State Route 105:
Benefit - Cost Analysis

northerneconomics inc.

in association with
Western Washington University ❖ Coastal Geologic Services
Fairbanks Environmental Services, Inc.

Prepared for

Washington State
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June 2005

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16. ABSTRACT: The State Route 105 Emergency Stabilization project, completed in September of 1997, was an effort to protect the sole road into the North Cove area of Washington State—Route 105—from imminent destruction due to shore erosion. The report provides an assessment of: project impacts on local fish habitat; the projected timing and costs of future beach renourish; and a strategy to provide better analysis of potential environmental impacts for future emergency projects.

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Abbreviations

DNR	Washington Department of Natural Resource
EA	Environmental Analysis
GIS	Geographical Information System
HEP	Habitat Evaluation Procedure
MHHW	Mean Higher High Water
MLLW	Mean Lower Low Water
PIE	Pacific International Engineering
SR 105	State Route 105
USACE	US Army Corps of Engineers
WSDOT	Washington State Department of Transportation
WWU	Western Washington University

Executive Summary

The State Route 105 Emergency Stabilization project began in the summer of 1997 in an effort to protect the sole road into the North Cove area of Washington State—Route 105 (SR 105)—from imminent destruction due to shore erosion (Pacific International Engineering, Final Report, 2001). The lead agency was the Washington Department of Transportation (WSDOT).

Construction began in the early summer of 1998 and it was complete by September of that same year. Monitoring continued through the year 2001 and a final project report suggested that the combination of dikes and groins, coupled with beach nourishment, was successful.

In 2005, project managers with WSDOT contacted Dr. Hart Hodges, economist with Western Washington University, Bellingham. Dr. Hodges was asked to assist WSDOT in assessing the SR 105 project and, if possible, extending that project analysis to other beach erosion control projects. A decision tree that modeled the SR 105 project was an initial objective.

Northern Economics, Inc., also in Bellingham, was retained by WWU to provide project management assistance; an initial outline was developed and two additional project team specialists, a geologist and a biologist, were added in late spring of 2005.

Objectives

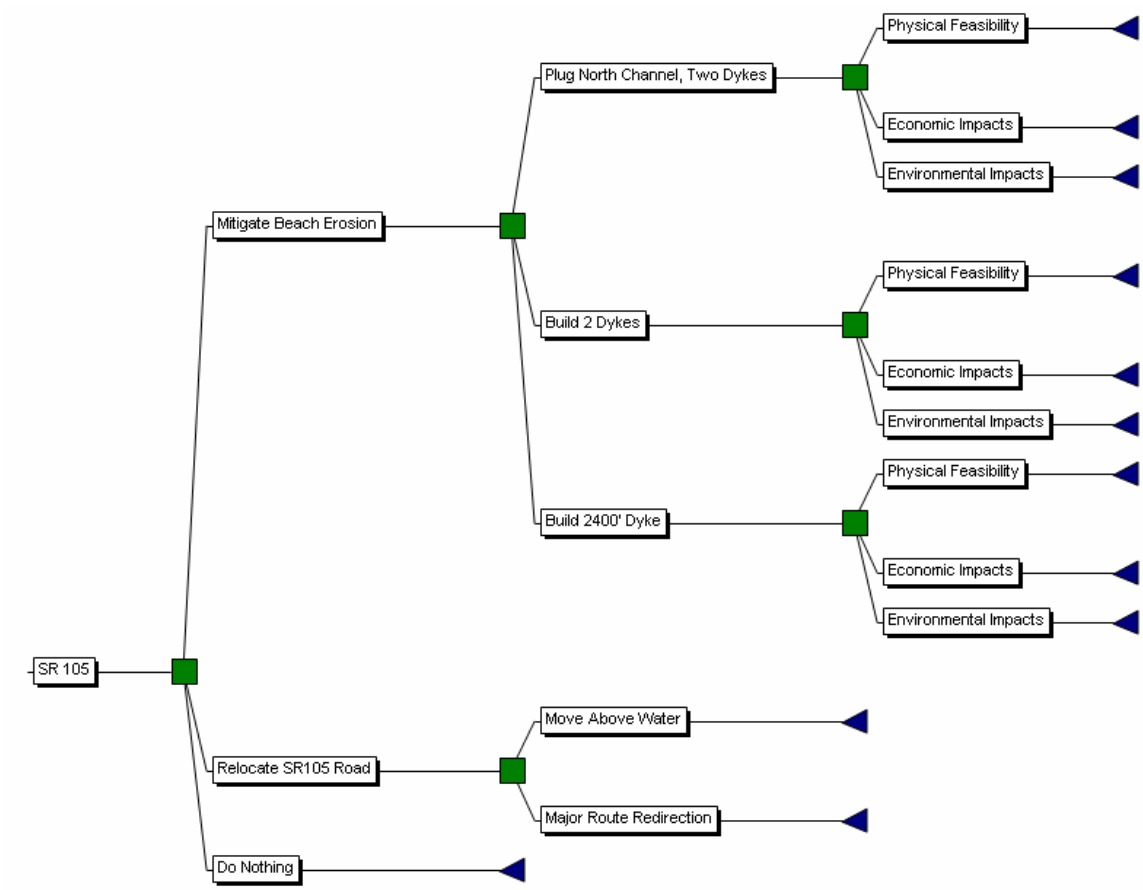
Discussions with Patty Lynch, Senior Compliance Manager with the WSDOT Environmental and Engineering Office, suggested the following SR 105 aspects were notable and should be reviewed carefully:

- What are the impacts on fish habitat from both the groin and dyke?
- How often will the beach need to be renourished with sand?
- This project was an emergency project to prevent major road damage; can a more measured and timely analysis help with environmental economics and impacts for future, but similar, projects?

Modeling

Figure ES -1 is a copy of the first decision tree. Efforts to expand this technique to the more general case indicated decision trees quickly became unwieldy and difficult to work with. By itself, a simple decision tree can help graphically identify the main decision points in a beach erosion control project. Order-of-magnitude costs and probabilities, if known (or derived), can be entered into the tool to help guide and structure the project.

Figure ES - 1. Initial SR 105 Decision Tree



Reports from an on-site visit in June of 2005 indicated a site-specific model should be used, preferably one that was more user friendly. Team scientists suggested a general model was impractical due to the unique characteristics, both on-shore and off-shore, of each potential beach site. Decision trees, however, at an initial level, can help WSDOT managers anticipate and plan for beach erosion control projects.

A risk-adjusted spreadsheet simulation was finally selected, using Palisade Corporation's @RISK, an add-in for Microsoft Excel. Three cases were analyzed: the original design with US Army Corps of Engineers costs (from 2000 and 2002 reports); the original design with 2005 costs (again, from the Corps of Engineers); and revised quantities and 2005 costs, based on the June 2005 geological analysis.

Results suggest original beach nourishment quantities and costs were underestimated.

Beach Nourishment

Initial design suggested beach nourishment would be needed every 6 years, with full re-nourishment on a 12-year cycle. This would mean sand (or perhaps gravel) would be placed on the SR 105 beach approximately 6 times during the projected 40-year design period.

After reviewing aerial photographs and developing maps, using a Geographical Information System, the project geologist suggested a more frequent nourishment schedule, from 2 to 4 years. Recent storms and high-energy wave events have exposed a long section of the rock-hardened revetment along SR 105 itself.

This revised interval was incorporated into the spreadsheet simulation.

Fish Habitat Impact

A site visit was conducted on June 9, 2005 during a –1.2 ft. low tide relative to mean lower low water (MLLW) to assess the current habitat conditions of the site. The exposed beach had a low slope that is beneficial for juvenile salmon; however, mean higher high water (MHHW) appeared to be about 3 ft. above the toe of the SR 105 revetment at the most exposed point. The beach was populated with amphipods observed on the beach surface and ghost shrimp as determined by their numerous burrows. The constructed groin and barb structure did not appear to provide salmon predators with advantageous habitat as documented through predator populations and stomach contents (Miller et al. 2002).

Surf smelt and sand lance fish are present at the project site and were captured with a variety of other fish in beach seine samples as part of a fish utilization and behavior study at the project site (Miller et al. 2002).

Findings

The major, general findings of the study are:

- Empirical models of ecosystems (physical and statistical) are especially limited because they are typically unique and applicable to the specific site of development.
- Ecological benefits and costs are more site dependent and much more difficult to evaluate than economic benefits and costs.
- The timely evaluation of potential ecological impacts during future emergency repairs would be improved by surveying areas where such events are most likely to occur. These surveys could systematically categorize the level of ecological services likely to be impacted and estimate the cost per unit to provide similar ecological services.
- Economic benefits and costs are relatively easy to estimate in a short time period.
- Current methods for evaluating multipurpose projects, such as SR 105, use monetary values to estimate net economic benefits and non-monetary measures such as physical units (acres of wetlands) or indexes (habitat indexes) to evaluate net ecological benefits.
- Benefit-cost models are widely used to evaluate economic net benefits and cost effective models–which do not require the assignment of monetary values to benefits–are widely used to evaluate ecological net benefits.
- When projects have the potential to produce both economic and non-economic impacts, a common approach (e.g., the USACE planning guidance) provides for evaluating trade-offs between net economic benefits and the cost of providing units (e.g., acres) of net ecological benefits.

Other findings of the study are:

- The SR 105 project will likely require re-nourishment, probably after the next winter season unless no large storms occur.
- The overall long-term impact on nearshore salmon habitat of beach nourishment for the 105 project appears to be neutral.
- The alternatives to re-nourishment are hard stabilization or relocating SR 105 landward (this would result in high initial costs and lower costs in the future).
- While coarser materials such as gravel beach nourishment have proven to provide relatively stable erosion control projects, the use of gravel is not recommended here. However, gravel beach nourishment has many applications in Puget Sound-Georgia Strait shores for erosion control. The use of slightly coarser sand would make for a slightly more stable re-nourishment, and this approach is supported by the current literature.

1 Introduction

The SR 105 Emergency Stabilization project began in the summer of 1997 to protect the North Cove area of Washington State Route 105 (SR 105) from imminent destruction due to shore erosion (Pacific International Engineering, Final Report, 2001). The project consisted of a rock groin[1] and dike structure along with beach nourishment. The lead agency was the Washington Department of Transportation (WSDOT).

Construction began in the early summer of 1998 and it was complete by September of that same year. Monitoring continued through the year 2001 and a final project report suggested that the combination of dikes and groins, coupled with beach nourishment, was successful.

In 2005, project managers with WSDOT contacted Dr. Hart Hodges, economist with Western Washington University, Bellingham. Dr. Hodges was asked to assist WSDOT in assessing the SR 105 project and, if possible, extending that project analysis to other beach erosion control projects. A decision tree that modeled the SR 105 project was an initial objective.

Northern Economics, Inc. was retained by WWU to provide project management assistance; an initial outline was developed and two additional project team specialists, a geologist and a biologist, were added in late spring of 2005.

There were two proposed phases for this project. In phase 1, an initial outline was developed in conjunction with WWU, and a four-branch decision tree was modeled by analysts with Northern Economics, Inc.

During phase 2 of the project, a site visit was made (in early June 2005) and both geological and biological technical memoranda were developed to assist Northern Economics and WWU in this report.

Project data from baseline monitoring, in 1997, through project completion monitoring in 2001, was used along with the 2005 geological and biological analysis. A structural approach was developed and is reported in this document.

1.1 Background

A project monitoring program began in September 1997, one year prior to construction, and included the collection and analysis of wave and current data, hydrographic and topographic surveys, and aerial photography. Construction began in the early summer of 1998 and was completed by September of that same year. Monitoring continued through the year 2001 and a final project report suggested that the combination of dikes and groin, coupled with beach nourishment, was successful.

Further (planned) monitoring was to indicate whether reduced beach erosion along the shoreline and stabilization of the shoreline along SR 105 was accomplished over the longer term. The total project design life was set at 40 years.

A review of background material for this project suggests it was contentious. Concerns were raised about the physical nature of the project, along with economic, social, and biological concerns.

[1] Groin - a rigid structure built out at an angle from a shore to protect the shore from erosion by currents, tides, and waves or to trap sand (as for making a beach). *Webster's Third New International Dictionary, Unabridged*. Merriam-Webster, 2002. http://unabridged.merriam-webster.com (22 Mar. 2005).

Engineering concerns were based on relatively innovative design and construction methods. For example, one option evaluated large bags of sand that would be dropped from barges to help stabilize and divert erosion. Contractors suggested these bags may burst when hitting the ocean floor; as a result, large rock was dropped instead.

Social concerns included the numerous homes, hundreds of acres of land, and a federal lighthouse reservation that had been lost due to the migrating north channel within Willapa Bay. Residents asked questions about the proposed emergency stabilization project's ability to actually solve these problems.

Biological concerns included fish habitat impacts, potential loss of cranberry bogs, and impacts on wetlands adjacent to the project.

1.2 Project Purpose and Objectives

As a result of this controversy and a desire to enhance its approach to future beach erosion projects, WSDOT staff requested Dr. Hart Hodges' assistance in preparing a decision tree model.

A decision tree is defined as:

> *…a diagram that describes a decision under consideration and the implications of choosing one or another of the available alternatives. It is used when some future scenarios or outcomes of actions are uncertain. It incorporates probabilities and the costs or [benefits] of each logical path of events and future decisions, and uses expected monetary value analysis to help the organization identify the relative values of alternative actions*[2]

The original purpose of this project was twofold:

- First, a specific model would be built, based on the SR 105 project and its decisions, actions, and follow-up.
- Second, a more general model would be extrapolated from the SR 105 model.

By generalizing from a specific project, the project approach and decision tree model can be more easily developed and tied to lessons learned. Specific objectives of the project were:

- Analyze the SR 105 project and note its decision points.
- Construct a decision tree for the SR 105 project with major branching.
- Develop a generalized decision tree model for similar projects in other locations.
- Provide estimates of benefits and costs.

Discussions with Patty Lynch., Senior Compliance Manager with the WSDOT Environmental and Engineering Office, suggested the following SR 105 aspects were notable and should be reviewed carefully:

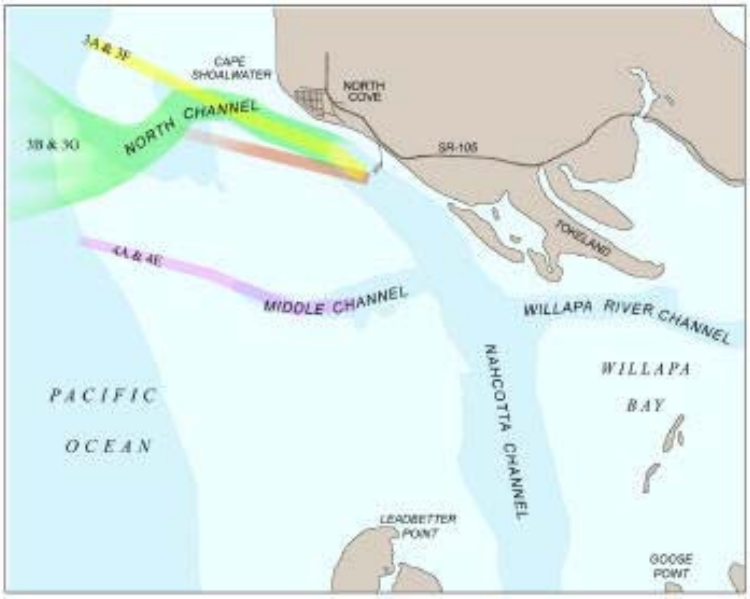
- What are the impacts on fish habitat from both the groin and dike?
- How often will the beach need to be renourished with sand?

[2] *A Guide to the Project Management Body of Knowledge (PMBOK Guide)* Third Edition, Project Management Institute, 2004.

- This project was an emergency project to prevent major road damage; can a more measured and timely analysis help with environmental economics and impacts for future, but similar, projects?

Figure 1 is a general project location map, illustrating Willapa Bay and SR 105.

Figure 1. General Willapa Bay Map



Source: www.washington-coastal.com/willapa_files/

As the project evolved, risk assessment and simulation were added to the decision tree analysis to suggest a range of costs that might be expected for similar projects.

Software selection resulted in a decision to use PrecisionTree by the Palisade Corporation. This software is in general use throughout many firms and universities; it is available at WWU.

In the 2005 scientific analysis, both sub-contractors indicated beach erosion projects were highly site-specific and suggested the proposed model expansion from SR 105 to other cases was problematic. The project team evaluated this and elected to run a sensitivity analysis on project spreadsheets; the program @RISK was selected. The full sensitivity analysis is included in Appendix A.

1.3 Project Participants

Northern Economics Inc., with offices in Bellingham, Washington, assisted WWU with this project by providing project management assistance, an initial project outline, and analysis of the future costs of beach nourishment options. Jim Johannessen and Andrea MacLennan of Coastal Geologic Services, Bellingham, assessed the geological considerations (Appendix B) at SR 105 for extrapolation to other bank stabilization projects. Chris Fairbanks of Fairbanks Environmental Services, Inc., Bellingham, assessed the biological considerations (Appendix C).

2 Results

Phase 1 project results included the probabilities, benefits, costs, and accumulated costs for each branch and node of the decision tree. However, an influence diagram, used as a precursor to the final decision trees, became unwieldy as additional choices and "branches" were added. In addition, the use of a decision tree beyond the specific case became problematic and risk-adjusted spreadsheet simulations were used instead, for Phase 2. Three cases were analyzed: the original SR 105 beach nourishment quantities and costs (1998 and 2000); the original forecasted nourishment quantities in conjunction with 2005 cost estimates; and revised quantities and costs, based on the 2005 geological and biological analysis and USACE cost estimates for area dredging projects.

Results are summarized in this section with more detailed information in following sections and the appendices.

2.1 Economic performance

- SR 105 will require re-nourishment, probably after the next extreme season.
- The nourishment schedule and recommended quantities based on that schedule were quantified and used as inputs to @RISK, a risk-analysis program.
- The recommended costs for required nourishment (and re-nourishment) are significantly higher than the costs originally forecast. This is a result of strong storm events, erosion along the SR 105 revetment, and increased costs per cubic yard of in-place material.
- Increased unit costs, according to the USACE, are due to a scarcity of appropriate equipment to hydraulically dredge and place beach material.

2.2 Ecological performance

- Impacts on fish habitat from both the groin and dike appear to be relatively small, with a neutral habitat impact (for salmonids).
- Limited impacts on pelican habitat are claimed by the Washington Department of Natural Resources (DNR), which, if confirmed, are very difficult to separate and attribute to the groin and beach nourishment.
- The optimum time for re-nourishment would be after an extreme storm season has severely impaired or destroyed the ecosystem and before an ecosystem is re-established.
- It appears to be difficult to time permits with beach re-nourishment at the optimum time for beach ecosystem health.

2.3 Future emergency projects

- Current methods for evaluating multipurpose projects, such as SR 105, use monetary values to estimate economic benefits and costs and non-monetary measures such as habitat indexes to evaluate the cost effectiveness of providing ecological benefits.
- Economic benefits and costs are relatively easy to estimate in a short time period and for a specific site.

- Ecological benefits and costs vary by site and are difficult to convert to monetary values
- Early studies that quantify the benefits of habitat improvement in Washington State, especially at sites where WSDOT structures are or are likely to become at risk, would enable a more systematic consideration of ecological benefits in emergency projects.
- The most cost-effective time for examining alternatives is at the very beginning of project development. The level of uncertainty is greatest at the project start and the ability of all stakeholders to influence cost and schedule is greatest at the beginning; it decreases as the project progresses. A systematic identification of at-risk WSDOT infrastructure and subsequent evaluation of the local ecology would extend the time available for analysis at the beginning of a project.

3 Beach Management Alternatives

Alternatives for the management of beach erosion can be grouped into three major categories:

1. Beach nourishment, (i.e., replenishing the beach with sand or gravel)
2. Constructing hard stabilizers such as groins, seawalls, and dikes
3. Relocating threatened property improvements and letting nature take its course.

The first and second alternatives are commonly used in tandem[3]. Hard stabilization tends to benefit owners of property improvements. Nourishment, while providing some protective value for property, may also increase beach amenity value to the public. Beach nourishment and hard stabilizers both disrupt natural accretion patterns and may cause serious side effects. The relocation alternative primarily affects property owners, who may, in theory, benefit if they are well-compensated for their losses. Visitors may also benefit from relocation if the resulting pattern of businesses and services is an improvement upon the status quo and, for example, if beach amenities are improved.

Individual management alternatives can produce both economic and environmental costs and benefits. Economic costs and benefits are typically evaluated using a benefit-cost framework. The benefit-cost framework requires that all benefits and costs be monetized and discounted to a single, net benefit value. Projects with a positive net benefit are deemed to be economically feasible.

Environmental benefits and costs, which are often an important aspect of beach stabilization projects, do not have market prices and are therefore difficult to monetize. Because of this difficulty in monetizing their value, environmental impacts are often analyzed with a cost effectiveness framework. In a cost effectiveness approach, the monetary costs of providing a unit of ecological benefits, i.e., acre of similar habitat, are estimated. Projects with lower costs per unit are generally preferred to projects with higher costs per unit.

3.1 Evaluation of alternatives

The U.S. Army Corps of Engineers (USACE) has well-documented procedures for conducting both benefit-cost analyses and cost effectiveness studies (ER 1105-2-100). For USACE studies, net economic benefits are measured in monetary values and net changes in ecosystem resources are measured in physical units or indexes (but not monetary units). When projects have the potential to produce both economic and non-economic impacts, the USACE planning guidance provides for evaluating the trade-offs "as long as the value of what is gained exceeds its implementation cost plus the value of what is foregone."

3.1.1 Economic benefits

The economic benefits of beach nourishment are typically measured by the probability-weighted present value of property saved from future damage. Recreation benefits can be included also. USACE guidelines allow inclusion of recreation in the benefit-cost analysis if the property protection benefits equal at least one-half of the project's costs.

[3] Kriesel, Warren; A. Keeler, and C. Landry. Financing Beach Improvements: Comparing Two Approaches on the Georgia Coast. *Coastal Management*. 32:433-447. 2004

3.1.2 Economic Costs

The economic costs of a beach nourishment policy include the costs of planning, permitting, mitigating, constructing, and maintaining the project over its expected life. Future economic costs are discounted to a current value using a discount rate. For the SR 105 project, a 2 percent inflation rate was used to estimate future costs and a 7 percent discount rate was used to discount future costs and benefits to a present value.

3.1.3 Environmental Benefits Analysis

Models to evaluate environmental benefits must identify at least two measures of ecosystem quality. One relates to satisfying the ecosystem restoration purpose, which is to restore ecosystem naturalness. The other is to restore ecological resources of recognized significance. Model outputs need to capture both ecological resource quality and resource quantity. USACE policy indicates that the models need to characterize ecosystem quality and quantity through either a direct measure (physical units) or an indirect measure (indexes).

Characterizations of relative quality have been very difficult to address. Most habitat models focus on output indicators of habitat quality, the outputs of which are then coupled with acreage (or other geographical measure) determined from maps of plan-affected area based on some prescribed method or protocol. One of the most widely used of these methods is the Habitat Evaluation Procedure (HEP).

While a "one-size-fits-all" model is very process efficient, if justifiable, the diversity of ecosystem and planning conditions prevents this. Empirical models (physical and statistical) are especially limited in this regard because they are typically unique and applicable to the specific site of development (Stakhiv, 2003).

As noted in a report written by Fairbanks Environmental Services, Inc. after the June site visit:

Potential negative impacts as a result of beach nourishment include:

- *Burial of habitat and benthic communities*
- *Increased turbidity*
- *Modification of sediment grain size*
- *Modification of tidal elevation and beach slope*
- *Loss of marine vegetation*
- *Habitat degradation in borrow site*

Modification of shorelines [with] *beach nourishment or engineered structure may…benefit salmon by improving shallow water habitat…attributes:*

- *Migration: juvenile and adult salmon use the shorelines as migration routs between habitat units*
- *Nursery: juvenile salmon use the shallow nearshore for rearing and predator avoidance*
- *Juvenile food production and feeding…*
- *Adult food product…*
- *Residence: nearshore habitat provides refuge habitat for juvenile salmon*

- *Physiological transition: juvenile and adult salmon use estuaries and nearshore habitat to transition between freshwater to marine life stages…*

The project appears to have had a neutral impact on nearshore habitat for salmonids based on the June 2005 site visit. There has been no discernible impact on the upland habitat, although highway use continues in the area.

3.2 Project Planning, Management

WSDOT requested input about more measured and timely analysis: could this help with environmental economics and impacts for future, but similar, projects? Answers to this question are generally based on early identification of problem areas and careful planning. However, in all projects, the political process can represent a considerable unknown as to urgency, influence, and, ultimately, project funding, as appears to be the case with SR 105.

According to the Project Management Institute (PMBOK, 2004):

- *The level of uncertainty is highest and, hence, risk of failing to achieve the objectives is greatest at the start of the project. The certainty of completion generally gets progressively better as the project continues.*
- *The ability of the stakeholders to influence the final characteristics of the project's product and the final cost of the project is highest at the start, and gets progressively lower as the project continues. A major contributor to this phenomenon is that the cost of changes and correcting errors generally increases as the project continues.*

This suggests money spent at the beginning of a project on plans and baselines will be well worth it during project execution.

