "riparian forest mid to late," which is shown as have an area

of 35,977 acres. Applying this area would give a range of annual flood protection benefit in the Snoqualmie Watershed of $272,000 to $8,481,000.

This study notes incidentally that "It was recently estimated that a 100-year flood along the Snoqualmie River would displace approximately 1600 residents in Snoqualmie alone and cost more than $29 million." This estimate is referenced to "100-year flood hazard exposure data by jurisdiction" developed in 2010 by "King County Flooding Services"; this source was not able to be located for this literature review.

Goodwin 2010—Green River Flooding Economic Impacts

Citation

Goodwin, Tom. 2010. Economic and Tax Revenue Impacts of Potential Flooding in the Green River Valley. Prepared by Tom Goodwin, Chief Economist, Office of Economic & Financial Analysis, Metropolitan King County. Seattle, Washington. 18 pp. January 13, 2010.

Scope

Because of water seeping through an earthen bank next to the Howard Hansen Dam after record high water in 2009, the U.S. Army Corps of Engineers must limit the amount of flood water it stores behind the dam until it can make permanent repairs. Given this dam storage limitation, Green River valley residents, businesses and farms below the have been preparing for a higher risk of flooding. This report addresses the potential economic and tax revenue impacts of such flooding.

Methodology

A computer simulation scenario constructed by the Corps of Engineers was the basis for this analysis. The Corps estimated the level of inundation for a Green River flow of 25,000 cfs measured by the gauge at Auburn, with no levee failures. This is a severe case but not the worst case. A GIS "shape file" with the exact coordinates of the 25,000 cfs scenario inundation area was created, and economic data sources were overlaid on this shape file. The mapped inundation area does not take into consideration recent defenses placed along the river such as levee fortification and sandbagging.

Conclusions

Key findings of this study are as follows:

- There are close to 100,000 jobs in the inundation area with a payroll of $16 million per day.
- The total value of all output in the inundation area is over $63 million per day.
- Over 100,000 people commute into or out of the inundation area.
- There are 4,771 retail business sites in the inundation area, which generated $4.7 billion in taxable retail sales in 2008.
- Based on 2008 data, over $1.2 million per day in sales tax revenue would be lost during a flood event. Of that, $156,000 per day would be lost to King County's general, criminal justice, mental illness and drug dependency, and Metro Transit funds; $111,000 per day would be lost to the cities of Auburn, Kent, Renton, and Tukwila.
- The assessed value of property in the inundation area was over $6.7 billion in 2008, generating $112 million in annual property tax. Property tax revenues would not be immediately affected but could depress new construction in the area and shift the tax burden to other parts of the county.

DSES-10 2011—Green River Valley Regional Consequence Assessment

Citation

DSES-10. 2011. Regional Consequence Assessment Report: 2010 Dams Sector Exercise Series, Green River Valley. Prepared by the Department of Homeland Security and the U.S. Army Corps of Engineers. 127 pp. May 2011.

Scope

A significant Green River flood event would create serious consequences for local communities and businesses. The 2010 Dams Sector Exercise Series (DSES-10) involved public and private stakeholders in the Green River valley to address regional disaster resilience in response to this potential threat. Los Alamos National Laboratory and the U.S. Army Corps of Engineers used a worst-reasonable-case flood scenario to assess potential Green River flood impacts on infrastructure, population, and the economy. The Regional Consequence Assessment presents the following findings of an evaluation of potential flooding consequences:

- Direct population and housing impacts
- Direct infrastructure impacts affected by floodwater and electric power outages
- Cascading infrastructure impacts
- Short- and long-term economic impacts.

The primary goal of the DSES-10 project is to achieve a greater understanding of potential impacts of significant flooding events along the Green River Valley and to identify critical infrastructure interdependencies that influence local and regional disruptions in such an event. A Regional Resilience Strategy will be developed as the overall outcome of the DSES-10 project.

Methodology

The Regional Consequence Assessment used a flood scenario based on a 1-percent-chance-annual-exceedance flood event and an emergency release from Howard Hanson Dam to maintain reservoir elevation at 1,167 feet. Levees were assumed to remain in place without added flood protection measures, except for a failure of the 180th Street levee (commonly referred to as the Tukwila 205 levee).

The hydrologic and hydraulic models used to evaluate flood impacts included a steady-state Hydrologic Engineering Center River Analysis System (HEC-RAS) model of the entire study reach and a two-dimensional hydraulic model (FLO-2D) for more urban areas.

The Hydraulic Engineering Center Flood Impact Analysis (HEC-FIA) model, Los Alamos National Laboratory infrastructure models, and the Regional Dynamics (REDYN) economic analysis model were used to identify and estimate the population, infrastructure and economic impacts, respectively.

Conclusions

Modeling of the extent and duration of floodwaters indicates that floodwater may take up to two weeks to recede from some areas. The following are key impacts were predicted by the evaluation:

- Estimated damage to structures, contents, and automobiles ranges from $3.70 to $3.76 billion, depending on the amount of time between the warning and the flood.

- Building restoration times are estimated to be as long as 36 months, depending on the type of construction and flood depth period. FEMA standards requiring non-residential buildings to elevate or flood-proof to 1 foot above base flood elevation after a flood could lengthen the restoration period beyond 36 months.
- Businesses exposed to the flood hazard include:
  - 5 farm/ranch businesses and 10 food processing and manufacturing facilities
  - 27 banking entities
  - Critical manufacturing facilities including steel plants, defense industrial base suppliers, and aerospace and aircraft industries
  - Many retail stores and warehouses
  - 24 long-term care facilities
- More than 15,000 customers may be affected by power outages.
- Road travel times and average trip distance may increase by 13 percent to 38 percent.
- When indirect and induced output losses are combined with direct output losses, King County economic output losses are as high as $40 billion the first year. These losses decrease but persist throughout the restoration period of up to three years. When the positive, offsetting effect of restoration investment is incorporated into the estimate, King County economic impacts are reduced but still negative; with first-year output losses of $16.7 billion and first-year employment losses of 71,900.
- Long-term negative impacts on the King County economy persist throughout most of the forecast period through 2030, largely due to King County losing market share to businesses outside King County as those businesses become more profitable and attract labor and other resources away from King County.