4 SR 105 Model Development

After the initial Phase 1 project outline and decision tree were constructed, the team attempted to expand the process to a more general case. Model complexity increased to the point of diminishing returns and an unwieldy, large-sized decision tree model was considered unhelpful.

Following the on-site visit, and technical memoranda, along with further analysis of coastal literature, it was determined that a decision tree could be coupled more successfully with spreadsheets and a Monte Carlo simulation for sensitivity analysis.

This section discusses the use of three project models:

- An influence diagram
- A decision tree
- A risk-based spreadsheet

Software

The software chosen for this project was developed and sold by the Palisade Corporation. It was selected after the review and test of several different programs, but the major factor was its availability in academic form for students and faculty at WWU. Another major advantage of Precision Tree Software is its functionality as an add-in to Microsoft Excel, the standard electronic spreadsheet used by most businesses, schools, and agencies. The Palisade Suite also includes @RISK, an Excel add-in program that allows simulation of a number of input variables.

4.1 Influence Diagram

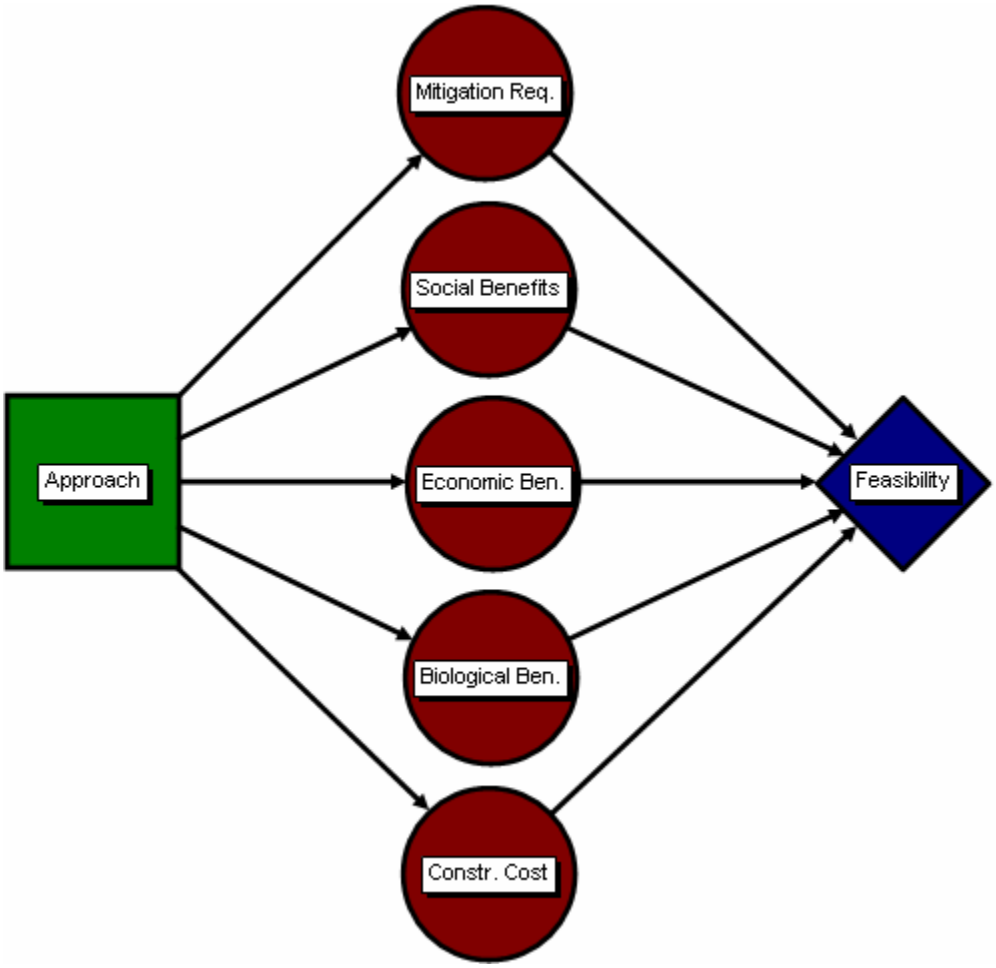
The first step in developing a decision tree for SR 105 was an influence diagram. Influence diagrams are described by Palisade Corporation[4] as follows:

> *Influence diagrams present a decision in a simple, graphical form. Decisions, chance events and payoffs (values) are drawn and shapes (called nodes) and are connected by arrows (called arcs) which define their relationship to each other. In this way, a complex decision may reduce to a few shapes and lines. Influence diagrams … [show] the general structure of a decision.*

Figure 2 illustrates the influence diagram developed for phase 1 of the SR 105 project.

[4] *PrecisionTree, Decision Analysis Add-In for Microsoft Excel*, Palisade Corporation (www.palisade.com), July 2000.

Figure 2. SR 105 Influence Diagram.



Source: Northern Economics Inc., PrecisionTree.

To develop this influence diagram, Northern Economics reviewed technical documents prepared by Pacific International Engineering (PIE) in 1998 as part of project design, as well as other news articles and publications written by the USACE. Three general and two specific areas were developed from the SR 105 project review, as discussed below.

Social Benefits and Costs

As noted on the PIE website, *The goal of the project was to prevent the loss and use of the highway and to prevent the need to perform an expensive highway realignment project*[5]. Doing nothing, which is always an option, was not possible, as loss of SR 105 could have isolated communities or required extensive re-routing to reach homes, businesses, and schools.

[5] Pacific International Engineering website, www.piengr.com, accessed in July, 2005.

Economic Benefits and Costs

Economic benefits and costs were analyzed in a detailed benefit-cost analysis submitted as part of the Project Environmental Analysis (EA) in 1997. Primary emphasis focused on construction costs, as noted in the section below. Major route relocation of SR 105 was ruled out, likely due to cost and the lead times required for highway survey, design, and construction.

Biological Benefits and Costs

Environmental concerns addressed included impacts on cranberry bogs, surficial and benthic organisms, and both short-term and long-term impacts on habitat (upland and marine). These were identified in the 1997 EA and were also included as part of the longer-term monitoring program.

Mitigation Requirements

Mitigation focused on beach nourishment and re-nourishment. As noted by PIE, *The work focused on the addition of beach fill and the construction of both a multi-purpose groin and an underwater dike to reduce wave-induced erosion and tidal channel migration at the site* (www.piengr.com).

Construction, Costs

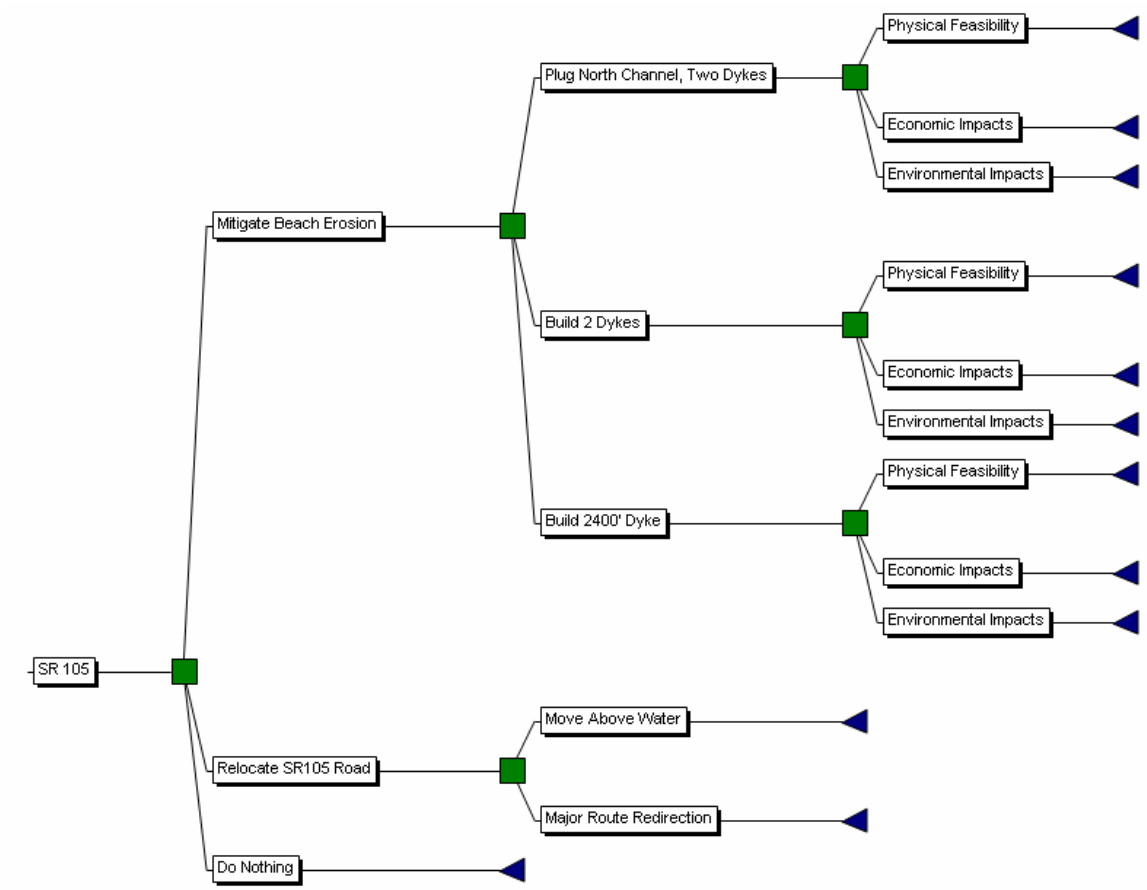
Construction costs were developed for three major types of structures: two dikes with a plug on the North Channel, two dikes without the proposed plug, and a 2,400 foot dike. The final selection was based on the project funds available and the effectiveness of the structures as projected by wave and tide simulation models.

4.2 Decision Tree

Using PrecisionTree, influence diagrams can be quickly developed, modified, and then a more complex graphic developed. Both use symbols, or nodes, with lines (or arcs) to connect them. Decision Trees are a more formal structure with decisions and uncertain (chance) events linked from left to right in a sequence that mimics the natural progress of a decision.

Figure 3 illustrates a decision tree based on the as-built construction of the SR 105 project.

Figure 3. SR 105 Decision Tree, Original Design



Source: Northern Economics Inc., adapted from PIE Technical Memoranda, 1998.

The result is a tree structure with the "root" on the left and branches for each chance event or decision extending to the right. Probabilities of events occurring and payoffs for events and decisions are added to each node in the tree.

For the specific SR 105 project, there appeared to be three fundamental approaches that are typical of beach nourishment projects:

- Do nothing – allowing nature to take its course; this would soon require abandonment of the current SR 105 alignment.
- Relocate State Route 105 itself.
- Mitigate beach erosion through a combination of hard structures (dikes and groins) and beach nourishment (placing sand or local material to mimic coastal processes)

4.2.1 Do nothing

Because the do-nothing approach was unacceptable to most residents and members of local communities, estimates for costs associated with this approach were not calculated for SR 105.

4.2.2 Relocate SR 105

The second major branch (going up from the bottom branch), relocating the road, is similar to the first. It, too, can provide an order of magnitude cost estimate for moving the road higher in elevation, or along another route. This decision tree branch is useful for engineering cost estimates, as it provides detailed quantities and costs for the engineering, construction, and operation of a major route location. The environmental and social implications of the decision can also be tied to this branch.

4.2.3 Mitigate Beach Erosion

The third approach, mitigating beach erosion, includes beach nourishment and hard stabilizers (revetment and a groin and dike). The terms nourishment and re-nourishment are further defined below (Coastal Geologic Services, 2005):

> *Beach nourishment, as defined in a recent Glossary of Coastal Geomorphology, is "the natural or artificial supply of sand or gravel to a beach. Also termed beach restoration, beach fill and beach re-nourishment" (Bird 2005). Beach nourishment is also referred to as beach replenishment, and in some Pacific Northwest applications the use of beach nourishment using gravel has been referred to as constructing a protective berm.*
>
> *Another pair of well-respected authors recently described beach nourishment as "the artificial (mechanical) placement of sand along an eroded stretch of coast where only a small beach, or no beach, previously existed. Efforts to artificially maintain beaches that are deprived of natural sediment thus attempt to proxy nature and (re)nourish the beach by mechanical placement of sand. The beach sediment is thus replenished by artificial means (Finkl and Walker 2005)."*
>
> *Beach re-nourishment typically refers to the resupplying of nourishment material at a previously nourished beach where erosion (of artificial material) has persisted.*

Engineers evaluated three basic solutions for the SR 105 project:

- Plug the North Channel with two dikes.
- Built two shorter dikes and use them for sand accumulation.
- Build a single 2400-foot long dike.

A combination of hard stabilizers, (e.g., a groin and underwater dike) and nourishment was ultimately selected for the SR 105 project. Beach nourishment itself was included with the groin and dike, as part of the initial design.

It was anticipated the hard stabilization structures of the SR 105 project would require very little maintenance over their 40-year life and these structures appear to be performing as anticipated, although the outer portion of the dike has settled. Forecasted maintenance for the nourishment included two total re-nourishments during the same 40-year period; the 2005 geological report suggests this may be optimistic, and the anticipated costs of future re-nourishment are a focus of this study.

4.2.4 Other Decision Tree Branching

There are other decision tree branches shown. For the selected decision, mitigating beach erosion, each of the three potential design solutions has three sub-branches:

- Physical feasibility (and cost)

- Economic impacts (benefits and costs)
- Environmental impacts (including, if possible, non-market costs)

Precision Tree has the ability to conduct both sensitivity analyses as well as develop risk profiles; these were anticipated for use in the general decision tree model.

4.2.5 Major Decision Tree Branches, General Case

Northern Economics was asked to identify major branches for a decision tree model as extrapolated to a more general case. As proposed, the costs of each alternative would include the economic costs for each alternative, the economic benefits, and the environmental benefits. The economic benefits would be estimated within a four-category framework of avoided land costs, capital costs, transition costs and proximity costs used by Parsons and Powell (2001). The benefits of avoided land, capital, proximity and transition costs are measured as the difference between the do-nothing case and each alternative. Methods of calculating each of these costs are discussed briefly below. For the general decision tree process, order of magnitude costs would be calculated for comparison with the selected alternative.

Land costs

When calculating the value of lost land, it is important not to include the value of waterfront amenities which are often present and command a premium. As land is lost, the waterfront amenity value is most often simply transferred to neighboring property. The loss of land is the value of land with the least amount of beach-related amenities. A hedonic models and discussions with local real estate experts are commonly used to determine this type of valuation.

Capital costs

Capital costs include the value of housing, commercial buildings, utilities and public infrastructure independent of the value of the land. This information can often be obtained from local assessor's records and meetings with local public works and utilities representatives.

Transition costs

Transition costs include the demolition or relocation of structures. These are generally assumed to be relatively small and are often omitted from the analysis.

Proximity costs

Proximity costs include impacts on the density of development near a shoreline. As erosion becomes more apparent, there is a reduction in the density of the development and the value of the land. As with transition costs, proximity costs are generally assumed to be relatively small and are often omitted from the analysis.

The potential benefits of each alternative include the economic value of the land protected (assumed to be zero if no action is taken) plus the amenity and ecological benefits provided by the alternative. Economic benefits are expressed as a monetary value. The monetary value of amenity benefits could, in theory, be derived using willingness to pay studies for specific beach amenities. However, the value of shoreline amenities near the SR 105 project was assumed to be small relative to the economic value of the land and was not calculated. In other parts of Washington, there are substantially large values relative to economic land value.

The ecological benefits of alternatives are difficult to express in monetary terms and, for this study, are described using a "high", "medium", and "low" scale. Fortunately, the variation in ecological benefits among the management alternatives for this project does not appear to be large.

4.3 Model Complexity

A general model was developed and tested with order-of-magnitude values and probabilities. As reports and results of the on-site visit were submitted, however, it became apparent that each area was unique both geologically and biologically, as noted below (Coastal Geologic Services, 2005).

> *It cannot be over-emphasized that each site has its own characteristics (Shipman 2002) and that it is not appropriate to apply a cost-benefit analysis or erosion control approach for one site to other sites in the state.*

Project team members reviewed objectives and results to date. Reports from both sub-contractors suggested beach nourishment and re-nourishment changes could be forecasted (and monitored) for both volumes and frequency of application. As a result, the project team decided to use risk-based spreadsheets to conduct a sensitivity analysis.

4.4 Risk-based Spreadsheet Simulation

As decision tree models were discarded due to complexity and the uniqueness of each beach (project) site, the team developed an alternative model, using risk-based spreadsheets. Spreadsheets are familiar to most agencies and general users; they are usually understood as well as word-processing programs. The project team elected to use the @RISK add-in for Microsoft Excel for risk-based spreadsheet analysis.

@Risk is based on an awareness of future uncertainty, or the inability to predict what the future will bring in response to a given action today. It also implies that a given action has more than one possible outcome. According to Palisade:

- *Risk can be either objective or subjective. An object of risk can be described precisely based in theory, experiment, or common sense. Everyone agrees with a description of an objective risk. Describing a subject of risk is open ended-you can always refine and assessment of uncertainty based on new information, further study, or expert opinion. Most risks are subjective.*
- *Deciding the something is risky requires personal judgment, even for objective risks.*
- *Risky actions and results from these actions can often be selected or avoided. Individuals, agencies, and governments differ in the amount of risk they willingly accept.*

Phase 2 of the SR 105 project focuses on beach re-nourishment. There are three factors with particular impact on beach re-nourishment requirements, volumes, and costs.

1. Frequency. The initial project designers felt there would be partial nourishment required on certain sections of exposed revetment. These were expected to require nourishment at approximately 6-year intervals. In addition complete re-nourishment of the beach was projected at 12 year intervals, or three complete re-nourishments required at year 12, year 24, and year 36. The design life of the project was set at 40 years.
2. Volume. Initial quantity of beach nourishment was set at approximately 350,000 cubic yards. Partial re-nourishments were projected at 50,000 cubic yards and a

complete re-nourishment was forecast at 150,000 cubic yards. These were based on initial and final design elements, along with results from transects in the year 2001. Analysis by project geologists in June of 2005 suggests both frequency and volume may need to be adjusted.

3. Cost. The US Army Corps of Engineers published extensive reports in 2000 and 2002 that included estimates of costs for beach re-nourishment in the project area. These costs ranged from approximately four dollars per cubic yard to over eight dollars per cubic yard.

These three variables were placed into an Excel spreadsheet, using timelines that extended from 1997, the baseline monitoring year, to the year 2040. These are presented and discussed in the following sections.

4.4.1 Case 1 – Initial Design and Costs

Case 1 uses the original project design and original project costs, along with the projected time line for both nourishment and re-nourishment of SR 105 beaches (including harder material along the east portion of SR 105, or the revetment). Table 1 illustrates these variables.

Real price increases between 1998, 2000 and 2005 were ignored as not material, especially in light of recent price increases (2005) that were 2 to 2.5 times as large as the original estimates. The 5.0 percent real value used for discounting is same value that was used in the 1997 Environmental Assessment, a 7.0 percent total rate less 2.0 percent assumed inflation.

Table 1. SR 105 Initial Design and Costs, 1998.

Calendar Year	Year Nbr	Event	Quantity Cubic Yards	Costs Cubic Yard	Total Costs	Notes, Present Value
1997	Plan	EA - April 1997				
1998	0	Construction: June - July 1998			$100,000	Mob, demob $
1999	1				800,000	Total Yards
2000	2	Initial Corps Report		$4.30	$0.13	Mob $/CY
2001	3					
2002	4	Second Corps Report #2			Disc Rate	5.0%
2003	5					PV
2004	6	1st 50,000 CY Due	50,000	$4.43	$ 221,250	$221,250
2005	7					
2006	8					
2007	9					
2008	10					
2009	11					
2010	12	All nourishment - 250,000 CY	250,000	$4.43	$1,106,250	$825,501
2011	13					
2012	14					
2013	15					
2014	16					
2015	17					
2016	18	2nd 50,000 CY Due	50,000	$4.43	$ 221,250	$123,200
2017	19					
2018	20					
2019	21					
2020	22					
2021	23					
2022	24	2nd all nourishment - 250,000 CY	250,000	$4.43	$1,106,250	$459,670
2023	25					
2024	26					
2025	27					
2026	28					
2027	29					
2028	30	3rd 50,000 CY	50,000	$4.43	$221,250	$68,603
2029	31					
2030	32					
2031	33					
2032	34					
2033	35					
2034	36	3rd all nourishment - 250,000 CY	250,000	$4.43	$1,106,250	$255,961
		Total	900,000		$3,982,500	
		Present Value at 5% real rate.				$1,954,185

Source: Northern Economics Inc., adapted from PIE design memoranda.
Note: PV is present value; CY is cubic yards; EA is Environmental Analysis: Mob refers to Mobilization and De-mobilization costs.

Present value refers to a future amount, but one that is expressed in today's dollars. A discount rate, such as the 5.0 percent noted in Table 1, is used to reflect this time value of money. For example, a

value of $1.00 received in one year (future value) has a present value (today) of $0.95 at a 5.0 percent discount rate.

4.4.2 Case 2 – Initial Design and Current Costs

In Case 2, shown in Table 2, original design quantities and beach nourishment schedules are shown, but using 2005 costs, based on costs quoted by the USACE.

Table 2. SR 105 Initial Design Quantities and Schedules, 2005 Projected Costs.

Calendar Year	Year Nbr	Event	Quantity Cubic Yards	Costs Cubic Yard	Total Costs	Notes, Present Value
1997	Plan	EA - April 1997				
1998	0	Construction: June - July 1998			$100,000	Mob, demob $
1999	1				800,000	Total Yards
2000	2	Initial Corps Report		$4.30	$0.13	Mob $/CY
2001	3					
2002	4	Second Corps Report #2			Disc Rate	5.0%
2003	5					PV
2004	6	1st 50,000 CY Due	50,000	$22.00	$1,100,000	$1,100,000
2005	7					
2006	8					
2007	9					
2008	10					
2009	11					
2010	12	All nourishment - 250,000 CY	250,000	$22.00	$5,500,000	$4,104,185
2011	13					
2012	14					
2013	15					
2014	16					
2015	17					
2016	18	2nd 50,000 CY Due	50,000	$22.00	$1,100,000	$612,521
2017	19					
2018	20					
2019	21					
2020	22					
2021	23					
2022	24	2nd nourishment - 250,000 CY	250,000	$22.00	$5,500,000	$2,285,364
2023	25					
2024	26					
2025	27					
2026	28					
2027	29					
2028	30	3rd 50,000 CY	50,000	$22.00	$1,100,000	$341,075
2029	31					
2030	32					
2031	33					
2032	34					
2033	35					
2034	36	3rd nourishment - 250,000 CY	250,000	$22.00	$5,500,000	$1,272,576
		Total	900,000		$19,800,000	
		Present Value at 5% real rate.				$9,715,720

Source: Northern Economics Inc.

There is a significant difference in present value between the two tables; first, the original forecasted beach nourishment costs suggested a PV of $1.95 million over the project life (n = 36 years), while using current costs increased this amount to $9.72 million, an increase of approximately five times (5X) as costly.

4.4.3 Case 3 – 2005 Geological Analysis Quantities, Current Costs

Case 3, shown in Table 3, includes the project team's estimates as to beach nourishment, both in quantity and frequency, along with current costs from the USACE.

Table 3. SR 105 Revised 2005 Quantities and Estimated Costs.

Calendar Year	Year Nbr	Event	Quantity Cubic Yards	Costs Cubic Yard	Total Costs	Notes, Present Value
1997	Plan	EA - April 1997				
1998	0	Construction: June - July 1998			$100,000	Mob Costs
1999	1				800,000	Quantity
2000	2	Initial Corps Report		$4.30	$0.13	Mob$/CY
2001	3					
2002	4	Second Corps Report #2				
2003	5				Disc Rate	5.0%
2004	6					PV
2005	7	1st 150,000 CY Due	150,000	$22.00	$3,300,000	$3,300,000
2006	8					
2007	9					
2008	10	2nd 150,000 CY Due	150,000	$22.00	$3,300,000	$2,850,664
2009	11					
2010	12					
2011	13	1st nourishment - 250,000 CY	250,000	$22.00	$5,500,000	$4,104,185
2012	14					
2013	15					
2014	16	3rd 150,000 CY Due	150,000	$22.00	$3,300,000	$2,127,209
2015	17					
2016	18					
2017	19	4th 150,000 CY Due	150,000	$22.00	$3,300,000	$1,837,563
2018	20					
2019	21					
2020	22	5th 150,000 CY Due	150,000	$22.00	$3,300,000	$1,587,356
2021	23					
2022	24					
2023	25	2nd nourishment - 250,000 CY	250,000	$22.00	$5,500,000	$2,285,364
2024	26					
2025	27					
2026	28	6th 150,000 CY Due	150,000	$22.00	$3,300,000	$1,184,510
2027	29					
2028	30					
2029	31	7th 150,000 CY Due	150,000	$22.00	$ 3,300,000	$1,023,224
2030	32					
2031	33					
2032	34	8th 150,000 CY Due	150,000	$22.00	$3,300,000	$883,899
2033	35					
2034	36					
2035	37	4th nourishment - 250,000 CY	250,000	$22.00	$5,500,000	$1,272,576
		Total	1,950,000		$42,900,000	
		Present Value at 5% real rate.				$22,456,551

Source: Northern Economics Inc., Coastal Geologic Services Inc.

The present value increased to $22.5 million, over the expected project life (n = 37 years shown), over 11.5 times as expensive as the original forecast and over twice as expensive as the original forecasted beach nourishment, with current costs.

4.5 Sensitivity Analysis

The Palisade program termed @RISK was used to analyze the quantities and costs shown in all three cases. @RISK uses defined input and output variables to conduct the risk analysis, using a method known as Monte Carlo simulation. As stated by Palisade:

> *@RISK uses simulation, sometimes called Monte Carlo simulation, to do a risk analysis. Simulation in this sense refers to a method whereby the distribution of possible outcomes is generated by letting a computer recalculate your worksheet over and over again, each time using different randomly selected sets of values for the probability distributions in your cell values and formulas. In effect, the computer is trying all valid combinations of the values of input variables to simulate all possible outcomes. This is just as if you ran hundreds or thousands of "what-if" analyses on your worksheet, all in one sitting.*

Two main inputs were varied within the simulation: the quantity of beach nourishment and the price per cubic yard. Sand quantities were varied by up to 65 percent of the projected amount; this rather high amount of variability was determined by Coastal Geologic Services from mapping (prepared from historical aerial photographs and geographic information systems [GIS]) and the June 2005 site inspection. There were ten (or more) cells in each spreadsheet that identified beach nourishment quantities, at a give time, and a cost for that quantity.

The costs per cubic yard were based on conversations with the USACE[6]. Recent data indicate the cost for hydraulic pipeline dredging and placement in the Willapa Bay area would be approximately $16 - $20 per cubic yard for volumes much larger than SR 105 re-nourishment would require. This is a significant difference from the Corps' 2002 estimate of $8.74 per cubic yard; project engineers state this is due to a current shortage of qualified operators and equipment, not the recent high prices for fuel or other factors. For these sensitivity runs, at substantially lower volumes than recent USACE projects, prices were increased to allow for fixed costs of mobilization (and demobilization) allocated over fewer cubic yards.

Triangular distributions were used for the sensitivity analysis. These were based on three estimates: a low amount (or cost), a high amount, and the most likely amount.

Output variables for this risk analysis were total quantity (of beach material), total cost (calculated from quantity times cost per cubic yard), and Present Value of the costs, in 2005 dollars, discounted at five percent. In addition, present values (in year 2005 constant dollars) were calculated with a five percent discount rate. This discount rate is based on a two percent inflation rate and a seven percent total discount, the same rates used in the 1997 study.

4.6 Three Case Summary Results, Sensitivity Analysis

Full results for these three cases are contained in Appendix A. Table 4 summarizes results for the three cases by the three output variables: quantity, cost (per cubic yard and total), and present value.

[6] Personal communication between Dr. Ken Lemke, Northern Economics, and USACE staff, July 18, 2005.

Table 4. Three Sensitivity Analysis, Results by Case.

Quantity, Cost, PV	Initial Q and Cost	Initial Q and 2005 Cost	2005 Analysis
Total Quantity			
Average	900,000	900,000	1,950,000
Minimum	747,900	749,700	1,712,400
Maximum	1,040,700	1,049,800	2,165,000
Total Cost			
Average	$3,983,100	$19,795,000	$42,911,000
Minimum	$2,956,200	$15,480,700	$35,328,200
Maximum	$5,168,000	$24,416,700	$49,675,000
Cost per Cubic Yard			
Average	$4.43	$21.99	$22.01
Minimum	$3.95	$20.65	$20.63
Maximum	$4.97	$23.26	$22.94
Present Values @ 5.0%			
Average	$1,955,000	$9,713,000	$22,461,000
Minimum	$1,381,000	$7,482,000	$18,277,000
Maximum	$2,585,000	$12,549,000	$26,402,000

Source: Northern Economics Inc.

This risk assessment suggests the following:

- The 1998 forecasted quantities of material needed for beach nourishment appear low.
- The June 2005 geological analysis indicated exposed highway revetment should be nourished to reduce impacts from upcoming winter storms and any significant weather events.
- Costs published by the USACE in 2000 and 2002 are substantially lower than 2005 costs used for a potential dredging project in the area.
- The present values calculated for the three cases differ significantly, due to the increased quantity recommend for beach nourishment and the increased unit costs for in-place beach material.

4.7 Sensitivity Analysis Results

This section outlines details of the more complete analyses in Appendix A.

4.7.1 Simulation Summary

Each detailed analysis in Appendix A contains a simulation summary, listing the number of iterations (n = 1000), the number of inputs, and the number of outputs.

Each output shows results by spreadsheet cell and cell name. Mean, minimum, and maximum values are presented, along with statistics for the 95 percent confidence level (a certainty of 19 times out of 20 chances).

4.7.2 Output Statistics

Output statistics are shown in more detail for the three selected variables: total quantity, total cost, and present value. In addition, a certainty table lists the calculated outputs for each variable from 5 percent to 95 percent likelihood. For example, the 50 percent values are very close to the mean, and they suggest half of the project amounts will be greater than the 50 percent amounts and half will be less.

4.7.3 Output Graphs

Output graphs are contained in Appendix A. They illustrate the calculated distributions, as histograms, for each of the selected outputs. These indicate dispersion about the mean calculated values.

4.7.4 Tornado Graphs

Tornado graphs are a graphical means of displaying those inputs that have the most impact on the calculated output. They are graphed from the most significant to the less significant and are based on regression analysis of each run.

4.7.5 Output and Input summary Statistics

The second to the last report provides an input of general information and more detailed output and input summary statistics for each combination of quantity, cost, and present value.

4.7.6 Sensitivity Report and Correlation Coefficient

The last report presented for each case is the sensitivity ranking for step-wise regression. The ten main combinations of input functions for each output are shown, along with their regression and correlation coefficients.

5 References

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6 Appendices

Appendix A – Full Sensitivity Model Results

Appendix B – Coastal Geologic Services, Inc. Report

Appendix C – Fairbanks Environmental Services, Inc. Report

Appendix A – Full Sensitivity Model Results

Simulation Summary

Summary Information	
Workbook Name	e beach replenishment ver4 With/
Number of Simulations	1
Number of Iterations	1000
Number of Inputs	10
Number of Outputs	3
Sampling Type	Latin Hypercube
Simulation Start Time	7/18/2005 13:43
Simulation Stop Time	7/18/2005 13:43
Simulation Duration	00:00:03
Random Seed	1796068493

Output		Statistics						
Name	Cell	Minimum	Mean	Maximum	x1	p1	x2	p2
Total Quantity	E41	747,854	900,000	1,040,690	809,705	5%	988,631	95%
Total Cost	G41	$ 2,956,240	$ 3,983,100	$ 5,168,012	$ 3,432,579	5%	$ 4,572,942	95%
Present Value, PV @ 5% real rat	H42	$ 1,380,870	$ 1,954,480	$ 2,584,763	$ 1,680,602	5%	$ 2,252,636	95%

Input		Statistics						
Name	Cell	Minimum	Mean	Maximum	x1	p1	x2	p2
All nourishment - 250,000 CY / C	E16	176,217	249,999	322,732	198,665	5%	301,203	95%
All nourishment - 250,000 CY / C	F16	$ 3.11	$ 4.43	$ 5.75	$ 3.52	5%	$ 5.33	95%
2nd 50,000 CY Due / Quantity (C	E22	35,546	50,000	64,407	39,735	5%	60,223	95%
2nd 50,000 CY Due / Cost ($CY)	F22	$ 3.12	$ 4.43	$ 5.73	$ 3.51	5%	$ 5.33	95%
2nd all nourishment - 250,000 C	E28	178,254	249,998	322,262	198,525	5%	301,150	95%
2nd all nourishment - 250,000 C	F28	$ 3.14	$ 4.42	$ 5.74	$ 3.52	5%	$ 5.33	95%
3rd 50,000 CY / Quantity (CY)	E34	35,564	50,000	64,437	39,702	5%	60,253	95%
3rd 50,000 CY / Cost ($CY)	F34	$ 3.15	$ 4.42	$ 5.69	$ 3.51	5%	$ 5.33	95%
3rd all nourishment - 250,000 CY	E40	177,957	250,003	323,643	198,627	5%	301,137	95%
3rd all nourishment - 250,000 CY	F40	$ 3.13	$ 4.42	$ 5.70	$ 3.52	5%	$ 5.33	95%

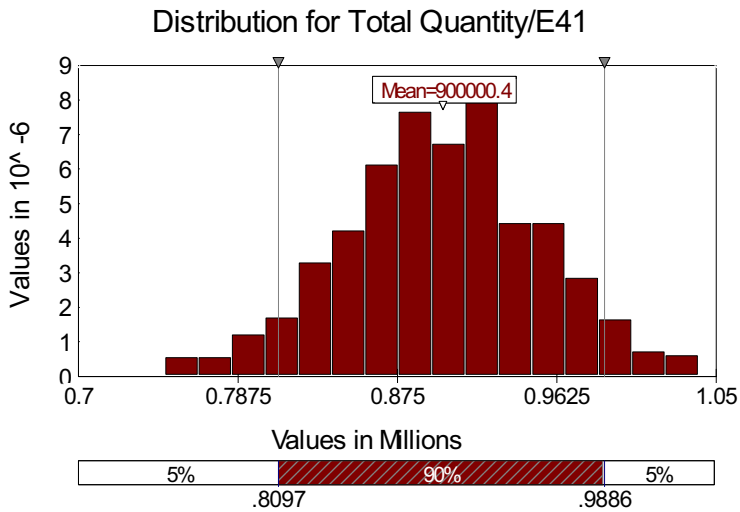
@RISK Output Details Report

Output Statistics

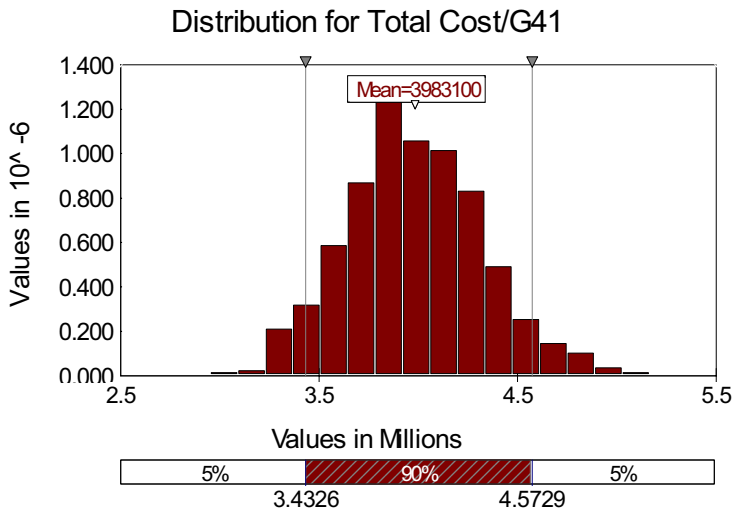
Outputs	Total Quantity	Total Cost	Present Value, PV @ 5% real rate. / PV
Simulation	1	1	1
Statistics / Cell	E41	G41	H42
Minimum	747,854	$ 2,956,240	$ 1,380,870
Maximum	1,040,690	$ 5,168,012	$ 2,584,763
Mean	900,000	$ 3,983,100	$ 1,954,480
Standard Deviation	53,931	$ 342,259	$ 173,802
Variance	2908532258	1.17141E+11	30207038479
Skewness	-0.061757161	0.242276018	0.222835891
Kurtosis	2.876429996	3.060499495	3.026663749
Number of Errors	0	0	0
Mode	888,114	$ 3,956,773	$ 2,042,814
5.0%	809,705	$ 3,432,579	$ 1,680,602
10.0%	829,566	$ 3,547,376	$ 1,727,659
15.0%	844,781	$ 3,631,759	$ 1,768,045
20.0%	855,763	$ 3,690,349	$ 1,799,992
25.0%	864,098	$ 3,759,433	$ 1,832,412
30.0%	872,518	$ 3,802,942	$ 1,862,547
35.0%	879,940	$ 3,844,789	$ 1,886,837
40.0%	886,882	$ 3,882,123	$ 1,905,942
45.0%	893,211	$ 3,921,341	$ 1,928,105
50.0%	899,805	$ 3,958,567	$ 1,946,016
55.0%	907,292	$ 4,005,706	$ 1,965,407
60.0%	914,404	$ 4,059,246	$ 1,992,170
65.0%	919,854	$ 4,105,672	$ 2,018,062
70.0%	926,677	$ 4,155,284	$ 2,041,176
75.0%	934,420	$ 4,210,773	$ 2,067,559
80.0%	946,208	$ 4,260,465	$ 2,100,078
85.0%	957,009	$ 4,329,902	$ 2,137,922
90.0%	971,436	$ 4,418,330	$ 2,182,129
95.0%	988,631	$ 4,572,942	$ 2,252,636

@RISK Output Graphs

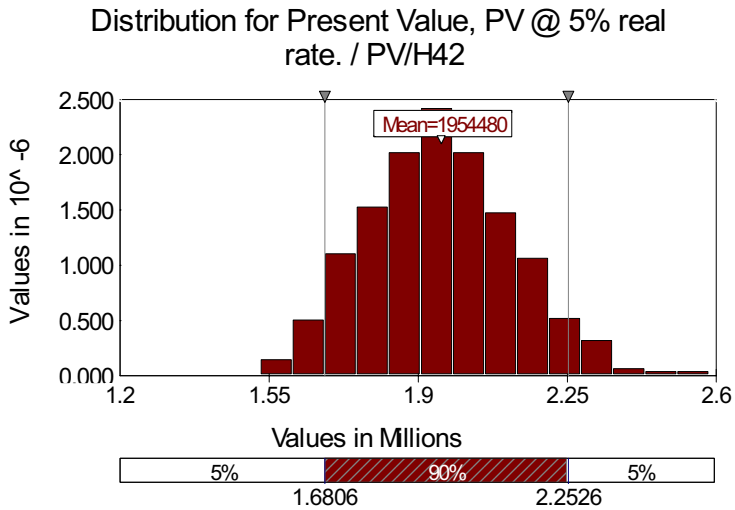
Simulation: 1 / Output: Total Quantity



Simulation: 1 / Output: Total Cost



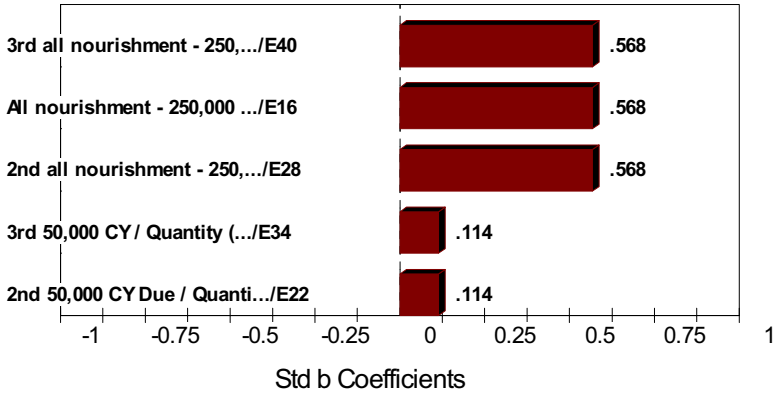
Simulation: 1 / Output: Present Value, PV @ 5% real rate. / PV



@RISK Tornado Graphs

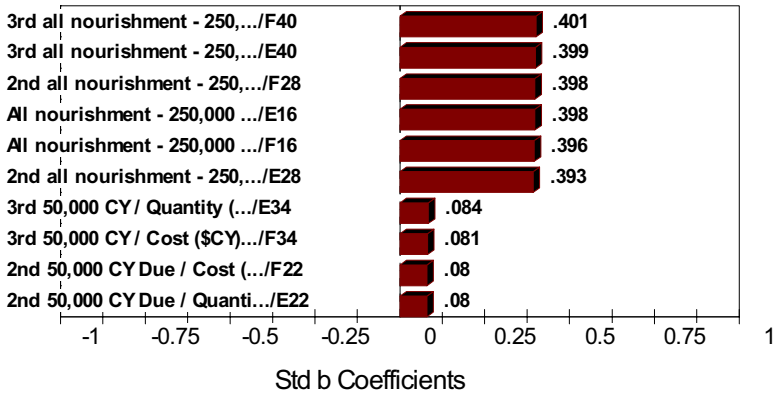
Simulation: 1 / Output: Total Quantity

Regression Sensitivity for Total Quantity/E41



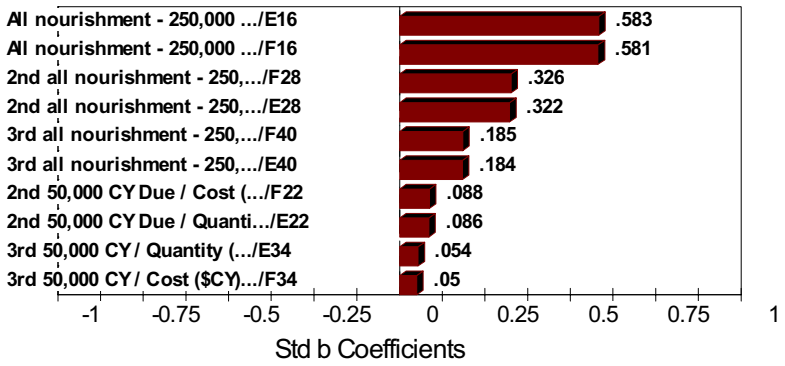
Simulation: 1 / Output: Total Cost

Regression Sensitivity for Total Cost/G41



Simulation: 1 / Output: Present Value, PV @ 5% real rate. / PV

Regression Sensitivity for Present Value, PV
@ 5% real r...



@RISK Summary Report

General Information

Workbook Name	Date table beach replenishment ver4 WithAtRisk.xls
Number of Simulations	1
Number of Iterations	1000
Number of Inputs	10
Number of Outputs	3
Sampling Type	Latin Hypercube
Simulation Start Time	7/18/05 13:43:19
Simulation Stop Time	7/18/05 13:43:22
Simulation Duration	0:00:03
Random Seed	1796068493
Total Errors	0

Output and Input Summary Statistics

Output Name	Output Cell	Simulation	Minimum	Maximum	Mean	Std Dev	x1	p1	x2	p2	x2-x1	p2-p1	Errors
Total Quantity	**E41**	**1**	747,854	1,040,690	900,000	53,931	809,705	5.0%	988,631	95.0%	178,927	90.0%	0
Total Cost	**G41**	**1**	$ 2,956,240	$ 5,168,012	$ 3,983,100	$ 342,259	$ 3,432,579	5.0%	$ 4,572,942	95.0%	$ 1,140,363	90.0%	0
Present Value, PV @ 5% real	**H42**	**1**	$ 1,380,870	$ 2,584,763	$ 1,954,480	$ 173,802	$ 1,680,602	5.0%	$ 2,252,636	95.0%	$ 572,034	90.0%	0

Input Name	Input Cell	Simulation	Minimum	Maximum	Mean	Std Dev	x1	p1	x2	p2	x2-x1	p2-p1	Errors
All nourishment - 250,000 CY	**E16**	**1**	176,217	322,732	249,999	30,637	198,665	5.0%	301,203	95.0%	102,539	90.0%	0
All nourishment - 250,000 CY	**F16**	**1**	$ 3.11	$ 5.75	$ 4.43	$ 0.54	$ 3.52	5.0%	$ 5.33	95.0%	$ 1.81	90.0%	0
2nd 50,000 CY Due / Quantity	**E22**	**1**	35,546	64,407	50,000	6,125	39,735	5.0%	60,223	95.0%	20,488	90.0%	0
2nd 50,000 CY Due / Cost ($C	**F22**	**1**	$ 3.12	$ 5.73	$ 4.43	$ 0.54	$ 3.51	5.0%	$ 5.33	95.0%	$ 1.82	90.0%	0
2nd all nourishment - 250,00	**E28**	**1**	178,254	322,262	249,998	30,630	198,525	5.0%	301,150	95.0%	102,625	90.0%	0
2nd all nourishment - 250,00	**F28**	**1**	$ 3.14	$ 5.74	$ 4.42	$ 0.54	$ 3.52	5.0%	$ 5.33	95.0%	$ 1.82	90.0%	0
3rd 50,000 CY / Quantity (CY)	**E34**	**1**	35,564	64,437	50,000	6,127	39,702	5.0%	60,253	95.0%	20,551	90.0%	0
3rd 50,000 CY / Cost ($CY)	**F34**	**1**	$ 3.15	$ 5.69	$ 4.42	$ 0.54	$ 3.51	5.0%	$ 5.33	95.0%	$ 1.82	90.0%	0
3rd all nourishment - 250,000	**E40**	**1**	177,957	323,643	250,003	30,638	198,627	5.0%	301,137	95.0%	102,510	90.0%	0
3rd all nourishment - 250,000	**F40**	**1**	$ 3.13	$ 5.70	$ 4.42	$ 0.54	$ 3.52	5.0%	$ 5.33	95.0%	$ 1.82	90.0%	0

@RISK Sensitivity Report

Sensitivity Ranking
Step-Wise Regression

Rank	Name	Cell	Function	Regression	Correlation
Total Quantity at E41, for Simulation 1					
1	3rd all nourishment - 2	E40	RiskTriang(K39,L39,M39)	0.568091661	0.545763475
2	All nourishment - 250,0	E16	RiskTriang(K15,L15,M15)	0.568081909	0.550509582
3	2nd all nourishment - 2	E28	RiskTriang(K27,L27,M27)	0.567951608	0.554612932
4	3rd 50,000 CY / Quanti	E34	RiskTriang(K33,L33,M33)	0.11360831	0.135053637
5	2nd 50,000 CY Due / C	E22	RiskTriang(K21,L21,M21)	0.11357617	0.168380059
6	3rd all nourishment - 2	F40	RiskTriang(K40,L40,M40)	-1.82574E-08	-0.016708223
7	All nourishment - 250,0	F16	RiskTriang(K16,L16,M16)	1.49377E-08	-0.033427
8	2nd all nourishment - 2	F28	RiskTriang(K28,L28,M28)	-1.14485E-08	0.045362769
9	3rd 50,000 CY / Cost (	F34	RiskTriang(K34,L34,M34)	9.21334E-09	-0.009207603
10	2nd 50,000 CY Due / C	F22	RiskTriang(K22,L22,M22)	5.16718E-09	0.008635965
Total Cost at G41, for Simulation 1					
1	3rd all nourishment - 2	F40	RiskTriang(K40,L40,M40)	0.40067746	0.370739975
2	3rd all nourishment - 2	E40	RiskTriang(K39,L39,M39)	0.398584597	0.381350109
3	2nd all nourishment - 2	F28	RiskTriang(K28,L28,M28)	0.398188061	0.45190832
4	All nourishment - 250,0	E16	RiskTriang(K15,L15,M15)	0.398080319	0.380565129
5	All nourishment - 250,0	F16	RiskTriang(K16,L16,M16)	0.396303406	0.372097488
6	2nd all nourishment - 2	E28	RiskTriang(K27,L27,M27)	0.393086421	0.38966583
7	3rd 50,000 CY / Quanti	E34	RiskTriang(K33,L33,M33)	0.084092317	0.058375282
8	3rd 50,000 CY / Cost (	F34	RiskTriang(K34,L34,M34)	0.080959895	0.062981667
9	2nd 50,000 CY Due / C	F22	RiskTriang(K22,L22,M22)	0.0804058	0.073159645
10	2nd 50,000 CY Due / C	E22	RiskTriang(K21,L21,M21)	0.079509697	0.10016854
Present Value, PV @ 5% real rate. / PV at H42, for Simulation 1					
1	All nourishment - 250,0	E16	RiskTriang(K15,L15,M15)	0.582706629	0.576399324
2	All nourishment - 250,0	F16	RiskTriang(K16,L16,M16)	0.581152228	0.573221205
3	2nd all nourishment - 2	F28	RiskTriang(K28,L28,M28)	0.326404493	0.387655864
4	2nd all nourishment - 2	E28	RiskTriang(K27,L27,M27)	0.321657468	0.302159054
5	3rd all nourishment - 2	F40	RiskTriang(K40,L40,M40)	0.18450556	0.150716419
6	3rd all nourishment - 2	E40	RiskTriang(K39,L39,M39)	0.183989831	0.167256539
7	2nd 50,000 CY Due / C	F22	RiskTriang(K22,L22,M22)	0.08753846	0.05564114
8	2nd 50,000 CY Due / C	E22	RiskTriang(K21,L21,M21)	0.086162418	0.100096072
9	3rd 50,000 CY / Quanti	E34	RiskTriang(K33,L33,M33)	0.054075073	0.022472254
10	3rd 50,000 CY / Cost (	F34	RiskTriang(K34,L34,M34)	0.049912064	-0.006123558