Tetra Tech 2011—180th to 200th Street Levee Setback Study (Draft)

Citation

Tetra Tech. 2011. 180th to 200th Street Levee Setback Study—DRAFT. Prepared for King County Water and Land Resources Division by Tetra Tech, Inc. Seattle, Washington. 382 pp. May 2011.

Scope

As an early component of a King County project to replace 2.7 miles of levees along the Green River between South 180th Street and South 200th Street was a series of technical analyses to assess the advantages and disadvantages of building the new levees in the same location as the existing levees or setting them back various distances from the river. The 180th to 200th Street Levee Setback Study describes those analyses and their key findings. Key elements of the levee setback study include a flood-damage risk assessment and an analysis of the value of ecosystem services that could be provided by various setback options. Although these analyses are for a specific project location on the Green River, their methodologies and general conclusions are meaningful for a broader assessment of flood economic impacts throughout King County.

The version of the study report reviewed for this summary report was a draft; the final report has yet to be completed and accepted by King County.

Methodology

Estimated Costs

Construction costs were estimated for three levee options:

- Replace the existing levee in the same alignment along the river bank.
- Remove the existing levee and build a levee set back 300 feet from the river bank.
- Remove the existing levee and build a levee set back 600 feet from the river bank.

Estimated Benefits

Avoided cost for each alignment option was calculated through a risk assessment that estimated flood damage with and without the proposed project for three flooding scenarios:

- Scenario 1—Howard Hanson Dam providing its full design level of flood control
- Scenario 2—Howard Hanson Dam providing a partial level of flood control below its design level
- Scenario 3—No flood control provided by Howard Hanson Dam

The risk assessment was based on the following:

- A hydrologic analysis that established probabilities for various river stages
- A geotechnical analysis that estimated probability of levee failure as a function of river stage
- A levee breach analysis that estimated extent and depth of floodwaters in the event of a levee breach
- Hazus modeling to estimate damage costs associated with modeled levee breaches
- Modeling using FEMA's Benefit Cost Analysis Re-engineering (BCAR) software to calculate annualized avoided damage and the net present value of avoided damage over the project's effective life.

Estimates were made of the value of ecosystem services that could be enhanced by making additional riparian area available with the levee setback alignment options. Methods for estimating each ecosystem service were as follows:

- Wetland Habitat—Determine the increase in area providing wetland habitat due to the proposed levee setback; determine wetland value per acre based on a literature review
- Salmon Habitat—Make an assumption about salmon population increase resulting from setback; determine household willingness to pay for salmon based on assumed increase, using data from a previous study; multiply household willingness to pay by number of households in Puget Sound region
- Outdoor Recreation—Calculate new riparian area within setback as a percentage of current park area in project vicinity; determine the increase in number of area recreational activities by applying the area percentage increases to the number of recreational activities in one year by residents within 2 miles of the project (from previous studies); multiply the number of additional recreational activities by an estimated "recreational surplus value" per activity (from a previous study).

- Precipitation Storage—Estimate the precipitation storage value of increased impervious surface in the setback area as equal to the cost of constructing an infiltration facility that would provide an equivalent volume of storage.
- Carbon Absorption—Estimate the number of trees that would grow in within the new setback areas; estimated tons of carbon dioxide sequestered by those trees based on previous studies; determine unit value of carbon dioxide sequestration from a literature review of previous studies.
- Air Quality—Estimate the number of trees that would grow in within the new setback areas; estimated tons of non-carbon pollutants sequestered by those trees based on previous studies; determine unit value of carbon dioxide sequestration from a literature review of previous studies.

Conclusions

The costs and benefits estimated for the three levee options are summarized in Table 8.

TABLE 8.
SUMMARY OF REPLACEMENT LEVEE COSTS AND BENEFITS FROM TETRA TECH 2011 (DRAFT)

Benefit or Cost	In-Place Replacement Levee	300-Foot Setback Levee	600-Foot Setback Levee
Costs			
Levee Construction	$81.9 million	$58.8 million	$55.2 million
Parcel Acquisition	$155.5 million	$224.6 million	$293.8 million
River Corridor Restoration	$0	$4.4 million - $14.4 million	$7.1 million - $23.0 million
River Corridor Excavation	$0	$0.43 million - $6.5 million	$5.0 million - $9.0 million
Benefits			
50-Year Present Value of Avoided Flood Damage			
Scenario 1 (Full Dam Flood Control)	$30.2 million	$31.2 million	$32.0 million
Scenario 2 (Partial Dam Flood Control)	$129.4 million	$138.0 million	$159.9 million
Scenario 3 (No Dam Flood Control)	$230.8 million	$153.6 million	$204.9 million
50-Year Present Value of Ecosystem Service Benefit			
Wetland Habitat	$0	$3.5 million - $5.2 million	$4.2 million - $8.6 million
Salmon Habitat	$0	$30.9 million - $38.3 million	$61.7 million - $76.7 million
Outdoor Recreation	$0	$84.5 million	$145.0 million
Precipitation Storage	$0	$9.8 million	$17.4 million
Carbon Absorption	$0	$3.7 million - $3.3 million	$8.4 million - $7.4 million
Air Quality	$0	$0.6 million - $0.7 million	$1.5 million - $1.6 million