Sensitivity Ranking
Correlation Coefficient

Rank	Name	Cell	Function	Regression	Correlation
Total Quantity at E41, for Simulation 1					
1	2nd all nourishment - 2	E28	RiskTriang(K27,L27,M27)	0.567951608	0.554612932
2	All nourishment - 250,0	E16	RiskTriang(K15,L15,M15)	0.568081909	0.550509582
3	3rd all nourishment - 2	E40	RiskTriang(K39,L39,M39)	0.568091661	0.545763475
4	2nd 50,000 CY Due / C	E22	RiskTriang(K21,L21,M21)	0.11357617	0.168380059
5	3rd 50,000 CY / Quanti	E34	RiskTriang(K33,L33,M33)	0.11360831	0.135053637
6	2nd all nourishment - 2	F28	RiskTriang(K28,L28,M28)	-1.14485E-08	0.045362769
7	All nourishment - 250,0	F16	RiskTriang(K16,L16,M16)	1.49377E-08	-0.033427
8	3rd all nourishment - 2	F40	RiskTriang(K40,L40,M40)	-1.82574E-08	-0.016708223
9	3rd 50,000 CY / Cost (	F34	RiskTriang(K34,L34,M34)	9.21334E-09	-0.009207603
10	2nd 50,000 CY Due / C	F22	RiskTriang(K22,L22,M22)	5.16718E-09	0.008635965
Total Cost at G41, for Simulation 1					
1	2nd all nourishment - 2	F28	RiskTriang(K28,L28,M28)	0.398188061	0.45190832
2	2nd all nourishment - 2	E28	RiskTriang(K27,L27,M27)	0.393086421	0.38966583
3	3rd all nourishment - 2	E40	RiskTriang(K39,L39,M39)	0.398584597	0.381350109
4	All nourishment - 250,0	E16	RiskTriang(K15,L15,M15)	0.398080319	0.380565129
5	All nourishment - 250,0	F16	RiskTriang(K16,L16,M16)	0.396303406	0.372097488
6	3rd all nourishment - 2	F40	RiskTriang(K40,L40,M40)	0.40067746	0.370739975
7	2nd 50,000 CY Due / C	E22	RiskTriang(K21,L21,M21)	0.079509697	0.10016854
8	2nd 50,000 CY Due / C	F22	RiskTriang(K22,L22,M22)	0.0804058	0.073159645
9	3rd 50,000 CY / Cost (	F34	RiskTriang(K34,L34,M34)	0.080959895	0.062981667
10	3rd 50,000 CY / Quanti	E34	RiskTriang(K33,L33,M33)	0.084092317	0.058375282
Present Value, PV @ 5% real rate. / PV at H42, for Simulation 1					
1	All nourishment - 250,0	E16	RiskTriang(K15,L15,M15)	0.582706629	0.576399324
2	All nourishment - 250,0	F16	RiskTriang(K16,L16,M16)	0.581152228	0.573221205
3	2nd all nourishment - 2	F28	RiskTriang(K28,L28,M28)	0.326404493	0.387655864
4	2nd all nourishment - 2	E28	RiskTriang(K27,L27,M27)	0.321657468	0.302159054
5	3rd all nourishment - 2	E40	RiskTriang(K39,L39,M39)	0.183989831	0.167256539
6	3rd all nourishment - 2	F40	RiskTriang(K40,L40,M40)	0.18450556	0.150716419
7	2nd 50,000 CY Due / C	E22	RiskTriang(K21,L21,M21)	0.086162418	0.100096072
8	2nd 50,000 CY Due / C	F22	RiskTriang(K22,L22,M22)	0.08753846	0.05564114
9	3rd 50,000 CY / Quanti	E34	RiskTriang(K33,L33,M33)	0.054075073	0.022472254
10	3rd 50,000 CY / Cost (	F34	RiskTriang(K34,L34,M34)	0.049912064	-0.006123558

Simulation Summary

Summary Information	
Workbook Name	e beach replenishment ver4 With/
Number of Simulations	1
Number of Iterations	1000
Number of Inputs	10
Number of Outputs	3
Sampling Type	Latin Hypercube
Simulation Start Time	7/18/2005 14:00
Simulation Stop Time	7/18/2005 14:00
Simulation Duration	00:00:03
Random Seed	193548243

Output		Statistics						
Name	Cell	Minimum	Mean	Maximum	x1	p1	x2	p2
Total Quantity	E41	749,718	900,005	1,049,795	810,339	5%	985,371	95%
Total Cost	G41	$ 15,480,687	$ 19,795,004	$ 24,416,668	$ 17,152,922	5%	$ 22,680,164	95%
Present Value, PV @ 5% real rat	H42	$ 7,482,045	$ 9,712,829	$ 12,549,469	$ 8,420,491	5%	$ 11,081,211	95%

Input		Statistics						
Name	Cell	Minimum	Mean	Maximum	x1	p1	x2	p2
All nourishment - 250,000 CY / C	E16	177,916	250,001	322,372	198,587	5%	301,087	95%
All nourishment - 250,000 CY / C	F16	$ 15.58	$ 22.00	$ 28.48	$ 17.48	5%	$ 26.50	95%
2nd 50,000 CY Due / Quantity (C	E22	35,388	50,000	64,432	39,708	5%	60,237	95%
2nd 50,000 CY Due / Cost ($CY)	F22	$ 15.63	$ 22.00	$ 28.35	$ 17.48	5%	$ 26.50	95%
2nd all nourishment - 250,000 CY	E28	177,044	250,003	322,450	198,630	5%	301,138	95%
2nd all nourishment - 250,000 CY	F28	$ 15.57	$ 22.00	$ 28.36	$ 17.48	5%	$ 26.50	95%
3rd 50,000 CY / Quantity (CY)	E34	35,421	49,999	64,519	39,711	5%	60,228	95%
3rd 50,000 CY / Cost ($CY)	F34	$ 15.57	$ 22.00	$ 28.31	$ 17.47	5%	$ 26.51	95%
3rd all nourishment - 250,000 CY	E40	175,987	250,001	323,905	198,626	5%	301,050	95%
3rd all nourishment - 250,000 CY	F40	$ 15.64	$ 22.00	$ 28.38	$ 17.48	5%	$ 26.50	95%

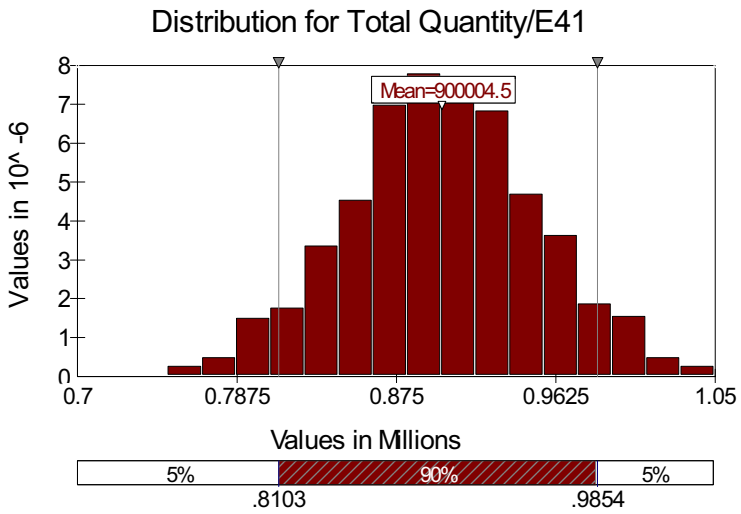
@RISK Output Details Report

Output Statistics

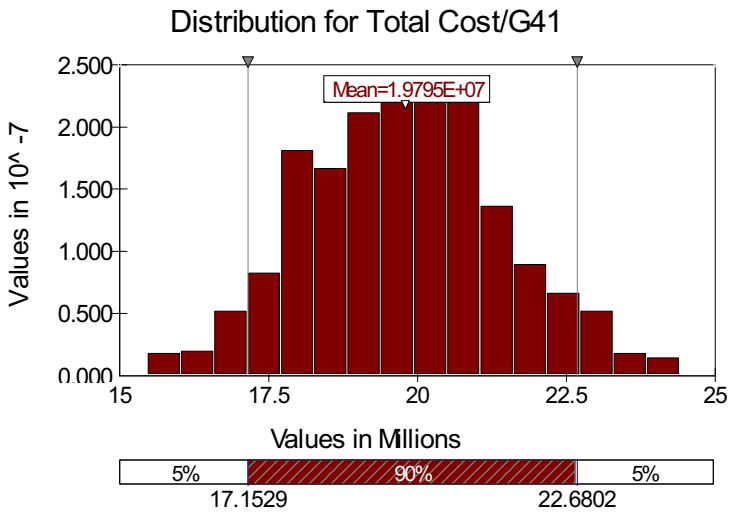
Outputs	Total Quantity	Total Cost	Present Value, PV @ 5% real rate. / PV
Simulation	1	1	1
Statistics / Cell	E41	G41	H42
Minimum	749,718	$ 15,480,687	$ 7,482,045
Maximum	1,049,795	$ 24,416,668	$ 12,549,469
Mean	900,005	$ 19,795,004	$ 9,712,829
Standard Deviation	51,862	$ 1,645,209	$ 827,497
Variance	2689678861	2.70671E+12	6.84751E+11
Skewness	-0.007292707	0.099121436	0.162167347
Kurtosis	2.883360472	2.763262851	2.73469419
Number of Errors	0	0	0
Mode	878,516	$ 19,044,717	$ 9,494,814
5.0%	810,339	$ 17,152,922	$ 8,420,491
10.0%	832,221	$ 17,740,248	$ 8,653,823
15.0%	845,986	$ 18,020,656	$ 8,809,788
20.0%	857,845	$ 18,302,614	$ 8,947,047
25.0%	866,376	$ 18,621,112	$ 9,098,728
30.0%	872,961	$ 18,866,780	$ 9,248,754
35.0%	880,425	$ 19,077,270	$ 9,371,795
40.0%	886,999	19,351,048	9,489,709
45.0%	893,308	$ 19,627,664.00	$ 9,571,290.00
50.0%	899,754	19,802,054	9,688,845
55.0%	906,760	$ 20,011,148.00	$ 9,796,742.00
60.0%	912,872	20,225,702	9,905,020
65.0%	919,872	$ 20,451,342.00	$ 10,042,530.00
70.0%	925,968	20,637,332	10,163,495
75.0%	933,342	$ 20,875,098.00	$ 10,286,628.00
80.0%	943,626	21,109,500	10,405,327
85.0%	954,092	$ 21,497,138.00	$ 10,601,186.00
90.0%	966,501	$ 21,943,486	$ 10,805,875
95.0%	985,371	$ 22,680,164	$ 11,081,211

@RISK Output Graphs

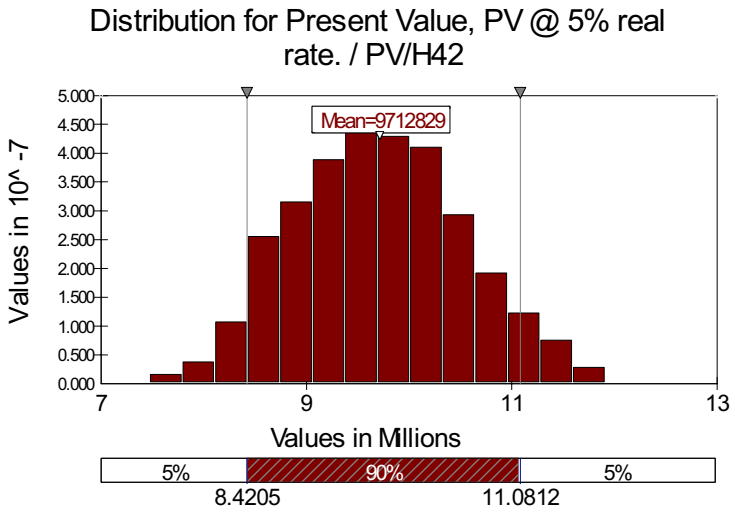
Simulation: 1 / Output: Total Quantity



Simulation: 1 / Output: Total Cost



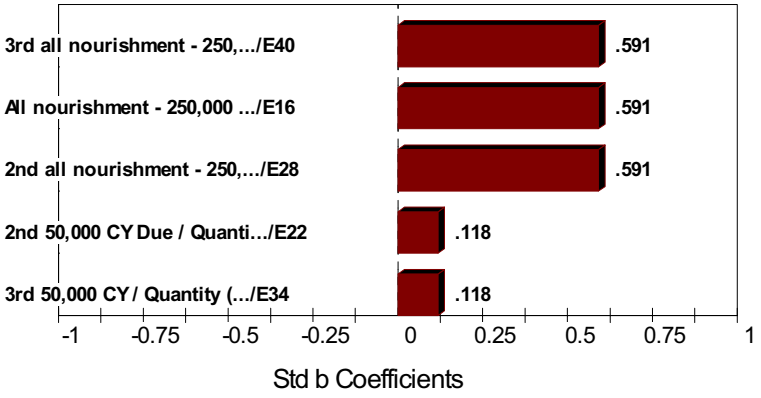
Simulation: 1 / Output: Present Value, PV @ 5% real rate. / PV



@RISK Tornado Graphs

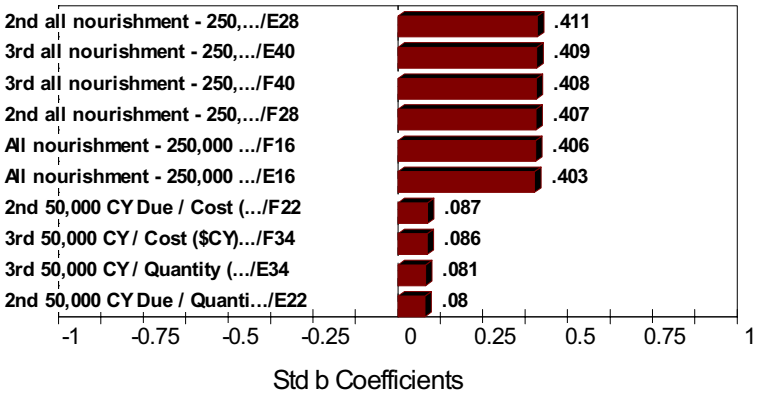
Simulation: 1 / Output: Total Quantity

Regression Sensitivity for Total Quantity/E41



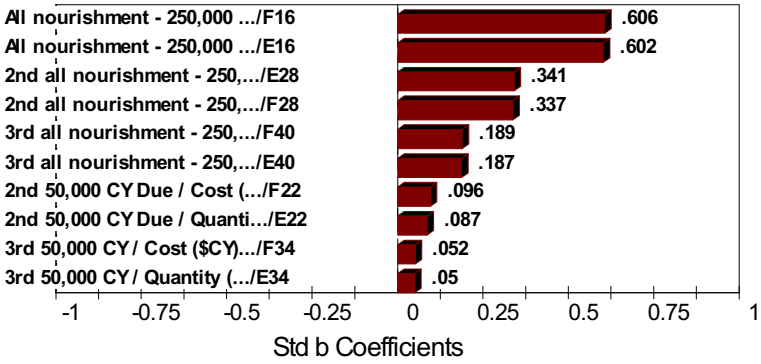
Simulation: 1 / Output: Total Cost

Regression Sensitivity for Total Cost/G41



Simulation: 1 / Output: Present Value, PV @ 5% real rate. / PV

Regression Sensitivity for Present Value, PV @ 5% real r...



@RISK Summary Report

General Information

Workbook Name	Date table beach replenishment ver4 WithAtRisk.xls
Number of Simulations	1
Number of Iterations	1000
Number of Inputs	10
Number of Outputs	3
Sampling Type	Latin Hypercube
Simulation Start Time	7/18/05 14:00:16
Simulation Stop Time	7/18/05 14:00:19
Simulation Duration	0:00:03
Random Seed	193548243
Total Errors	0

Output and Input Summary Statistics

Output Name	Output Cell	Simulation	Minimum	Maximum	Mean	Std Dev	x1	p1	x2	p2	x2-x1	p2-p1	Errors
Total Quantity	**E41**	**1**	749,718	1,049,795	900,005	51,862	810,339	5.0%	985,371	95.0%	175,032	90.0%	0
Total Cost	**G41**	**1**	$ 15,480,687	$ 24,416,668	$ 19,795,004	$ 1,645,209	$ 17,152,922	5.0%	$ 22,680,164	95.0%	$ 5,527,242	90.0%	0
Present Value, PV @ 5% real	**H42**	**1**	$ 7,482,045	$ 12,549,469	$ 9,712,829	$ 827,497	$ 8,420,491	5.0%	$ 11,081,211	95.0%	$ 2,660,720	90.0%	0

Input Name	Input Cell	Simulation	Minimum	Maximum	Mean	Std Dev	x1	p1	x2	p2	x2-x1	p2-p1	Errors
All nourishment - 250,000 CY	**E16**	**$ 1.00**	177,916	322,372	250,001	30,631	198,587	5.0%	301,087	95.0%	102,500	90.0%	0
All nourishment - 250,000 CY	**F16**	**1**	$ 15.58	$ 28.48	$ 22.00	$ 2.70	$ 17.48	5.0%	$ 26.50	95.0%	$ 9.02	90.0%	0
2nd 50,000 CY Due / Quantity	**E22**	**$ 1.00**	35,388	64,432	50,000	6,127	39,708	5.0%	60,237	95.0%	20,529	90.0%	0
2nd 50,000 CY Due / Cost ($C	**F22**	**1**	$ 15.63	$ 28.35	$ 22.00	$ 2.70	$ 17.48	5.0%	$ 26.50	95.0%	$ 9.02	90.0%	0
2nd all nourishment - 250,00	**E28**	**$ 1.00**	177,044	322,450	250,003	30,627	198,630	5.0%	301,138	95.0%	102,508	90.0%	0
2nd all nourishment - 250,00	**F28**	**1**	$ 15.57	$ 28.36	$ 22.00	$ 2.70	$ 17.48	5.0%	$ 26.50	95.0%	$ 9.02	90.0%	0
3rd 50,000 CY / Quantity (CY)	**E34**	**$ 1.00**	35,421	64,519	49,999	6,126	39,711	5.0%	60,228	95.0%	20,517	90.0%	0
3rd 50,000 CY / Cost ($CY)	**F34**	**1**	$ 15.57	$ 28.31	$ 22.00	$ 2.70	$ 17.47	5.0%	$ 26.51	95.0%	$ 9.04	90.0%	0
3rd all nourishment - 250,00	**E40**	**$ 1.00**	175,987	323,905	250,001	30,642	198,626	5.0%	301,050	95.0%	102,423	90.0%	0
3rd all nourishment - 250,00	**F40**	**1**	$ 15.64	$ 28.38	$ 22.00	$ 2.70	$ 17.48	5.0%	$ 26.50	95.0%	$ 9.02	90.0%	0

@RISK Sensitivity Report

Sensitivity Ranking
Step-Wise Regression

Rank	Name	Cell	Function	Regression	Correlation
Total Quantity at E41, for Simulation 1					
1	3rd all nourishment - 2	E40	RiskTriang(K39,L39,M39)	0.590839606	0.526332394
2	All nourishment - 250,0	E16	RiskTriang(K15,L15,M15)	0.590618267	0.517344301
3	2nd all nourishment - 2	E28	RiskTriang(K27,L27,M27)	0.590541294	0.553155865
4	2nd 50,000 CY Due / C	E22	RiskTriang(K21,L21,M21)	0.118131618	0.147114351
5	3rd 50,000 CY / Quanti	E34	RiskTriang(K33,L33,M33)	0.118126241	0.087811756
6	2nd 50,000 CY Due / C	F22	RiskTriang(K22,L22,M22)	-1.97818E-08	-0.009068793
7	3rd all nourishment - 2	F40	RiskTriang(K40,L40,M40)	-1.20089E-08	0.033189513
8	3rd 50,000 CY / Cost ($	F34	RiskTriang(K34,L34,M34)	-7.94433E-09	-0.05217886
9	All nourishment - 250,0	F16	RiskTriang(K16,L16,M16)	4.79221E-09	-0.019076971
10	2nd all nourishment - 2	F28	RiskTriang(K28,L28,M28)	9.5211E-10	0.007745876
Total Cost at G41, for Simulation 1					
1	2nd all nourishment - 2	E28	RiskTriang(K27,L27,M27)	0.411178715	0.369031737
2	3rd all nourishment - 2	E40	RiskTriang(K39,L39,M39)	0.40906255	0.383054327
3	3rd all nourishment - 2	F40	RiskTriang(K40,L40,M40)	0.40842601	0.426154446
4	2nd all nourishment - 2	F28	RiskTriang(K28,L28,M28)	0.407471931	0.418655483
5	All nourishment - 250,0	F16	RiskTriang(K16,L16,M16)	0.405825567	0.367838324
6	All nourishment - 250,0	E16	RiskTriang(K15,L15,M15)	0	0
7	2nd 50,000 CY Due / C	F22	RiskTriang(K22,L22,M22)	$ 0.09	$ 0.05
8	3rd 50,000 CY / Cost ($	F34	RiskTriang(K34,L34,M34)	0	0
9	3rd 50,000 CY / Quanti	E34	RiskTriang(K33,L33,M33)	$ 0.08	$ 0.06
10	2nd 50,000 CY Due / C	E22	RiskTriang(K21,L21,M21)	0	0
Present Value, PV @ 5% real rate. / PV at H42, for Simulation 1					
1	All nourishment - 250,0	F16	RiskTriang(K16,L16,M16)	1	1
2	All nourishment - 250,0	E16	RiskTriang(K15,L15,M15)	$ 0.60	$ 0.55
3	2nd all nourishment - 2	E28	RiskTriang(K27,L27,M27)	0	0
4	2nd all nourishment - 2	F28	RiskTriang(K28,L28,M28)	$ 0.34	$ 0.33
5	3rd all nourishment - 2	F40	RiskTriang(K40,L40,M40)	0.188646577	0.209420933
6	3rd all nourishment - 2	E40	RiskTriang(K39,L39,M39)	0.187483238	0.164640369
7	2nd 50,000 CY Due / C	F22	RiskTriang(K22,L22,M22)	0.095575473	0.050530983
8	2nd 50,000 CY Due / C	E22	RiskTriang(K21,L21,M21)	0.087000395	0.147682624
9	3rd 50,000 CY / Cost ($	F34	RiskTriang(K34,L34,M34)	0.05157112	0.030848299
10	3rd 50,000 CY / Quanti	E34	RiskTriang(K33,L33,M33)	0.050045349	0.015320511

Sensitivity Ranking
Correlation Coefficient

Rank	Name	Cell	Function	Regression	Correlation
Total Quantity at E41, for Simulation 1					
1	2nd all nourishment - 2	E28	RiskTriang(K27,L27,M27)	0.590541294	0.553155865
2	3rd all nourishment - 2	E40	RiskTriang(K39,L39,M39)	0.590839606	0.526332394
3	All nourishment - 250,0	E16	RiskTriang(K15,L15,M15)	0.590618267	0.517344301
4	2nd 50,000 CY Due / C	E22	RiskTriang(K21,L21,M21)	0.118131618	0.147114351
5	3rd 50,000 CY / Quanti	E34	RiskTriang(K33,L33,M33)	0.118126241	0.087811756
6	3rd 50,000 CY / Cost ($	F34	RiskTriang(K34,L34,M34)	-7.94433E-09	-0.05217886
7	3rd all nourishment - 2	F40	RiskTriang(K40,L40,M40)	-1.20089E-08	0.033189513
8	All nourishment - 250,0	F16	RiskTriang(K16,L16,M16)	4.79221E-09	-0.019076971
9	2nd 50,000 CY Due / C	F22	RiskTriang(K22,L22,M22)	-1.97818E-08	-0.009068793
10	2nd all nourishment - 2	F28	RiskTriang(K28,L28,M28)	9.5211E-10	0.007745876
Total Cost at G41, for Simulation 1					
1	3rd all nourishment - 2	F40	RiskTriang(K40,L40,M40)	0.40842601	0.426154446
2	2nd all nourishment - 2	F28	RiskTriang(K28,L28,M28)	0.407471931	0.418655483
3	3rd all nourishment - 2	E40	RiskTriang(K39,L39,M39)	0.40906255	0.383054327
4	2nd all nourishment - 2	E28	RiskTriang(K27,L27,M27)	0.411178715	0.369031737
5	All nourishment - 250,0	F16	RiskTriang(K16,L16,M16)	0.405825567	0.367838324
6	All nourishment - 250,0	E16	RiskTriang(K15,L15,M15)	0.403122691	0.341169605
7	2nd 50,000 CY Due / C	E22	RiskTriang(K21,L21,M21)	0.080077134	0.142583303
8	3rd 50,000 CY / Quanti	E34	RiskTriang(K33,L33,M33)	0.08129562	0.064260784
9	3rd 50,000 CY / Cost ($	F34	RiskTriang(K34,L34,M34)	0.085725142	0.050412446
10	2nd 50,000 CY Due / C	F22	RiskTriang(K22,L22,M22)	0.086998751	0.046588367
Present Value, PV @ 5% real rate. / PV at H42, for Simulation 1					
1	All nourishment - 250,0	F16	RiskTriang(K16,L16,M16)	0.606377627	0.560847873
2	All nourishment - 250,0	E16	RiskTriang(K15,L15,M15)	0.601968268	0.54816128
3	2nd all nourishment - 2	F28	RiskTriang(K28,L28,M28)	0.337372779	0.327351015
4	2nd all nourishment - 2	E28	RiskTriang(K27,L27,M27)	0.341071433	0.290889867
5	3rd all nourishment - 2	F40	RiskTriang(K40,L40,M40)	0.188646577	0.209420933
6	3rd all nourishment - 2	E40	RiskTriang(K39,L39,M39)	0.187483238	0.164640369
7	2nd 50,000 CY Due / C	E22	RiskTriang(K21,L21,M21)	0.087000395	0.147682624
8	2nd 50,000 CY Due / C	F22	RiskTriang(K22,L22,M22)	0.095575473	0.050530983
9	3rd 50,000 CY / Cost ($	F34	RiskTriang(K34,L34,M34)	0.05157112	0.030848299
10	3rd 50,000 CY / Quanti	E34	RiskTriang(K33,L33,M33)	0.050045349	0.015320511

Simulation Summary

Summary Information	
Workbook Name	e beach replenishment ver4 With/
Number of Simulations	1
Number of Iterations	1000
Number of Inputs	22
Number of Outputs	3
Sampling Type	Latin Hypercube
Simulation Start Time	7/18/2005 13:56
Simulation Stop Time	7/18/2005 13:56
Simulation Duration	00:00:04
Random Seed	607397353

Output		Statistics						
Name	Cell	Minimum	Mean	Maximum	x1	p1	x2	p2
Total Quantity	E42	1,712,414	1,950,005	2,164,964	1,827,285	5%	2,074,212	95%
Total Cost	G42	$ 35,328,224	$ 42,910,942	$ 49,675,028	$ 39,064,556	5%	$ 46,749,880	95%
Present Value, PV @ 5% real rat	H43	$ 18,276,822	$ 22,460,820	$ 26,401,580	$ 20,299,970	5%	$ 24,691,912	95%

Input		Statistics						
Name	Cell	Minimum	Mean	Maximum	x1	p1	x2	p2
1st 150,000 CY Due / Quantity ((	E11	105,769	150,002	194,892	119,159	5%	180,754	95%
1st 150,000 CY Due / Cost ($CY	F11	$ 15.64	$ 22.00	$ 28.32	$ 17.48	5%	$ 26.50	95%
2nd 150,000 CY Due / Quantity (	E14	106,954	150,002	194,531	119,184	5%	180,670	95%
2nd 150,000 CY Due / Cost ($CY	F14	$ 15.62	$ 22.00	$ 28.55	$ 17.47	5%	$ 26.51	95%
1st all nourishment - 250,000 CY	E17	177,704	249,999	322,406	198,675	5%	301,099	95%
1st all nourishment - 250,000 CY	F17	$ 15.61	$ 22.00	$ 28.38	$ 17.47	5%	$ 26.50	95%
3rd 150,000 CY Due / Quantity ((	E20	106,534	150,000	193,106	119,107	5%	180,680	95%
3rd 150,000 CY Due / Cost ($CY	F20	$ 15.69	$ 22.00	$ 28.39	$ 17.47	5%	$ 26.51	95%
4rd 150,000 CY Due / Quantity ((	E23	106,762	150,000	193,058	119,224	5%	180,638	95%
4rd 150,000 CY Due / Cost ($CY	F23	$ 15.61	$ 22.00	$ 28.35	$ 17.47	5%	$ 26.51	95%
5rd 150,000 CY Due / Quantity ((	E26	106,973	150,001	194,160	119,186	5%	180,725	95%
5rd 150,000 CY Due / Cost ($CY	F26	$ 15.64	$ 22.00	$ 28.37	$ 17.48	5%	$ 26.51	95%
2nd all nourishment - 250,000 CY	E29	178,063	250,000	322,724	198,651	5%	301,187	95%
2nd all nourishment - 250,000 CY	F29	$ 15.69	$ 22.00	$ 28.47	$ 17.48	5%	$ 26.49	95%
6th 150,000 CY Due / Quantity ((	E32	106,712	150,002	193,098	119,225	5%	180,699	95%
6th 150,000 CY Due / Cost ($CY	F32	$ 15.59	$ 22.00	$ 28.37	$ 17.49	5%	$ 26.51	95%
7th 150,000 CY Due / Quantity ((	E35	106,894	150,001	193,407	119,101	5%	180,700	95%
7th 150,000 CY Due / Cost ($CY	F35	$ 15.65	$ 22.00	$ 28.40	$ 17.47	5%	$ 26.49	95%
8th 150,000 CY Due / Quantity ((	E38	106,633	149,998	193,338	119,204	5%	180,678	95%
8th 150,000 CY Due / Cost ($CY	F38	$ 15.69	$ 22.00	$ 28.46	$ 17.48	5%	$ 26.50	95%
4th all nourishment - 250,000 CY	E41	177,313	250,000	322,836	198,534	5%	301,198	95%
4th all nourishment - 250,000 CY	F41	$ 15.55	$ 22.00	$ 28.36	$ 17.47	5%	$ 26.51	95%

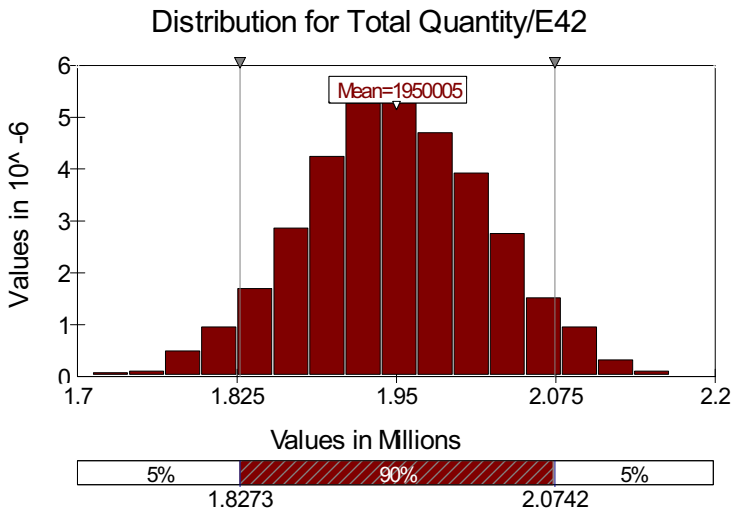
@RISK Output Details Report

Output Statistics

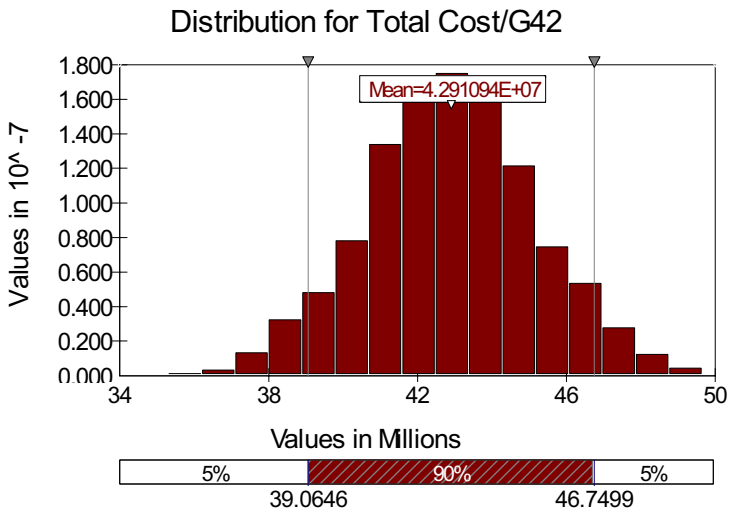
Outputs	Total Quantity	Total Cost	Present Value, PV @ 5% real rate. / PV
Simulation	1	1	1
Statistics / Cell	E42	G42	H43
Minimum	1,712,414	$ 35,328,224	$ 18,276,822
Maximum	2,164,964	$ 49,675,028	$ 26,401,580
Mean	1,950,005	$ 42,910,942	$ 22,460,820
Standard Deviation	73,074	$ 2,268,628	$ 1,302,513
Variance	5339846993	5.14667E+12	1.69654E+12
Skewness	-0.020882906	0.017086127	0.098691392
Kurtosis	2.872708242	2.977320335	2.850176117
Number of Errors	0	0	0
Mode	1,956,932	$ 42,502,484	$ 21,301,666
5.0%	1,827,285	$ 39,064,556	$ 20,299,970
10.0%	1,856,739	$ 39,958,708	$ 20,747,686
15.0%	1,874,104	$ 40,612,840	$ 21,081,408
20.0%	1,887,869	$ 41,036,592	$ 21,306,112
25.0%	1,899,265	$ 41,420,552	$ 21,576,218
30.0%	1,911,179	$ 41,731,028	$ 21,777,356
35.0%	1,920,253	$ 42,100,380	$ 21,903,696
40.0%	1,930,388	42,328,520	22,069,070
45.0%	1,940,224	$ 42,608,524.00	$ 22,313,486.00
50.0%	1,949,599	42,881,256	22,482,180
55.0%	1,960,597	$ 43,217,176.00	$ 22,658,950.00
60.0%	1,967,720	43,482,672	22,807,268
65.0%	1,977,134	$ 43,734,060.00	$ 22,962,112.00
70.0%	1,989,606	43,997,760	23,080,640
75.0%	1,999,274	$ 44,364,528.00	$ 23,254,808.00
80.0%	2,011,939	44,711,376	23,548,270
85.0%	2,028,186	$ 45,218,044.00	$ 23,772,902.00
90.0%	2,044,620	45,848,180	24,178,714
95.0%	2,074,212	$ 46,749,880.00	$ 24,691,912.00

@RISK Output Graphs

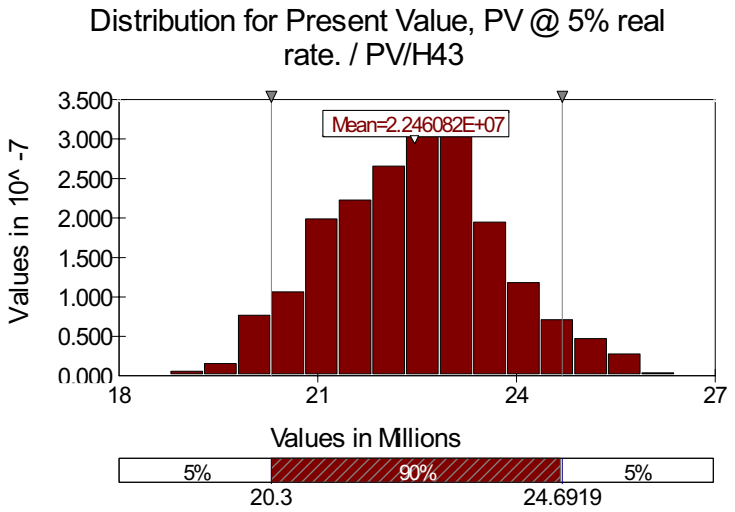
Simulation: 1 / Output: Total Quantity



Simulation: 1 / Output: Total Cost



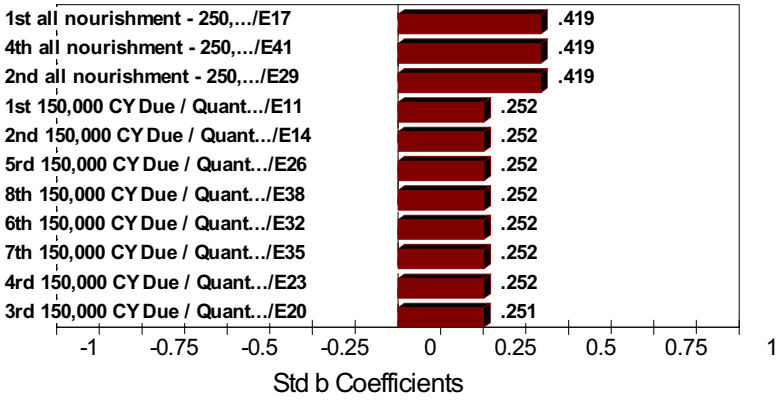
Simulation: 1 / Output: Present Value, PV @ 5% real rate. / PV



@RISK Tornado Graphs

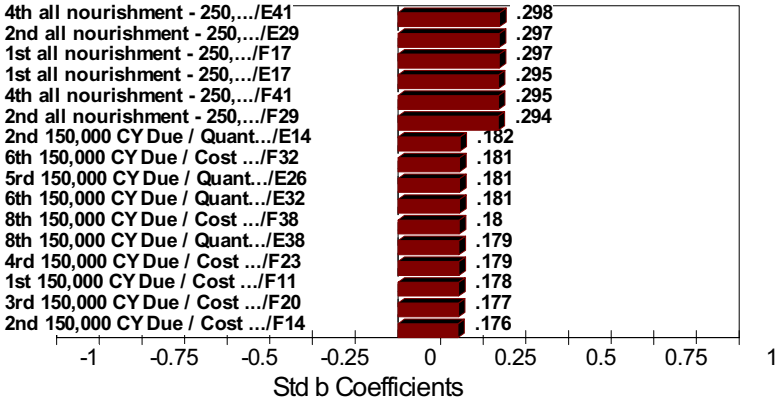
Simulation: 1 / Output: Total Quantity

Regression Sensitivity for Total Quantity/E42



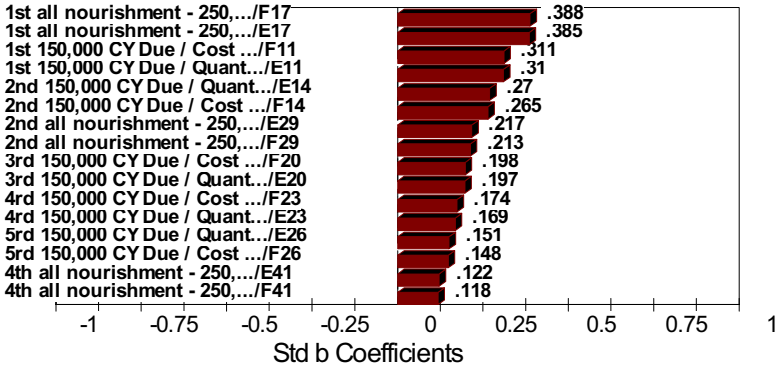
Simulation: 1 / Output: Total Cost

Regression Sensitivity for Total Cost/G42



Simulation: 1 / Output: Present Value, PV @ 5% real rate. / PV

Regression Sensitivity for Present Value, PV @ 5% real r...



@RISK Summary Report

General Information

Workbook Name	Date table beach replenishment ver4 WithAtRisk.xls
Number of Simulations	1
Number of Iterations	1000
Number of Inputs	22
Number of Outputs	3
Sampling Type	Latin Hypercube
Simulation Start Time	7/18/05 13:56:12
Simulation Stop Time	7/18/05 13:56:16
Simulation Duration	0:00:04
Random Seed	607397353
Total Errors	0

Output and Input Summary Statistics

Output Name	Output Cell	Simulation	Minimum	Maximum	Mean	Std Dev	x1	p1	x2	p2	x2-x1	p2-p1	Errors
Total Quantity	**E42**	**1**	1,712,414	2,164,964	1,950,005	73,074	1,827,285	5.0%	2,074,212	95.0%	246,927	90.0%	0
Total Cost	**G42**	**1**	$ 35,328,224	$ 49,675,028	$ 42,910,942	$ 2,268,628	$ 39,064,556	5.0%	$ 46,749,880	95.0%	$ 7,685,324	90.0%	0
Present Value, PV @ 5% real	**H43**	**1**	$ 18,276,822	$ 26,401,580	$ 22,460,820	$ 1,302,513	$ 20,299,970	5.0%	$ 24,691,912	95.0%	$ 4,391,942	90.0%	0

Input Name	Input Cell	Simulation	Minimum	Maximum	Mean	Std Dev	x1	p1	x2	p2	x2-x1	p2-p1	Errors
1st 150,000 CY Due / Quantit	**E11**	**$ 1.00**	105,769	194,892	150,002	18,384	119,159	5.0%	180,754	95.0%	61,595	90.0%	0
1st 150,000 CY Due / Cost ($	**F11**	**1**	$ 15.64	$ 28.32	$ 22.00	$ 2.70	$ 17.48	5.0%	$ 26.50	95.0%	$ 9.03	90.0%	0
2nd 150,000 CY Due / Quantit	**E14**	**$ 1.00**	106,954	194,531	150,002	18,383	119,184	5.0%	180,670	95.0%	61,486	90.0%	0
2nd 150,000 CY Due / Cost ($	**F14**	**1**	$ 15.62	$ 28.55	$ 22.00	$ 2.70	$ 17.47	5.0%	$ 26.51	95.0%	$ 9.04	90.0%	0
1st all nourishment - 250,000	**E17**	**$ 1.00**	177,704	322,406	249,999	30,634	198,675	5.0%	301,099	95.0%	102,424	90.0%	0
1st all nourishment - 250,000	**F17**	**1**	$ 15.61	$ 28.38	$ 22.00	$ 2.70	$ 17.47	5.0%	$ 26.50	95.0%	$ 9.03	90.0%	0
3rd 150,000 CY Due / Quantit	**E20**	**$ 1.00**	106,534	193,106	150,000	18,378	119,107	5.0%	180,680	95.0%	61,573	90.0%	0
3rd 150,000 CY Due / Cost ($	**F20**	**1**	$ 15.69	$ 28.39	$ 22.00	$ 2.70	$ 17.47	5.0%	$ 26.51	95.0%	$ 9.04	90.0%	0
4rd 150,000 CY Due / Quantit	**E23**	**$ 1.00**	106,762	193,058	150,000	18,379	119,224	5.0%	180,638	95.0%	61,414	90.0%	0
4rd 150,000 CY Due / Cost ($	**F23**	**1**	$ 15.61	$ 28.35	$ 22.00	$ 2.70	$ 17.47	5.0%	$ 26.51	95.0%	$ 9.04	90.0%	0
5rd 150,000 CY Due / Quantit	**E26**	**$ 1.00**	106,973	194,160	150,001	18,382	119,186	5.0%	180,725	95.0%	61,539	90.0%	0
5rd 150,000 CY Due / Cost ($	**F26**	**1**	$ 15.64	$ 28.37	$ 22.00	$ 2.70	$ 17.48	5.0%	$ 26.51	95.0%	$ 9.04	90.0%	0
2nd all nourishment - 250,00	**E29**	**$ 1.00**	178,063	322,724	250,000	30,628	198,651	5.0%	301,187	95.0%	102,536	90.0%	0
2nd all nourishment - 250,00	**F29**	**1**	$ 15.69	$ 28.47	$ 22.00	$ 2.70	$ 17.48	5.0%	$ 26.49	95.0%	$ 9.01	90.0%	0
6th 150,000 CY Due / Quantit	**E32**	**$ 1.00**	106,712	193,098	150,002	18,380	119,225	5.0%	180,699	95.0%	61,474	90.0%	0
6th 150,000 CY Due / Cost ($	**F32**	**1**	$ 15.59	$ 28.37	$ 22.00	$ 2.70	$ 17.49	5.0%	$ 26.51	95.0%	$ 9.02	90.0%	0
7th 150,000 CY Due / Quantit	**E35**	**$ 1.00**	106,894	193,407	150,001	18,380	119,101	5.0%	180,700	95.0%	61,599	90.0%	0
7th 150,000 CY Due / Cost ($	**F35**	**1**	$ 15.65	$ 28.40	$ 22.00	$ 2.70	$ 17.47	5.0%	$ 26.49	95.0%	$ 9.02	90.0%	0
8th 150,000 CY Due / Quantit	**E38**	**$ 1.00**	106,633	193,338	149,998	18,381	119,204	5.0%	180,678	95.0%	61,474	90.0%	0
8th 150,000 CY Due / Cost ($	**F38**	**1**	$ 15.69	$ 28.46	$ 22.00	$ 2.70	$ 17.48	5.0%	$ 26.50	95.0%	$ 9.02	90.0%	0
4th all nourishment - 250,000	**E41**	**$ 1.00**	177,313	322,836	250,000	30,634	198,534	5.0%	301,198	95.0%	102,665	90.0%	0
4th all nourishment - 250,000	**F41**	**1**	$ 15.55	$ 28.36	$ 22.00	$ 2.70	$ 17.47	5.0%	$ 26.51	95.0%	$ 9.04	90.0%	0

@RISK Sensitivity Report

Sensitivity Ranking
Step-Wise Regression

Rank	Name	Cell	Function	Regression	Correlation
Total Quantity at E42, for Simulation 1					
1	1st all nourishment - 25	E17	RiskTriang(K16,L16,M16)	0.419221753	0.410254778
2	4th all nourishment - 25	E41	RiskTriang(K40,L40,M40)	0.419214536	0.370479058
3	2nd all nourishment - 2	E29	RiskTriang(K28,L28,M28)	0.419135895	0.392560977
4	1st 150,000 CY Due / (	E11	RiskTriang(K10,L10,M10)	0.251574154	0.277229401
5	2nd 150,000 CY Due /	E14	RiskTriang(K13,L13,M13)	0.251568342	0.251519088
6	5rd 150,000 CY Due / (	E26	RiskTriang(K25,L25,M25)	0.251545604	0.22569457
7	8th 150,000 CY Due / (	E38	RiskTriang(K37,L37,M37)	0.251535232	0.236390228
8	6th 150,000 CY Due / (	E32	RiskTriang(K31,L31,M31)	0.25153173	0.172943561
9	7th 150,000 CY Due / (	E35	RiskTriang(K34,L34,M34)	0.251519067	0.241040257
10	4rd 150,000 CY Due / (	E23	RiskTriang(K22,L22,M22)	0.25151672	0.232306048
11	3rd 150,000 CY Due / (	E20	RiskTriang(K19,L19,M19)	0.251497565	0.257284277
12	4th all nourishment - 25	F41	RiskTriang(K41,L41,M41)	-2.31525E-08	0.016863401
13	8th 150,000 CY Due / (	F38	RiskTriang(K38,L38,M38)	2.23194E-08	0.032435756
14	4rd 150,000 CY Due / (	F23	RiskTriang(K23,L23,M23)	1.79732E-08	-0.006814531
15	2nd 150,000 CY Due /	F14	RiskTriang(K14,L14,M14)	-1.22235E-08	-0.060358884
16	5rd 150,000 CY Due / (	F26	RiskTriang(K26,L26,M26)	-7.32285E-09	-0.034472446
17	1st 150,000 CY Due / (	F11	RiskTriang(K11,L11,M11)	0	0
18	7th 150,000 CY Due / (	F35	RiskTriang(K35,L35,M35)	$ (0.00)	$ (0.00)
19	2nd all nourishment - 2	F29	RiskTriang(K29,L29,M29)	0	(0)
20	6th 150,000 CY Due / (	F32	RiskTriang(K32,L32,M32)	$ (0.00)	$ 0.01
21	1st all nourishment - 25	F17	RiskTriang(K17,L17,M17)	(0)	0
22	3rd 150,000 CY Due / (	F20	RiskTriang(K20,L20,M20)	$ 0.00	$ (0.01)
Total Cost at G42, for Simulation 1					
1	4th all nourishment - 25	E41	RiskTriang(K40,L40,M40)	$ 0.30	$ 0.25
2	2nd all nourishment - 2	E29	RiskTriang(K28,L28,M28)	0	0
3	1st all nourishment - 25	F17	RiskTriang(K17,L17,M17)	$ 0.30	$ 0.30
4	1st all nourishment - 25	E17	RiskTriang(K16,L16,M16)	0	0
5	4th all nourishment - 25	F41	RiskTriang(K41,L41,M41)	$ 0.29	$ 0.29
6	2nd all nourishment - 2	F29	RiskTriang(K29,L29,M29)	0	0
7	2nd 150,000 CY Due /	E14	RiskTriang(K13,L13,M13)	$ 0.18	$ 0.21
8	6th 150,000 CY Due / (	F32	RiskTriang(K32,L32,M32)	0	0
9	5rd 150,000 CY Due / (	E26	RiskTriang(K25,L25,M25)	$ 0.18	$ 0.17
10	6th 150,000 CY Due / (	E32	RiskTriang(K31,L31,M31)	0	0
11	8th 150,000 CY Due / (	F38	RiskTriang(K38,L38,M38)	$ 0.18	$ 0.16
12	8th 150,000 CY Due / (	E38	RiskTriang(K37,L37,M37)	0	0
13	4rd 150,000 CY Due / (	F23	RiskTriang(K23,L23,M23)	$ 0.18	$ 0.15
14	1st 150,000 CY Due / (	F11	RiskTriang(K11,L11,M11)	0	0
15	3rd 150,000 CY Due / (	F20	RiskTriang(K20,L20,M20)	$ 0.18	$ 0.17
16	2nd 150,000 CY Due /	F14	RiskTriang(K14,L14,M14)	0.176403445	0.10609915
17	3rd 150,000 CY Due / (	E20	RiskTriang(K19,L19,M19)	0.175717638	0.170501883
18	7th 150,000 CY Due / (	E35	RiskTriang(K34,L34,M34)	0.175247107	0.165847498
19	1st 150,000 CY Due / (	E11	RiskTriang(K10,L10,M10)	0.175238424	0.181177424
20	5rd 150,000 CY Due / (	F26	RiskTriang(K26,L26,M26)	0.175136989	0.107536398
21	4rd 150,000 CY Due / (	E23	RiskTriang(K22,L22,M22)	0.174920145	0.147585532
22	7th 150,000 CY Due / (	F35	RiskTriang(K35,L35,M35)	0.174533511	0.149586978
Present Value, PV @ 5% real rate. / PV at H43, for Simulation 1					
1	1st all nourishment - 25	F17	RiskTriang(K17,L17,M17)	0.387620199	0.398842359
2	1st all nourishment - 25	E17	RiskTriang(K16,L16,M16)	0.385127149	0.382154746
3	1st 150,000 CY Due / (	F11	RiskTriang(K11,L11,M11)	0.311156544	0.307020223

4	1st 150,000 CY Due / (	E11	RiskTriang(K10,L10,M10)	0.310312119	0.320066384
5	2nd 150,000 CY Due /	E14	RiskTriang(K13,L13,M13)	0.270351746	0.32373372
6	2nd 150,000 CY Due /	F14	RiskTriang(K14,L14,M14)	0.264640518	0.19793697
7	2nd all nourishment - 2	E29	RiskTriang(K28,L28,M28)	0.217271484	0.195031599
8	2nd all nourishment - 2	F29	RiskTriang(K29,L29,M29)	0.212831327	0.210541759
9	3rd 150,000 CY Due / (	F20	RiskTriang(K20,L20,M20)	0.197952013	0.201514114
10	3rd 150,000 CY Due / (	E20	RiskTriang(K19,L19,M19)	0.197394203	0.191596104
11	4rd 150,000 CY Due / (	F23	RiskTriang(K23,L23,M23)	0.174250444	0.145484209
12	4rd 150,000 CY Due / (	E23	RiskTriang(K22,L22,M22)	0.16863956	0.13410551
13	5rd 150,000 CY Due / (	E26	RiskTriang(K25,L25,M25)	0.151228812	0.139922612
14	5rd 150,000 CY Due / (	F26	RiskTriang(K26,L26,M26)	0.148012252	0.083161499
15	4th all nourishment - 2	E41	RiskTriang(K40,L40,M40)	0.121777738	0.055230091
16	4th all nourishment - 2	F41	RiskTriang(K41,L41,M41)	0.118268323	0.116590497
17	6th 150,000 CY Due / (	F32	RiskTriang(K32,L32,M32)	0.116218845	0.152776881
18	6th 150,000 CY Due / (	E32	RiskTriang(K31,L31,M31)	0.112621534	0.058190854
19	7th 150,000 CY Due / (	E35	RiskTriang(K34,L34,M34)	0.092536771	0.102863239
20	7th 150,000 CY Due / (	F35	RiskTriang(K35,L35,M35)	0.092047778	0.076628645
21	8th 150,000 CY Due / (	E38	RiskTriang(K37,L37,M37)	0.084031758	0.082330978
22	8th 150,000 CY Due / (	F38	RiskTriang(K38,L38,M38)	0.083488317	0.080714493

Sensitivity Ranking
Correlation Coefficient

Rank	Name	Cell	Function	Regression	Correlation
Total Quantity at E42, for Simulation 1					
1	1st all nourishment - 25	E17	RiskTriang(K16,L16,M16)	0.419221753	0.410254778
2	2nd all nourishment - 2	E29	RiskTriang(K28,L28,M28)	0.419135895	0.392560977
3	4th all nourishment - 25	E41	RiskTriang(K40,L40,M40)	0.419214536	0.370479058
4	1st 150,000 CY Due / (	E11	RiskTriang(K10,L10,M10)	0.251574154	0.277229401
5	3rd 150,000 CY Due / (	E20	RiskTriang(K19,L19,M19)	0.251497565	0.257284277
6	2nd 150,000 CY Due /	E14	RiskTriang(K13,L13,M13)	0.251568342	0.251519088
7	7th 150,000 CY Due / (	E35	RiskTriang(K34,L34,M34)	0.251519067	0.241040257
8	8th 150,000 CY Due / (	E38	RiskTriang(K37,L37,M37)	0.251535232	0.236390228
9	4rd 150,000 CY Due / (	E23	RiskTriang(K22,L22,M22)	0.25151672	0.232306048
10	5rd 150,000 CY Due / (	E26	RiskTriang(K25,L25,M25)	0.251545604	0.22569457
11	6th 150,000 CY Due / (	E32	RiskTriang(K31,L31,M31)	0.25153173	0.172943561
12	2nd 150,000 CY Due /	F14	RiskTriang(K14,L14,M14)	-1.22235E-08	-0.060358884
13	5rd 150,000 CY Due / (	F26	RiskTriang(K26,L26,M26)	-7.32285E-09	-0.034472446
14	8th 150,000 CY Due / (	F38	RiskTriang(K38,L38,M38)	2.23194E-08	0.032435756
15	1st all nourishment - 25	F17	RiskTriang(K17,L17,M17)	-2.31738E-09	0.017629866
16	4th all nourishment - 25	F41	RiskTriang(K41,L41,M41)	-2.31525E-08	0.016863401
17	6th 150,000 CY Due / (	F32	RiskTriang(K32,L32,M32)	-3.57192E-09	0.011915964
18	2nd all nourishment - 2	F29	RiskTriang(K29,L29,M29)	5.4422E-09	-0.009789034
19	3rd 150,000 CY Due / (	F20	RiskTriang(K20,L20,M20)	1.96812E-09	-0.007616648
20	4rd 150,000 CY Due / (	F23	RiskTriang(K23,L23,M23)	1.79732E-08	-0.006814531
21	1st 150,000 CY Due / (	F11	RiskTriang(K11,L11,M11)	7.07377E-09	0.003902668
22	7th 150,000 CY Due / (	F35	RiskTriang(K35,L35,M35)	-5.85734E-09	-0.000399828
Total Cost at G42, for Simulation 1					
1	1st all nourishment - 25	E17	RiskTriang(K16,L16,M16)	0.294979252	0.304085585
2	1st all nourishment - 25	F17	RiskTriang(K17,L17,M17)	0.297342176	0.30144413
3	4th all nourishment - 25	F41	RiskTriang(K41,L41,M41)	0.294566579	0.290642548
4	2nd all nourishment - 2	F29	RiskTriang(K29,L29,M29)	0.294496802	0.267188956
5	2nd all nourishment - 2	E29	RiskTriang(K28,L28,M28)	0.297356837	0.251289894
6	4th all nourishment - 25	E41	RiskTriang(K40,L40,M40)	0.298477225	0.249656866
7	2nd 150,000 CY Due /	E14	RiskTriang(K13,L13,M13)	0.182402271	0.20960991
8	1st 150,000 CY Due / (	F11	RiskTriang(K11,L11,M11)	0.177818647	0.197258406
9	6th 150,000 CY Due / (	F32	RiskTriang(K32,L32,M32)	0.181312059	0.194594973
10	1st 150,000 CY Due / (	E11	RiskTriang(K10,L10,M10)	0.175238424	0.181177424
11	3rd 150,000 CY Due / (	F20	RiskTriang(K20,L20,M20)	0.176730991	0.17120929
12	3rd 150,000 CY Due / (	E20	RiskTriang(K19,L19,M19)	0.175717638	0.170501883
13	5rd 150,000 CY Due / (	E26	RiskTriang(K25,L25,M25)	0.180974407	0.167836428
14	7th 150,000 CY Due / (	E35	RiskTriang(K34,L34,M34)	0.175247107	0.165847498
15	8th 150,000 CY Due / (	E38	RiskTriang(K37,L37,M37)	0.178760536	0.165070054
16	8th 150,000 CY Due / (	F38	RiskTriang(K38,L38,M38)	0.179566594	0.164354607
17	7th 150,000 CY Due / (	F35	RiskTriang(K35,L35,M35)	0.174533511	0.149586978
18	4rd 150,000 CY Due / (	F23	RiskTriang(K23,L23,M23)	0.178714879	0.149433858
19	4rd 150,000 CY Due / (	E23	RiskTriang(K22,L22,M22)	0.174920145	0.147585532
20	6th 150,000 CY Due / (	E32	RiskTriang(K31,L31,M31)	0.180961641	0.128877795
21	5rd 150,000 CY Due / (	F26	RiskTriang(K26,L26,M26)	0.175136989	0.107536398
22	2nd 150,000 CY Due /	F14	RiskTriang(K14,L14,M14)	0.176403445	0.10609915
Present Value, PV @ 5% real rate. / PV at H43, for Simulation 1					
1	1st all nourishment - 25	F17	RiskTriang(K17,L17,M17)	0.387620199	0.398842359
2	1st all nourishment - 25	E17	RiskTriang(K16,L16,M16)	0.385127149	0.382154746
3	2nd 150,000 CY Due /	E14	RiskTriang(K13,L13,M13)	0.270351746	0.32373372

4	1st 150,000 CY Due / (	E11	RiskTriang(K10,L10,M10)	0.310312119	0.320066384
5	1st 150,000 CY Due / (	F11	RiskTriang(K11,L11,M11)	0.311156544	0.307020223
6	2nd all nourishment - 2	F29	RiskTriang(K29,L29,M29)	0.212831327	0.210541759
7	3rd 150,000 CY Due / (	F20	RiskTriang(K20,L20,M20)	0.197952013	0.201514114
8	2nd 150,000 CY Due /	F14	RiskTriang(K14,L14,M14)	0.264640518	0.19793697
9	2nd all nourishment - 2	E29	RiskTriang(K28,L28,M28)	0.217271484	0.195031599
10	3rd 150,000 CY Due / (	E20	RiskTriang(K19,L19,M19)	0.197394203	0.191596104
11	6th 150,000 CY Due / (	F32	RiskTriang(K32,L32,M32)	0.116218845	0.152776881
12	4rd 150,000 CY Due / (	F23	RiskTriang(K23,L23,M23)	0.174250444	0.145484209
13	5rd 150,000 CY Due / (	E26	RiskTriang(K25,L25,M25)	0.151228812	0.139922612
14	4rd 150,000 CY Due / (	E23	RiskTriang(K22,L22,M22)	0.16863956	0.13410551
15	4th all nourishment - 2	F41	RiskTriang(K41,L41,M41)	0.118268323	0.116590497
16	7th 150,000 CY Due / (	E35	RiskTriang(K34,L34,M34)	0.092536771	0.102863239
17	5rd 150,000 CY Due / (	F26	RiskTriang(K26,L26,M26)	0.148012252	0.083161499
18	8th 150,000 CY Due / (	E38	RiskTriang(K37,L37,M37)	0.084031758	0.082330978
19	8th 150,000 CY Due / (	F38	RiskTriang(K38,L38,M38)	0.083488317	0.080714493
20	7th 150,000 CY Due / (	F35	RiskTriang(K35,L35,M35)	0.092047778	0.076628645
21	6th 150,000 CY Due / (	E32	RiskTriang(K31,L31,M31)	0.112621534	0.058190854
22	4th all nourishment - 2	E41	RiskTriang(K40,L40,M40)	0.121777738	0.055230091

Appendix B – Coastal Geologic Services, Inc. Report

Beach Nourishment for Erosion Control With Emphasis on SR-105/ Washaway Beach Emergency Stabilization Project

June 2005

Prepared for:
Northern Economics Inc &
Washington State Department of Transportation Department

Prepared By:
Jim Johannessen, Licensed Engineering Geologist, MS
and Andrea MacLennan, MS

COASTAL GEOLOGIC SERVICES

Coastal Geologic Services, Inc.
Bellingham, WA

INTRODUCTION

Purpose
This report was prepared under sub-contract to Northern Economics Inc., which was under contract to the Washington State Department of Transportation (WSDOT) through Western Washington University. The purpose of this study was to identify and analyze the geological considerations for evaluating the use of sand renourishment in highway bank stabilization projects.

Scope and Organization
The scope of this report was to provide a qualitative assessment of the physical performance of the beach nourishment project that was built to protect a portion of the older road revetment and maintain the intertidal beach near the revetment, and to provide as much information as possible, given the limited time and budget, for a cost benefit analysis by Northern Economics.

The project site was located on the north shore of Willapa Bay in Pacific County, Washington. The nourishment site was adjacent to the Washington State Route 105 (SR-105) groin and dike. The beach nourishment fronted a large rock revetment that was constructed earlier to protect a portion of SR-105 (an approximately 2,000 ft long reach) near North Cove.

The beach nourishment was placed immediately southeast (referred to as "east" in this report for simplicity) of a 1,600 ft long rock groin. An underwater rock dike extended an additional 500 ft into Willapa Bay (at depths of –18 ft to –90 ft MLLW). The project was designed by Pacific International Engineering PLLC (PIE) for the Washington State Department of Transportation (WSDOT).

Findings and observations in this report relied on published literature on beach nourishment and monitoring reports. Most of the sources used were peer-reviewed in professional journals or were from books by leading coastal specialists. Some sources included a limited number of conference proceedings. Monitoring program performance, data collection, and reporting were carried out by PIE.

This report consists of two parts, the first of which outlines geological considerations when using sand renourishment for coastal erosion control and bank stabilization projects in general, and the second of which addresses geological considerations for stabilizing a portion of SR-105 near North Cove.

PART I. BEACH NOURISHMENT FOR EROSION CONTROL OVERVIEW

MANAGEMENT APRROACH AND BEACH NOURISHMENT

Selecting a Management Approach
Selecting a coastal erosion management approach is a complex decision that should ideally incorporate clearly defined goals and objectives, a thorough understanding of the site's conditions and history, the potential environmental impacts, its economic viability, and the measurable degree of risk. A wide variety of techniques are currently used to manage shoreline erosion, ranging from hard or soft shore protection to managed shoreline retreat. Erosion control strategies can take the form of "hard" armoring methods that use large boulders or cement seawalls to prevent erosion, "soft" methods such as beach nourishment, composite methods, which combine both hard and soft components, and nonstructural activities. Throughout the twentieth century "hard" structures have been most often utilized.

More recently, the beach itself has been recognized as an effective wave attenuator or breakwater, and efforts have focused increasingly on trying to retain the beach to protect adjacent lands from loss or damage—typically referred to as "soft" methods (Shipman 2002, Cox et al. 1994). No erosion control technique is perfect; each is limited in performance, and the site-specific nature of the success of erosion control structures cannot be emphasized enough. The principal factors in determining appropriate shore protection methods for a specific location should include local shoreline geology, wave energy regime, and the goal of the shore protection. However, only the first and second factors should be used in defining an appropriate solution, without regard for the goal (Cox et al. 1994).

Beach nourishment projects are typically designed to emulate a natural shore and are allowed to deform in response to wave action. Because the shoreline deforms in response to varying intensities of wave action, the beach geometry might change both spatially and temporally, as well as appearing to erode and accrete (grow). The line of defense is not constant for a deformable shoreline as it is with hard structures; therefore continuous protection of a specific location is less easy to guarantee (Cox et al. 1994). Despite this fact, beach nourishment has become a popular method of erosion control and has been applied on coasts throughout the country and across the globe (Finkl and Walker 2005).

Beach Nourishment

Beach nourishment, as defined in a recent Glossary of Coastal Geomorphology, is "the natural or artificial supply of sand or gravel to a beach. Also termed beach restoration, beach fill, and beach renourishment" (Bird 2005). Beach nourishment is also referred to as beach replenishment, and in some Pacific Northwest applications the use of beach nourishment using gravel has been referred to as constructing a protective berm.

Another pair of well-respected authors recently described beach nourishment as "the artificial (mechanical) placement of sand along an eroded stretch of coast where only a small beach, or no beach, previously existed. Efforts to artificially maintain beaches that are deprived of natural sediment thus attempt to proxy nature and (re)nourish the beach by mechanical placement of sand. The beach sediment is thus replenished by artificial means (Finkl and Walker 2005)."

Beach *re*nourishment typically refers to the resupplying of nourishment material at a previously nourished beach where erosion (of artificial material) has persisted.

Beach nourishment applications often have differing objectives. Nourishment objectives range from protection of structures and property to increasing recreation opportunities and enhancing habitat value. Each objective maintains the underlying goal of slowing or preventing (further) landward recession of the shoreline or beach at a defined location.

GEOLOGIC/GEOMORPHIC CONTEXT FOR BEACH NOURISHMENT

A number of geologic controls play key roles in planning and design stages for beach erosion control efforts that include the consideration of nourishment as an option. Specific characteristics make any particular site more or less favorable for the use of beach nourishment. Design parameters directly influence the performance of a nourishment project once installed. Unless noted differently, the term nourishment refers to sand nourishment. In several sections gravel nourishment is discussed, and the word gravel will be used in these cases.

The major factors used in determining the suitability for nourishment and in development a beach nourishment design are introduced here.

Volume Density
The density or amount of sediment per unit of shore length is an important design consideration that needs to balance cost with durability. Nourished beaches often have erosion "hotspots" where one or several areas of a nourished beach suffer greater losses than adjacent areas (Dean 2002) and if volume density is low, such areas can suffer unacceptable sediment losses such that renourishment is required after a short interval or the public perception of the project success is reduced. Determining an appropriate volume density depends primarily on wave climate background and erosion rates, although other factors affect the decision process to a lesser extent.

In a study by Verhagen (1996), eight sand nourishment projects were analyzed using a model that measured nourishment material loss. Results showed that in general, (initial) nourishment volumes should be multiplied by a factor of 2.2 and initial losses averaged approximately 10%.

Placement Location on Beach Profile
Beach nourishment sediment can be placed in a variety of locations on the beach profile. Nourishment placement can occur over the entire beach profile from the backshore area down to the depth of closure (as deep as –20 m NGVD), to just over a small portion of the beach profile. The term "equilibrium profile" refers to the generally accepted understanding that a beach, with an unchanged sediment size, will have a dynamically stable beach profile. Following this reasoning, if sediment (of the same grain size as the native sediment) is placed at only some elevations of the beach profile, the profile will adjust back to its original slopes (Bruun 1985). Sand nourishment projects that only nourish the dune area or the upper foreshore tend to experience relatively rapid erosion following placement (Bruun 1988). Many smaller sand nourishment projects have occurred on just the subaerial (upper) portion of the profile, such that they should be expected to lose substantial volumes from the upper beach to the lower foreshore and subaqueous portions of the profile, and potentially alongshore (Bruun 1988, Finkl and Walker 2005).

Gravel Nourishment Relative to Sand
In contrast to sand, gravel (also referred to as "shingle" in the European literature) tends to form a relatively steep beach profile, with slopes of 7:1 to 10:1 (Horizontal:Vertical; Van-Hijum 1974) or steeper. Therefore the equilibrium profile of a gravel beach is considerably steeper than that of a sand beach (Bray 1996). Areas with abundant gravel in natural beaches, such as the Puget Sound-Georgia Strait area and the United Kingdom, have proven to be very good sites for gravel beach nourishment. Gravel beaches have proven to be an efficient practical form of coastal protection (MAFF 1993). Gravel tends to remain high on the intertidal and supratidal beach profile, minimizing loss to the adjacent subtidal area. Indeed, project monitoring has shown that virtually no loss of gravel offshore has occurred in Puget Sound and Georgia Strait projects (Johannessen 2002, Shipman 2002)

Beach nourishment in the Puget Sound and Georgia Strait area (also called beach feeding or beach replenishment) typically consists of the placement of select size(s) of rounded gravel on the upper beach to significantly slow (not halt) beach erosion (Shipman 2002, Johannessen 2002). The general goal of beach nourishment in our region has been to build up (or re-build) a high elevation, protective gravel berm to limit storm damage and recreate a wider beach at high tide (Johannessen 2000, Johannessen 2002). Beach nourishment projects that use gravel often nourish from the mid tidal range up to and including the backshore area (Shipman 2002). Since gravel stays high on the beach profile this makes for a relatively stable placement (Bray 1996). Gravel beach nourishment, where natural gravel-rich beaches occur, has involved substantially smaller fill volumes than sand nourishment and requires much less frequent renourishment, and has therefore proven to be much cheaper then the use of sand.

The use of finer sediment sizes for intertidal habitat reasons has been incorporated into gravel beach nourishment design in the Puget Sound and Georgia Strait area (Hummel et al. 2005, Johannessen 2003). Habitats such as surf smelt spawning substrate have been successfully recreated in these projects (Johannessen 2003).

Sediment Compatibility
This term refers to the degree to which the nourishment sediment would perform compared to nourishment with native sediment (Dean 2002). Beach nourishment sediment should resemble native material as much as possible. Coarser fill will typically erode more slowly than finer grain sizes. Sediment selected for beach nourishment must be at least as texturally coarse as the original beach material (Dean 2002). Sediment that is too fine leads to erosion of berm material and offshore deposition of sediment (Finkl and Walker 2005).

Newman (1989) recommended a mean grain diameter of at least 1.5 times that of the original sediment in quantities sufficient to establish the ultimate slope compatible with the wave climate. Re-nourishment should occur as needed.

Sediment coarser than original sediment will lead to a steeper beach slope, which may result in added wave reflection. Wave reflection can accelerate the removal of finer material and exacerbate the existing erosion problem in portions of the project area.

Background Erosion
Background erosion refers to historic coastal erosion that had occurred at a site prior to beach nourishment. This term is different from "structural erosion", which refers to erosion caused by engineering structures. Beach nourishment typically has been initiated at sites where background erosion has persisted (Dean 2002). The magnitude of background erosion should be quantified and considered in the beach nourishment design process. It is assumed that background erosion rates will be superimposed on a nourished beach (Dean 2002) or that erosion rates will be greater than background erosion rates since the profile is pushed waterward (Verhagen 1996). Persistent significant background erosion can jeopardize the success of any beach nourishment project.

Wave Climate
Along with the intensity of large windstorms, the relative wave energy (wave climate) experienced at a site is a critical factor in determining the amount of erosion that may occur at a site. Larger waves usually equate to larger net shore-drift rates (the net, long-tem effect of littoral drift).

Site Geometry
Site "geometry" refers to the configuration of the shore at and surrounding the potential nourishment site. This ranges from long straight coasts to complex headland-pocket beach configurations, and the geometry of a site plays a critical role in determining the location and degree of future erosion. A relatively recent article examined numerous beach nourishment projects and summarized physical parameters that should be considered in the design of any beach nourishment project (Charlier and DeMeyer 1995). Nourishment is most successful at beaches located between headlands, because removal can only take place in a cross-shore direction. Many Washington state nourishment projects were designed using headlands or rock structures to partially mimic pocket beach conditions (Shipman 2002, Shipman in prep.).

In terms of the overall alongshore extent of a nourishment project, size matters. Long beach nourishment projects appear to experience greater longevity in retaining nourishment material (Leonard et al. 1990). Shorter length nourishment projects will tend to have relatively greater

sediment loss than longer projects due to the dominance of both ends of the nourished beach (Dean 2002).

Shorelines near tidal inlets tend to be more dynamic and unstable than those along straight coastlines (Pompe and Rinehart 2000). Similarly, nourishment sites near dynamic spits and river channels would also be expected to be more dynamic and potentially unstable.

Structures

Structures placed near the ends of a beach nourishment project, such as a terminal groin, can reduce material losses (Leonard et al. 1990). Submerged shore-parallel structures limit seaward transport of sediment (also known as perched beach concept), particularly when fill sediment is finer than the original beach sediment (Charlier and DeMeyer 1995). Other structures, particularly up-drift crossshore structures, can cause down-drift erosion due to wave refraction around structures.

A bulkhead (seawall, revetment, or other similar shore-parallel wall) constructed near the ordinary high water mark (OHWM) in a moderate energy environment increases the reflectivity of the upper beach substantially, causing backwash (outgoing water after a wave strikes shore) to be more pronounced. Increased backwash velocity removes beach sediment from the intertidal beach, thereby lowering the beach profile (Macdonald et al. 1994). This also occurs when erosion of a nourished beach reaches a bulkhead during storms, and tends to increase erosion of the nourishment sediment. A bulkhead constructed lower on the beach causes more impacts. Construction of a bulkhead at or below the OHWM results in a coarsening of the beach sediment in front of the bulkhead (Macdonald et al. 1994, Kraus 1988) because relatively fine-gain size sediment (typically sand) is mobilized by the increased turbulence caused by the bulkhead (Miles 2001), and is preferentially transported away, leaving only the coarse material on the beach. This process also leads to the removal of large woody debris (LWD) from the upper beachface. Both of these impacts lead to changes in habitat along the armored portion of shore.

A number of local hydraulic impacts often occur in response to a bulkhead. These include the formation of a scour trough (a linear depression) directly in front of the wall probably as a result of increased reflectivity of the wave energy from the wall to the upper beach (Macdonald et al. 1994). Another hydraulic response is the formation of end scour erosion ("end effects"). This occurs at unprotected shores adjacent to the end of a bulkhead (Tait and Griggs 1991) where the wave energy is refracted at the end of the bulkhead causing beach and bluff toe erosion. "During storm" impacts, where seabed fluidization and scour occur at enhanced levels, may be pronounced in front of a bulkhead, but this process is not well understood.

BEACH NOURISHMENT GUIDELINES IN WASHINGTON STATE CONTEXT

An annotated bibliography of beach nourishment and its applicability to the Puget Sound area was compiled by Terich, Schwartz, and Johannessen (1994), first printed in 1991, for the Washington Department of Ecology. Dr. Maurice Schwartz has been an internationally recognized coastal specialist on beach nourishment, the only person of this stature residing in Washington State. Dr. Thomas Terich has performed many analyses on coastal processes in Washington State over recent decades and is also a leading coastal specialist locally. The document discussed issues as they apply to Puget Sound and surrounding areas. The bibliography reviewed and summarized relevant issues from the peer-reviewed literature on beach nourishment up to 1991, which was an extensive amount. More recent journal articles and conference papers are discussed in other sections of this report, but this annotated bibliography remains a valuable source of guidance for Washington state shores.

The primary synthesis provided in the annotated bibliography was a list of guidelines and methodology. Many of these guidelines were generally consistent with those developed for Southern California by Herron (1987). While the guidelines were written to apply to Puget Sound and Georgia Strait shores, there is good amount of applicability to other shores of Washington State.

The guideline and methodology synthesis from (Terich et al. 1994) are reprinted in their entirely below:

> The Guidelines are, in effect, essential "rule of thumb" requirements to be kept in mind in undertaking any artificial beach nourishment project. The Methodology items are procedural matters involved in carrying out such projects. No particular priority is implied in the order of the listings.
>
> **Guidelines**
>
> 1. Thorough planning must precede the implementation of any beach nourishment project; this is to include determination of the geographic setting of the site within the larger region, wind and wave regime, site erosion rate, sediment transport direction and rate, sediment characterization, fill-sediment source, cost-benefit ratio and financing.
>
> 2. Once beach nourishment is initiated, it must be continued. Replenishment is as necessary as was the original need to nourish. The renourishment factor, the expected replacement interval, should be anticipated at the outset of the project.
>
> 3. The entire beach profile must be nourished; thus providing adequate fill for the seasonally changing subaqueous and subaerial portions of the shore.
>
> 4. Ample sediment-emplacement density (volume per unit length) enhances the success of the nourishment project. At the time of each nourishment effort the over-fill factor must be calculated, to allow for volume depletion (by loss of sediment fines) and sediment transport beyond the project boundaries.
>
> 5. As a general rule, the replacement sediment should be slightly coarser than the original beach sediment. This should be accomplished within the aesthetics of the replacement sediment and the availability of a source of supply.
>
> 6. Beach nourishment should be carried out following the stormy, erosive season and during the seasonal calm, restorative period.
>
> 7. Beach nourishment apparently does not cause any long-term adverse biological effects on muddy, sandy or gravelly shores. The biotic communities are generally reestablished following each emplacement of sediment. Rocky shores and coral reefs require special consideration and treatment.
>
> 8. Monitoring profile changes following beach nourishment is necessary in order to judge the success of the project and to evaluate the need for the next phase of replenishment.
>
> 9. It may be advantageous, in some cases to install a groin or jetty at the downdrift end of a nourished beach to hold the sediment fill in place.
>
> 10. The single most important factor in the failure of beach nourishment projects is the occurrence of high-energy storms, a hazard that is shared equally by structural

engineering methods. Periodic great storms pose a calculated risk to any expectation of long-term beach longevity.

Methodology

1. When contemplating erosion prevention methods, a study should be done of the comparative advantages of beach nourishment, installing structures, or moving buildings back from the coast.

2. In some cases projects designs may be tested with numerical or physical models to obtain predictions of potential success.

3. When possible, it is best to nourish a coastal sector by starting at the updrift end and emplacing sediment progressively in the downdrift direction.

4. Filter cloth should be placed behind any exposed or buried seawall, revetment, rip-rap or cobble/bolder fill backing a nourished beach, to prevent the washing out of silt and clay-sized particles.

5. Nourishment of a beach may be achieved by placing the sediment offshore in shallow water, stockpiling on the beachface, distributing it along the length and width of the beach, or bypassing at inlets or channels.

6. With proper design of a beach fill, or on a larger scale, a landfill, a beach can be developed at a site where no beach existed before.

7. In making cost-benefit analyses, the long-term economy of beach nourishment as compared to the cost of structure should be taken into account.

8. Making success guarantees or longevity predictions for beach nourishment projects is to be avoided. Each nourishment project is undertaken to restore a recreational facility and/or protect property; the ultimate success of the project is realized in how well that is done over a period of time.

SUMMARY AND CONCLUSIONS RELATIVE TO WASHINGTON STATE NOURISHMENT PROJECTS

Beach nourishment can be an excellent choice for erosion control in many situations; however, all specific sites should be evaluated broadly prior to selection of any approach. A benefit unique to beach nourishment, if carried out properly with prior assessment of potential adverse impacts, is that nourishment general precludes lasting adverse impacts to adjacent shores, coastal processes, and biological communities (Finkl and Walker 2005).

All of the factors listed in the previous section must be evaluated before deciding on an erosion protection scheme for a specific site. This applies to consideration of the full range of alternatives, including hard structures, composite projects, sand nourishment, gravel nourishment, or managed retreat. This type of analysis should be carried out by coastal engineers working cooperatively with coastal geologists (coastal geomorphologists), and not just by staff from one of these two professions. This core team would also need to work with habitat biologists for input on shaping marine species habitat outcomes. The analysis should ideally be carried out independent of a permitting or mitigation framework, which would be best done prior to entering into permitting. A rushed emergency design and permitting process is not conducive to this type of analysis, and can lead to a project that does not perform well. Early planning and design work is critical to

achieving a solution with a reasonable lifespan that does not impact species any more than absolutely required.

The relative amount of wave energy (wave climate) and the geology (amount of background erosion and geomorphic setting) that a site experiences, as introduced above, are key parameters for consideration of any type of erosion control, including beach nourishment projects. Nearby coastal structures, improvements that require protection, habitats, and other factors are all also critical in evaluating an erosion control approach. None of these factors should be the only driver, while ignoring other factors, in selecting an erosion control approach

Retreat from a rapidly eroding coast is a realistic and sometimes cost-effective way of managing severe coastal erosion, as pointed out by Cox et al. (1994) and should be evaluated over the long-term to determine costs that can be compared to other alternatives. This is especially true given that beach nourishment (and other erosion control options) are almost always more expensive and require more renourishment than anticipated (Pilkey 1987).

It cannot be over-emphasized that each site has its own characteristics (Shipman 2002) and that it is not appropriate to apply a cost-benefit analysis or erosion control approach for one site to other sites in the state.

Areas with abundant gravel in natural beaches, such as the Puget Sound-Georgia Strait are proven areas for fairly stable and lasting gravel beach nourishment projects. Gravel nourishment would not be appropriate biologically or physically and would not be successful in a high-energy sand beach environment. Beach nourishment projects that use gravel often nourish from the mid tidal range up to and including the backshore area. Nourished gravel beaches have proven to be an efficient practical form of coastal protection as gravel tends to remain high on the intertidal and supratidal beach profile, minimizing loss to the adjacent subtidal area. Gravel beach nourishment, where natural gravel-rich beaches occur, has involved substantially smaller fill volumes than sand nourishment and requires much less frequent renourishment, and has therefore proven to be much cheaper than the use of sand.

The use of finer sediment sizes for intertidal habitat reasons has been incorporated into gravel beach nourishment design in the Puget Sound and Georgia Strait area where habitats such as surf smelt spawning substrate have been successfully recreated in these projects.

PART II. SR-105 EMERGENCY EROSION CONTROL PROJECT ANALYSIS

SR-105 REGIONAL SETTING AND PHYSICAL PARAMETERS

Regional Physical Issues

Eleven major and over 200 smaller dams installed since the mid 1900s have had a significant impact on Columbia River (Sherwood et al. 1990) sediment input to the Southern Washington and northernmost Oregon coast. Flow regulation preventing peak flows has also greatly reduced transport capacity. Columbia River sediment supply has decreased by a factor of 2 (8.7×10^6 cy/yr from 1878-1934, prior to significant flow modifications from dams, to 4.3×10^6 cy/yr from 1958-1997). Sand appears to be accumulating in reservoirs behind dams in the eastern sub-basin and along the main stem of Columbia River dams.

Sternberg (1986) suggests that 84% of the annual Columbia River sediment input can be accounted for on the continental shelf, slope and deep sea canyons and fans. Sternberg (1986) did not, however, estimate the sediment supply to the inner shelf, bays and coastal barriers.

The Columbia River littoral cell (CRLC) measures 165 km long. The SR-105 Emergency Stabilization Project (ESP) study area is located within the Grayland Plains sub-cell (Gelfenbaum et al. 1999). Tides are mixed semi-diurnal, with a 2-4 m tidal range. Summer conditions result in weak southerly-directed littoral transport. Winter conditions result in stronger northerly shelf currents (Gross et al. 1969) and large northerly-directed littoral drift.

Physical Setting of the North Willapa Bay Study Area

Schwartz et al. (1991) mapped net shore-drift in Washington State. The following is an excerpt for the Washaway Beach area from the Net Shore-drift of Pacific County section of that report, first produced in 1984:

> **Drift Cell 4-2**
> This drift cell beings at a zone of divergence in the area of Cape Shoalwater and continues eastward into Willapa Bay. Waves driven predominantly by southwest winds impinge on the shore at the zone of divergence causing sediment movement to both the north and east. Drift direction for this cell is indicated by long-term eastward development of spits and sand bars occurring within the north sides of the entrance to Willapa Bay.

The Columbia River Littoral Cell (CRLC), the region surrounding and including the Washaway Beach-North Cove shore, has been recently described by Ruggiero et al. (2005) as having the characteristics:

- Broad surf zones with multiple sandbars characterize the fully dissipative (Wright and Short 1983) infragravity energy-dominated nearshore zone of the CLRC.

- Beaches of the CLRC are comprised of well-sorted medium to fine sand with a time- and alongshore-averaged median mid-beach grain size of approximately 0.2mm (ranging from 0.12 to 0.71mm within the littoral cell (with a standard deviation of 0.11 mm). Grain size (generally) decreased with increasing distance from the Columbia River.

- Grain size change is partnered with change in beach slope (cc=0.75, p=0.05).

Morphological evidence indicated that Tokeland Spit formed either before or at the same time that the deep entrance channel to Willapa Bay was pinned on the north shore and occupied what is now

North cove marsh (Morton et al. 1999). Elevations and width of the spit suggest that it was exposed to deepwater ocean waves and overwash flooding during storms at spring high tides. Subsequent seaward and southward migration of the entrance channel, in a direction opposite that of net shore-drift resulted in the construction of Cape Shoalwater and a series of terminal spits recurved to the southeast.

Sediment transport within Willapa Bay is a function of multiple factors. These include tides, freshwater inflows, and wind as modified by short (wind-generated) waves. Shelf processes and the Columbia River freshwater plume and upwelling also play a role inside Willapa Bay (Ternberg 1986, Landry et al. 1989, Hickey 1989). El Nino can modify those factors of influence resulting in changes in sediment and salinity transport. Tidal amplitudes increase from the entrance into the interior of the bay (USACE 2000).

Wind data compiled by Sternberg (1986) are typically directed toward the north to northeast during October – April, and toward the south to southeast during May – September. The strongest winds occur during November – February.

Wave energy is high with monthly mean significant wave heights varying between 1.0 and 3.0 m and wave periods varying between 8 and 12 seconds. Extreme storms produce significant wave heights over 7 m and peak periods over 17 s (Ruggiero et al. 1997). Deepwater waves offshore of Willapa Bay have exceeded 30 ft (Fenical et al. 1999).

Shoreline erosion rates in the Cape Shoalwater-Washaway Beach area have frequently exceeded 150 ft/yr and historically have been observed to be greater than 250 ft/yr (Fenical et al. 1999). Therefore the study area is one of the fastest eroding shores in the lower 48 states of the US.

Dredging

The US Army Corps of Engineers (USACE) dredges an average of 3.41×10^6 m^3/yr of sand from the lower Willapa Bay estuary (USACE 1998). Dredge records since 1956 reveal that the majority of sand is moved to offshore disposal sites in water depths ranging from 15-55 meters. More recently, dredged sand has been placed in the nearshore waters near the present dike location in 1980, and northwest of the present groin location in 1995 and 1996 (USACE 2000, Figure H-2).

As of 2000, only the North Cove shoreline near the groin project is presently authorized for disposal of dredged spoils in Willapa Bay (USACE 2000). This was authorized under the WSDOT SR-105 Emergency Stabilization Project. Direct disposal had to be above elevation +3 ft MLLW and between SR-105 milepost 20.4 and 21. The use of this site for disposal was scheduled to expire in 2001 (USACE 2000).

The USACE document (2000; Appendix H) contains a figure that shows dredged sediment disposal that had seemed to occur in the immediately vicinity of the present groin in 1980 (in deeper water), 1995, and 1996 (both in the nearshore). However, no mention of these potential events could be found in the text of the report or appendix.

El Nino and La Nina

Recent work by researchers in the CRLC pointed out the importance of the El Nino cycle in driving littoral drift direction and rates, and most importantly, coastal erosion. Recent work by Allen and Komar (2002), titled "Extreme Storms on the Pacific Northwest Coast during the 1997-98 El Nino and 1998-99 La Nina" outlined the following findings:

- El Nino: 20 large storms with deepwater significant wave heights exceeding 6 m for 9 hr or longer.

- Ruggerio et al. (1996) projected a 100-yr storm significant wave height of 10 m. On Nov 19-20, 1997 wave heights exceeded that projection

- During the 1998-99 La Nina, 17-22 major storms occurred off the coast – with 4 generating deep-water significant wave heights over 10m. The largest storm on March 2-4, 1999, generated significant wave heights measuring 14.1m. Thus the successive El Nino-La Nina acted as a one-two punch causing severe erosion along the coast. Another storm with significant wave heights greater than 10m occurred during the 1999-2000 winter.

- Winter wave heights and periods have progressively increased during the past 25 years (Allan and Komar 2000). The greatest increase was documented along the coast of Washington (compared to S. Cal - Alaska) amounting to an increase of approximately 1 m over 25 years of wave measurements.

- Seven El Ninos have occurred over the past 20 years. 1982-83, 1997-98 were the strongest on record, 1990-95 persistent El Nino conditions were equal to the longest on record.

- During storm surges and El Nino events, in general, the sea surface is raised by 1cm for every millibar of decreased atmospheric pressure. On November 19-20, 1997 an elevated water level of 30-40 cm was due to El Nino conditions, as the storm approached, water levels reached a maximum at Toke Point of 0.98 m. A March 1999 storm surge at Toke Point resulted in water levels above predicted tide for 18 hours.

- Storm surges and La Nina: Higher surges were again observed along WA coast relative to OR coast. And were the largest seen during the past 25 years and appearing to follow a pattern of progressive increase in the North Pacific.

Recent findings of the relationship between El Nino and La Nina with shoreline erosion and accretion were summarized by Ruggiero et al. (2005). This article was published several years after the culmination of 5 years of intense data collection carried out by the US Geological Survey and the Washington Department of Ecology, along with others. Pertinent findings from (Ruggiero et al. 2005) are listed here:

- Strong El Ninos feature increased frequency of storm tracks from the south-southwest and higher than normal sea levels. During the 1982-83 El Nino large wave heights and acute southerly wave angles forced and increased the magnitude of offshore and northerly sand transport.

- The winter of 1997-98, which coincided with once of the strongest El Nino events on record for the US Pacific Northwest (Komar et al. 2000), caused much beach change. In each case the beach in the northern portion of the sub-cell prograded relative to the beach in the south. This pattern persisted for several years following the event (at 3-m contour

NGVD). Beaches also experienced monthly mean water levels up to 0.4 m higher than typical, monthly mean winter wave heights were up to 1.0 meter higher than usual, and wave directions had a more southwest approach (Kaminsky et al. 1998, Komar et al. 2000, Sallenger 2002).

- Between summer 1997 and winter 1998, the subaerial beachface within the CRLC lowered an average of approximately 0.4 meters and retreated horizontally, at the 3-meter contour NGVD, approximately 19 meters (ranging 11 to 71 m).

- A moderate La Nina followed the 1997-98 El Nino in 1998-99. The average rate of change during this 2-year period for all locations was approximately 2.7 m of shoreline recession. With the La Nina came an increased number of storms to the region with higher wave heights and more significant storm surges than previously experienced (Allan and Komar 2002).

- Komar et al. (2000) and Allan and Komar (2002) calculated the run-up of waves on beaches from the largest storms occurring during these two winters (1997-98 and 1998-99). These elevated water levels were sufficient to account, at least qualitatively for the observed erosion.

- Southwest wave approach caused by the El Nino resulted in northerly transport and large-scale shoreline reorientation in the entire cell.

- 1999-2000, 2000-01, and 2000-01 were moderate winters comparably, with water levels, wave heights/periods close to long-term averages. Many beaches recovered during this period.

EMERGENCY EROSION CONTROL PROJECT BACKGROUND

Objectives of Nourishment

Coastal erosion has been rapid at the project site (FHA and WSDOT 1997; see *Photo Pages*). According to a project write-up by S. Phillips and B. Pierce, entitled "Beach Erosion Control Project at North Cove, WA" (undated), "The project was designed and constructed to protect a portion of SR-105 from the effects of ongoing erosion." Phillips and Pierce stated that the groin and underwater dike at Washaway Beach/North Cove were designed with the following objectives:

- Control beach formation at the North Spit
- Eliminate migration of the deep tidal channel
- Minimize wave energy impacts along the existing shoreline
- Preclude maintenance requirements
- Preclude negative effects on the adjacent shoreline
- Satisfy strict environmental rules

Fenical et al. (1999) of PIE stated that the groin structure, combined with beach nourishment, was designed to dissipate wave energy along the shore nearest to SR-105 and retain sediment that would otherwise be lost from the system. The groin and beach nourishment area are visible in air photos taken between 1998 and 2005 in the attached *Photo Pages*.

The Federal Highway Administration (FHA) and Washington Department of Transportation (WSDOT) (1997) stated in the Environment Assessment that the groin was designed to act as a

"beach holder, breakwater, and wave deflector". The groin was intended to accumulate longshore sediment. The "beach holder" was intended to help contain sand placed between the groin and highway, thus reducing the long-term beach nourishment maintenance costs. The breakwater-like nature of the angled groin was intended to reduce the wave height of the waves impacting the slope adjacent to the highway, thereby reducing the long-term maintenance costs. The deflector/dike was intended to deflect the North Channel tidal currents in north Willapa Bay, and thereby protect the shoreline from undercutting of the toe of the beach.

The FHA and WSDOT (1997) stated that the nourished beach would need to be re-nourished (estimated) twice during the lifetime of the project (40 year life expectancy for the dike).

Bob Burkle of WDFW (Burkle per. com.) said that sand nourishment was used with the objectives of raising the beach elevation down-drift of the groin to create backshore habitat, create a buffer between the revetment adjacent to the state road and waves, and cover and reduce habitat degradation (primarily to fish) caused by the revetment.

Orrin H. Pilkey, James B. Duke Professor of Geology, and world-renowned expert on coastal erosion and management visited and observed coastal management along the SW Washington Coast in 1997. This experience resulted in Pilkey's critique of the management practices being applied to the Washington coast and the lack of a proper planning and project initiation in the decision making process. He questioned the dominance (at that time) of one company (PIE) in assisting in acquiring funds from government and then getting the contracts and selecting the design approach (Pilkey 1997). Pilkey stressed that the (relatively) pristine condition of the Washington Coast beaches should provide an opportunity to apply lessons learned from the East Coast, and the people of Washington should be mindful to preserve this condition for future generations.

Pilkey (1997) continued his critique by calling the SR105 project as purely experimental by nature of the engineering. He wrote that "rule number one in coastal engineering is to not put in a structure unless you have at least a fair idea of what will happen". And predicting how the shore (or channel) will respond to the large engineered structure was not impossible (within any reasonable level of accuracy).

Project Design

The design elements used in the process of formulation of the final design for the groin, dike, and beach nourishment project (Phillips and Pierce undated) were as follows (see *Photo Pages*):

- A multi-purpose rock groin extending seaward at an oblique angle from the existing shoreline to:
    - Acts as breakwater
    - "Beach-holder"; prolong life of beach fill
    - Designed to accommodate migrating juvenile salmon (along upper beach). Fish passage impacts were planned to be mitigated with sandy beach along a portion of the rock groin, 7H:1V slope on west side of groin and use of gravel to fill crevices. Where slope is greater than 7:1, sand to cover groin.

- An underwater dike extending from the seaward end of the groin to a point in the North Channel that was designed to:
    - Divert tidal flow from the shoreline and preclude undermining of the multi-purpose groin.

    - Scouring took place at western-end of dike following construction that could potentially destabilize the structure and deleteriously effect the overall performance of the project.

- Beach nourishment
    - 350,000 cy (cubic yards) of sand along the entire stretch of SR-105, majority of beach nourishment area was constructed up to elevation +30 ft MLLW, with the narrow perimeter area at a 3H:1:V slope down to existing beach surface.
    - Material for the nourishment was dredged and placed on the beach by cutterhead pipeline dredge. The borrow site was located 1 mile south of the project within Willapa Bay. Sediment size was generally reported as 0.25 mm, which apparently was very similar to the native beach sediment.
    - Beach nourishment created 1,000 acres of wide supratidal "beach" area, and 16 acres of shallow water habitat (a high-value habitat in the North Cove area).
    - Gravel nourishment into the groin was carried out with the objective of filling interstitial spaces in groin rock to minimize negative impacts to fish by filling the interstitial spaces between rock to minimize cover for predators.

The construction window was June 15, 1998 to October 27, 1998. Beach nourishment was started on June 15,1998 and completed on July 10, 1998 (Fenical et. al 1999).

SITE OBSERVATIONS

Site observations were made by Jim Johannessen, Licensed Engineering Geologist and MS of Coastal Geologic Services Inc., on June 9, 2005 during a period of low tide. Different areas around the groin and nourishment area are discussed separately in this section. See the attached *Photo Pages* for an overview of the project area.

Groin – West Face
The upper portion of the rock groin contained abundant large woody debris (LWD) above the spring high tide level along with assorted organic matter. The slope of the west face of the rock groin ranged between 13 and 16% overall. The uppermost face of the west side of the groin had a steeper slope, up to 20-35%, while the lower and middle face of the groin generally had a slope of 12-15%. This suggested that a portion of the rock that was placed high on the slope may have settled waterward. The waterward slope rocks were mostly covered with barnacles, which suggested moderate stability during the time of the field visit.

No gravel was observed within the rocks on the west face or the top of the rock groin. Generally no sand was present within the rock either. However, portions of the waterward end of the groin had minor amounts of sand between rocks.

The waterward end of the west face of the groin contained several areas where the rock protruded up to approximately 15-20 ft off to the side (southwestward), which suggested minor rock displacement following construction.

Groin – Waterward End
Side slopes of the groin near the waterward end ranged from 10-15%. The rock groin surface was slightly irregular at the waterward end. The crest of the groin in the waterward end was slightly irregular but the overall slope varied only moderately.

The lower intertidal sandy beach on the west side of the groin met the tip of the groin 40-45 ft waterward of the same elevation beach on the east side of the groin. In other words, the beach was offset 40-45 ft with the western beach being further waterward than the eastern beach. This could be interpreted as accretion on the west side of the groin.

Minor amounts of sand and gravel (primarily small pebble but ranging up to larger pebble and small cobble) were observed in the lower intertidal portion near the tip of the groin. Minor amounts of small angular rock were also present in this area.

East Side of Groin
Rock slopes on the east side of the groin were noticeably steeper than on the west side. Overall slopes ranged from 25 to 35%. The groin side slopes varied depending on elevation. The upper elevation portion of the groin was sloped between 8 and 15% while the lower side slope was sloped from 20 to 30%.

The upper and middle east side of the groin was covered with the larger armor rock. The lowermost side slope was covered only with smaller rock with sand and minor amounts of rounded gravel.

Beach West of Groin
The beach towards North Cove was composed of very a broad, low slope sandy beachface. The uppermost beach was slightly less gradual in slope. A narrow backshore area was present with herbaceous species immediately waterward of coniferous (spruce) forest. Evidence of recent erosion was present further west as spruce trees were fallen over the low bank.

The intertidal beach was composed of nearly flat broad sandbars. A small runnel-like feature was present adjacent to the groin where creek drainage and a portion of the beach drainage and intertidal beach drainage was occurring. A minor, low elevation sand slope was found along the length of the west side of the groin, reaching down to approximately low water.

Beach East of Groin
The nourishment area beach in June 2005 was composed of a steep backshore dune area fronted by a gently sloping, small woody debris-covered backshore area. Waterward of this was a gently sloping upper intertidal sand beach, fronted by a broad lower intertidal sand flat.

The dune area showed evidence of active aeolian (wind-blown) transport in that they lacked vegetation and showed recent ripples and bed forms. Only the area immediately adjacent to the highway contained vegetation, which consisted primarily of Scotch broom and grasses. The dune area of the backshore was an expansive one, with evidence of generally eastward aeolian transport (sand ripples). Minor amounts of pebble had been concentrated on the surface of the dunes over time as the wind had winnowed away finer material and left coarser material at the surface.

The backshore dune area immediately east of the groin appeared to be more stable and contained abundant dunegrass and LWD. The dunegrass-covered area extended for approximately 150 ft alongshore. The eastern end of this area showed evidence of relatively recent erosion in the form of a near vertical 2-3 ft scarp in the sand.

The supratidal backshore area showed evidence of sediment transport by waves within the last several months, likely more recently. The cross-shore width of this area above MHHW ranged from 70-80 ft over most of its length.

The slope of the upper intertidal beach face was on the order of 7-8% in the area close to the groin (the western 300 ft of the upper intertidal beach). The intertidal upper beachface was sloped slightly more gradually further east, near the east end of the remaining portion of the nourished beach. Here the slope was 6-7%.

SR-105 Revetment and Cable Protection

SR-105 bends waterward (approximately) 0.5 miles east of the 1998 nourishment area. The road in this area was on the lower hillslope. The base of this slope was defended by a riprap revetment. The upper half to two-thirds of this revetment was covered by cable netting. Portions of the toe of the revetment show evidence of erosion and settling, with some riprap scattered on the upper intertidal beach in certain areas. The intertidal beach was at low elevation in this reach with waves reaching the toe of the revetment at some point slightly above mid-tide level. The intertidal beach was being impinged upon by the old rock revetment, which extended down to approximately 2-3 ft below MHHW. Old marsh peat and silt beds were exposed on the intertidal beach waterward of the revetment, also indicative of beachface erosion.

The revetment curves landward further east. Immediately east of the revetment wave refraction had caused a considerable amount of landward erosion that has reached near the slope adjacent to SR-105 in places. This can be termed "flanking" erosion or "end effects" and was caused by ongoing wave attack combined with wave refraction as the waves from the west and southwest refract or bend around towards the bank and focus wave energy on the easily eroded silt and clay bank.

Shoreline East of Revetment and Nourishment Area

The backshore in this area contained outcrops of fairly dense fluvial-deposited sandstone. The area showed signs of ongoing erosion into the backshore area and downcutting of the intertidal and backshore sandstone. A small low bank area that was shaped as a narrow point also showed signs of erosion along most of its shore. The large coastal wetland complex started a short distance east and southeast of this location.

NOURISHMENT PROJECT PERFORMANCE

Previous Monitoring and Reporting

Initial project monitoring results were reported by PIE personnel (Fenical et al. 1999) covering the period from August 1997 to August 1998. Ten topographic profile surveys were completed in that period. Results of monitoring showed that the beach and bluffs down-drift and up-drift of the project were highly dynamic, and were subject to variable erosion and accretion rates. The beach nourishment in immediate vicinity of the groin and dike was redistributed along the protected length of the highway in the first year following construction. Some of the nourishment sediment in the southern portion of the project area was eroded and redistributed along the bottom slope and adjacent shoreline.

Erosion was reduced up to 4,000 ft northwest of the project area (based on topographic surveying), as the groin acted to hold sediment on the west side. Erosion continued further northwest 44+00W (4,000 ft from dike centerline) with the same erosion rate pre and post construction (though very large storms persisted in late 1998).

Hydrographic surveys revealed that the North Channel northern slopes accreted after construction of the dike near the project site. Southern channel slopes eroded along the entire measured channel length during pre and post construction (PIE 2001). Both changes to the channel are likely related to southward channel relocation (by the dike) in the project area. Scouring occurred at the waterward end of the underwater dike and some settling of rock was also reported.

As reported in the "Final Monitoring Report, SR-105 Emergency Stabilization Project Monitoring Program", dated October 11, 2001 (PIE 2001) in Part 1, *Section 1.2.2 - Beach Nourishment*:

> "The beach nourishment has performed according to design. The original volume of beach nourishment placed along the shoreline during construction was approximately 350,000 cu yd. The placed sediment was re-distributed along the shoreline and nearshore area by natural processes and provides efficient protection and wave dissipation. Currently, the volume of beach nourishment remaining at the upper beach area (above +3 ft MLLW) is estimated to be 170,000 cu yd."
>
> "Maintenance placement of sand may be required in 2-5 years (as estimated during design). The actual needs and volumes for maintenance of the beach nourishment should be determined based on the results of a future monitoring program."

At the end of the three years of monitoring, no accurate quantitative measurements were available for the volume of material remaining, only an estimate. This was because only beach profiles were measured (PIE 2001) and not beach topography. In summary, 3 years after the 1998 nourishment, the remaining nourishment sediment was *estimated* to be 170,000 cy. This was equivalent to 49% of the initial nourishment volume. Almost all of this volume loss occurred in the first winter.

It appears that almost all of the gravel placed in the groin was lost rapidly during the winter of 1998-99. Only a very small amount of gravel could be found during field assessment in Jun 2005. Voids between rocks in the groin were ubiquitous following the winter on 1998-99.

The larger area west of the project, experienced some accretion in the nearshore between 1998 and 2000 (Figure 5). However, the data did not continue all the way up the intertidal beach.

GIS Analysis

Analysis using a geographic information system (GIS) was carried out by Coastal Geologic Services as part of this study. This was done to provide data that was not provided by the project monitoring. Air photos received from WSDOT were reviewed and the best photos showing the nourishment project at lower tides and good scale were selected. These images were scanned, georeferenced to the project design drawing, and digitized. The mean higher high water (MHHW; as represented by the wet-dry line) was determined to be the best feature that could be used as a shoreline proxy. Also, since the monitoring only extended for 3 years after construction, it was hoped to extend that data record beyond 2001 with later air photos. Air photos were expected to cover at least a portion of the 2002-2005 period, however, as of final writing of this report, only 2001 photos were received.

Using the wet-dry line in the georeferenced digital air photos, the spatial extent (retention) of nourishment sediment in the upper beachface and backshore was mapped over time (Table 1, Figures 1 [attached] and 2). The beach area above MHHW decreased slightly by September, and then to approximately half of the design volume by January 1999. A low area was reached (42% of design) by the end of the winter in April 1999. Some beach recovery occurred by August 1999 as some sand likely moved back onshore. By April 2001, the last data pint, the beach area was at 58% of the design area.

In terms of active beach area, the percentage of upper intertidal beach and adjacent backshore was much lower than percentages listed in Table 1. This was because a large area was high elevation sand plain (design was at +25 ft MLLW), with very limited vegetation. Beach profiles (PIE 2001) showed that the elevation of this area was very close to +25 ft MLLW prior to horizontal erosion occurring. Aeolian processes had formed some sand dunes y June 2005, but the lack of vegetation

of any kind in most areas was causing the sand to blow onto the highway. In other words, upper beach habitat area was also much smaller in size than the numbers suggest.

Table 1. Beach area above MHHW based on GIS work, 1998-2001.

Nourishment area - high tide beach	Area (ft^2)	Loss(-)/Gain(+)	Percent of Design vol.
Design dimensions	680,492	n/a	n/a
Sep-98	624,765	-55,727	92%
Jan-99	353,686	-271,079	52%
Apr-99	287,519	-66,166	42%
Aug-99	460,662	173,143	68%
Apr-01	396,902	-63,760	58%

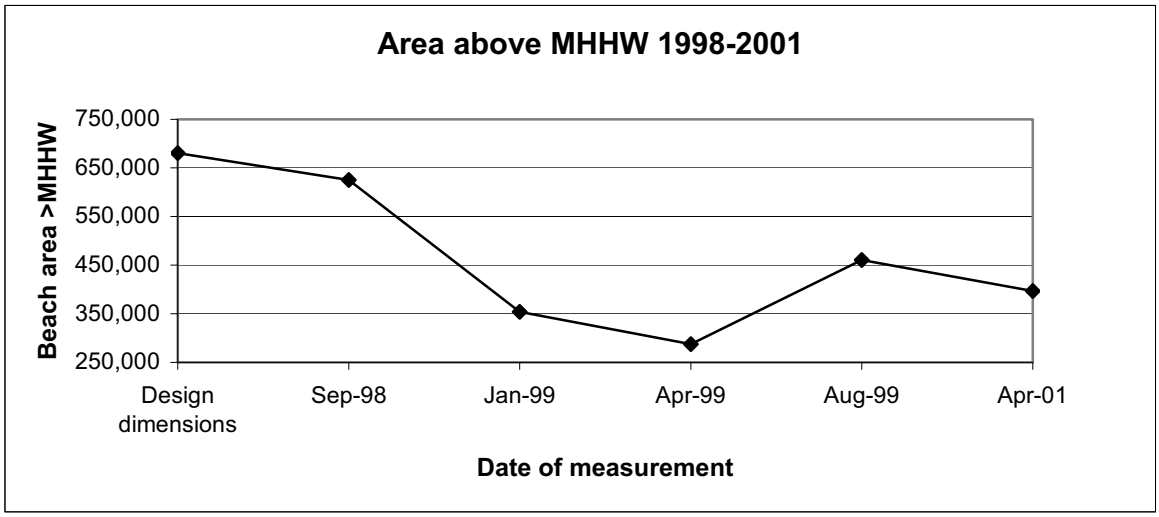


Figure 2. Beach area above MHHW based on GIS work, 1998-2001.

The length of the road revetment that was exposed to wave attack at the time of the air photos was also digitized using all available 1998-2001 photos. The revetment was fully protected in September 1998 but was then exposed along approximately half of its length (approximately 1,000 ft) by April 1999 (Table 2, Figures 3[attached] and 4). In April 2001, only 34% of the revetment length was protected by remaining sand nourishment sediment. Field measurements in June 2005 showed that slightly over half (55%) of the revetment length was fronted by sand. Therefore direct wave attack was occurring on the other 45% of the revetment length in summer 2005.

Table 2. Revetment length exposed to wave attack in eastern portion nourishment area based on GIS work, 1998-2001.

Date of Photo	Exposed revetment (ft)	Additional (ft) exposed	Percent of revet. Protected (ft)
Sep-98	0	n/a	100%
Apr-99	1020	1020	53%
Aug-99	1011	-9	53%
April-0 1	659	-352	34%
Jun-05	1059	400	55%

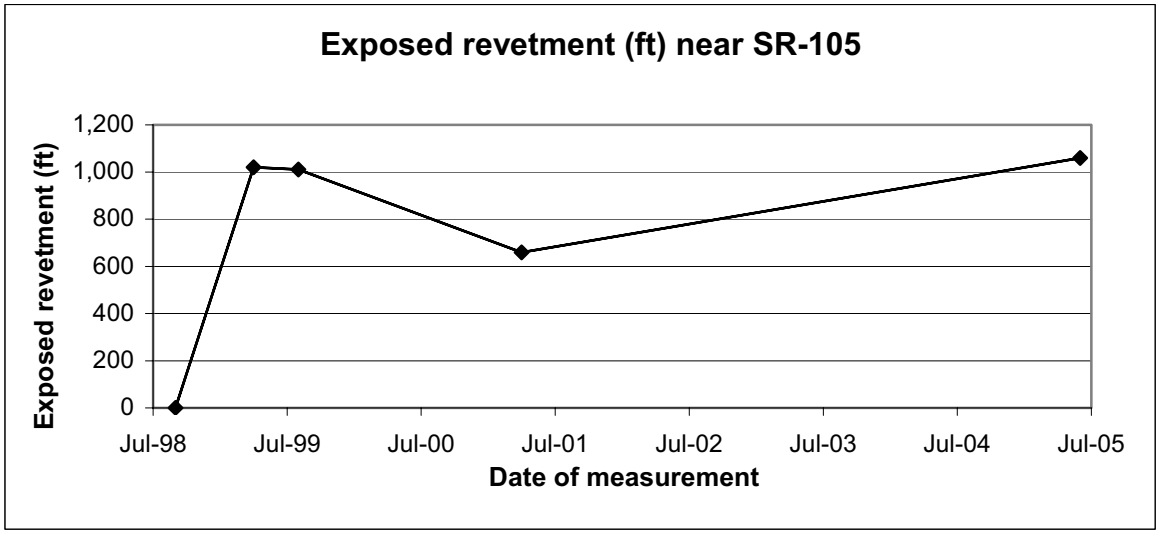


Figure 3. Beach area above MHHW based on GIS work and new field point, 1998-2005.

The distance of revetment protected is likely to decrease in winter, judging by past trends at the site since nourishment, and the fact that the winter beach profile is generally lower than the summer beach profile. If beach erosion continues in this area, the road revetment and the roadway will be threatened. Profile monitoring (using a reduced number of profiles) would be a very good way to track beach changes in the vicinity.

Sediment Analysis

A sediment sample was collected from the upper intertidal nourishment beach area for grain size analysis. The sample collection was integrated over a 100 ft stretch of the beach located approximately 150-250 ft east of the groin. The elevation of the sample was estimated to be from MHHW to 3 ft vertically below MHHW. A second sediment sample was collected from the northwest side of the groin for comparison with the nourishment area sample. This sample was collected between 500 and 700 ft northwest of the upper groin in the sloping upper beach west of the intertidal creek channel. This sample was collected in a consistent manner with the nourishment area sample between MHHW and approximately 3 ft below MHHW, from the upper 0.2 ft of the beach.

These samples were analyzed for grain size at an (independent) laboratory. Results indicate that the grain sizes were near identical in each sample (Appendix A). This suggests that the grain size of the nourishment sediment was almost identical to the native sediment. It also may indicated the groin has already "filled" to a large extent on the western, up-drift side and is bypassing sand to the east, which is consistent with field observations.

SUMMARY AND CONCLUSIONS RELATIVE TO SR-105 ESP

Initial Nourishment

The SR-105 Emergency Stabilization Project (ESP) shows that the relatively high wave energy and background erosion at the site contributed to the rapid loss of approximately half of the initial volume of sand nourishment. The rapid erosion of the nourishment sand was apparently due to the intense La Nina winter of 1998-99, which had 17-22 major windstorms and substantially elevated sea level (Allan and Komar 2002). Seven El Nino events have occurred over the 20 years leading up to the 1997-98 event. Therefore El Nino and La Nina winters should be expected to occur with a

frequency on the order of every 3-5 years with varying intensity such that any renourishment sediment placed at the site in the future may or may not be subjected to these highly erosive winter seasons soon after placement. In addition, climatologists and oceanographers project an increased frequency of El Nino events due to climate change.

During a field reconnaissance in June 2005, there were clear indicators of both wave shadowing and protection of the nourished beach immediately east of the groin, as well as negative impacts of the groin including erosion further to the east. The groin was angled alongshore to provide some protection of the immediate down-drift portion of the nourishment area (Fenical et al. 1999), and this has clearly helped "hold" the western part of the nourishment area. The western portion of the nourishment area has proven to be relatively stable since 1999 due to wave sheltering effect of the very large groin. However, the structure has also led to the wave refraction and increased of wave energy reaching roughly the east half of the nourishment area.

Additional evidence of wave refraction leading to erosion of some of the nourishment sediment is that the lower intertidal beaches are more eroded than the upper intertidal beaches further east of the groin. This is due to the fact that during low tide, the groin and upper dike cause wave refraction to erode the beach in a position further east than does the upper (more western) portions of the groin at high tide.

This type of down-drift erosion is a typical response that a large groin has on the down-drift beach (Komar 1984, Bird 1985). Although it was pointed out by PIE (1997b) that more erosion than originally anticipated may occur in the eastern end of the nourishment area, the design of the groin or nourishment project was not altered. (Besides the two brief technical memos that were found in researching this report: PIE 1997a and PIE 1997b, no more thorough documentation could be found by PIE staff in June 2005).

Renourishment

If renourishment were to occur, it is likely that sediment will again be lost in the eastern half of the nourishment area and the road revetment will again be exposed to winter storm waves. The timing of the loss of sand from the eastern half of the revetment is hard to determine due to the irregular timing and intensity of El Nino and La Nina events, but given the generally high energy wave regime, future renourishment needs at this location should be expected to be every 2-4 years (on average).

Leonard et al. (1990) defined the nourished "beach lifetime" as the amount of time between fill emplacement and the loss of at least 50% of the original fill volume. In the SR-105 case it appears that the effective lifetime of the initial nourishment was only 1 year, although it needs to be reiterated that the winter of 1998-99 was one of the stormiest on record in the northwest.

Based on a one-dimensional wave formation model, PIE (1997a) predicted that "nourishment should provide full attenuation of wave energy on the beach slope seaward of the existing revetment." PIE also preformed modeling that determined the renourishment sand would remain fronting the revetment for 8 years, at which time the revetment would begin to be exposed (PIE 1997a). They stated that based on their direct experience with "beach nourishment projects utilizing combinations of submerged breakwaters and beach-holding structures show that renourishment should be required 20-25 years after initial construction." PIE went on to say data from Florida had renourishment intervals of 3-20 years, without and "beach-holding" structures. PIE concluded that the structures made their predictions "conservative".

PIE (1997a and 1997b) averaged the two renourishment intervals mentioned here and recommended "limited renourishment of the unprotected shoreline should occur every 6 years" using 50,000 cy of sand (modified to only in years 6, 18, and 30 in PIE 1997b). They also stated that complete renourishment should occur every 12 years using 250,000 cy of sand (PIE 1997a). The timing of expected renourishment of the larger volume was spelled out to in years 12 24 and 36 (PIE 1997b). Monitoring was recommended to establish the actual maintenance schedule (PIE 1997a). This author agrees that (a reduced level of) monitoring needs to inform the potential timing of renourishment.

Anticipated sea level rise will exacerbate erosion of nourishment sediment. The rate of sea level rise has increased substantially in the last decade, accelerating to approximately 1 inch in 10 years (NASA 2005). This will increasingly threaten any nourishment or structures placed at the site more over time.

It cannot be over-emphasized that each beach has its own characteristics (Dean 2002, Shipman 2002) and that there is no single answer to a cost-benefit analysis or erosion control approach for one site that can be applied to other sites in the state.

Off-site Considerations
There are a number of considerations of how the groin, the initial nourishment, and potential renourishment would affect the surrounding area. This is particularly true for the down-drift shore to the east and southeast. A large coastal saltmarsh complex with multiple inlets is present (North Cove, near the Shoalwater Indian Reservation; see Photo Pages), which is important habitat for fish and other species.
USACE 2002

The groin limits the supply of sand to easterly beaches by trapping it west of the groin. Simultaneously, the initial nourishment has increased the sand supply to the east. Over a longer time period, the fixing in place of the shore near the groin while that surrounding area continues to erode on the order of 29 ft/yr will act to slowly change the shore orientation west of the groin. This would lead to the orientation of the shore approaching Cape Shoalwater to slowly change and gradually transport more sand to the west (northwest) and north, instead of to the east.

Renourishment would act to augment the sand transported to the barrier beach (spit) fronting the large saltmarsh complex, thereby reducing the sediment limiting effect of the groin. This could be seen as a benefit in that regard.

Overview of Options for SR-105
While it is beyond the scope of this report to critically examine and contrast the range of relevant options for the site, the feasible options are outlined below for further study.

1a. **Renourishment** – Assessment of the performance of the initial nourishment have been based largely on qualitative assessment along with site monitoring, which was not continued past 2001. The dataset was not complete and the limited scope of the present effort did not allow for an estimate of renourishment volumes necessary to protect the SR-105 revetment. It must be noted that any determination must be prefaced with the fact that the study area experiences highly variable winter storm intensity. This is caused by the El Nino-La Nina cycle, which has varied both in frequency and intensity in the past, and will undoubtedly continue to do in the future. In recent decades it has been shown that the storm intensity has increased in the North Pacific adjacent to the Pacific Northwest (Allan and Komar 2002). As outlined above, deepwater wave heights have increased on the order of 1 m, and intensity of El Nino winds and waves also appears to have

increased. This leads to heightened variability in project performance and makes the nourishment sediment vulnerable to erosion (Dean 2002).

In general, it appears that relatively frequent renourishment would be required to maintain toe protection along the eastern half of the threatened road revetment. It appears that renourishment would need to occur on a 2-4 year cycle to maintain adequate toe protection of the complete length of the revetment. The PIE Design Memo stated that renourishment requirements were expected to be every 6 years, which appears optimistic.

The first renourishment could occur at very low cost by moving sand from the high elevation backshore (that extends up to +25 ft MLLW) to the active beach system. There is a very large volume of sand well above the elevation of the active beach immediately east of the groin that could be bulldozed down to the active beach. This volume could be determined by topographic surveying for planning purposes. For rough planning purposes, a rough estimate of 70,000-100,000 cy of "available" sediment was made using the GIS work and examination of monitoring profiles.

1b. **Renourishment With New Down-Drift Groin** – The addition of a large rock groin at the down-drift (east) end of the threatened road revetment would prolong residence of renourishment sediment. A new shore-normal structure would act to trap eastward transport of nourishment sand and maintain better toe protection at the revetment. However, a large groin would likely exacerbate flanking erosion some distance to the east, along the beginning of the large spit complex that protects the (very large) saltmarsh complex. In addition the base of barrier spits is often the most subject to erosion and breaching, and thus would be a potential danger.

A second groin was briefly considered by PIE (1997b) but its exact location was not explained. It appeared that the groin would angle offshore similar to the existing groin such that it would not be as effective in holding sediment on the up-drift side. It would likely be more effective in acting as a wave attenuator relative to a shore-normal structure. A large groin in this environment would be quite expensive and would cause the additional loss of intertidal habitat.

2. **Rebuild Revetment** – This alternative entails completely reconstructing the rock revetment in at least the eastern half of the nourishment area. This option could initiate a minor loss of intertidal habitat but would be far less "intrusive" on the beach system than would a second groin. A new reach of revetment should have to extend further east than the present revetment to eliminate the flanking erosion that is occurring with the current configuration (although this may be inevitable in any case).

3. **Relocate Road** – The area has a long history as a rapidly eroding shore (see *Photo Pages*). In order to provide long-term protection of the roadway, the reach near the eroding shore would be relocated a considerable distance landward. This would also entail relocating the utility corridor and apparently a graveyard.

Retreat from a rapidly eroding coast is a realistic and sometimes cost-effective way of managing severe coastal erosion, as pointed out by Cox et al. (1994) and should be evaluated over the long-term to determine costs that can be compared to other alternatives. This is especially true given that beach nourishment (and other erosion control options) are almost always more expensive and require more renourishment than anticipated (Pilkey 1987).

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ATTACHMENTS

Photo 1 SR-105 1977 pre-construction

Photo 2 SR-105 1995 pre-construction

Photo 3 SR-105 ESP – August 2002

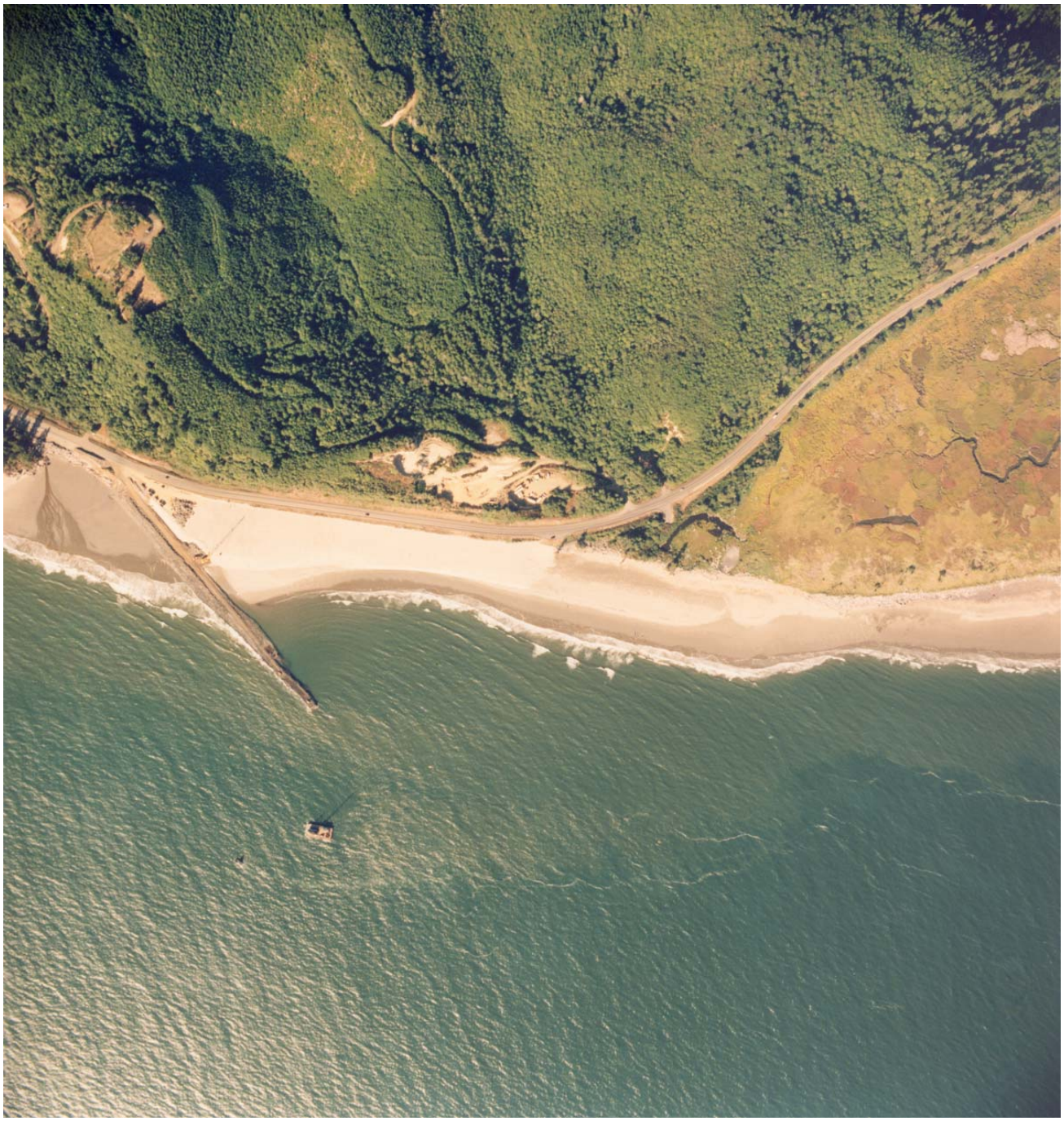


Photo 4 SR-105 ESP – August 14, 1998

Photo 5 SR-105 ESP – April 11, 1999

Photo 6 SR-105 ESP – April 11, 2001

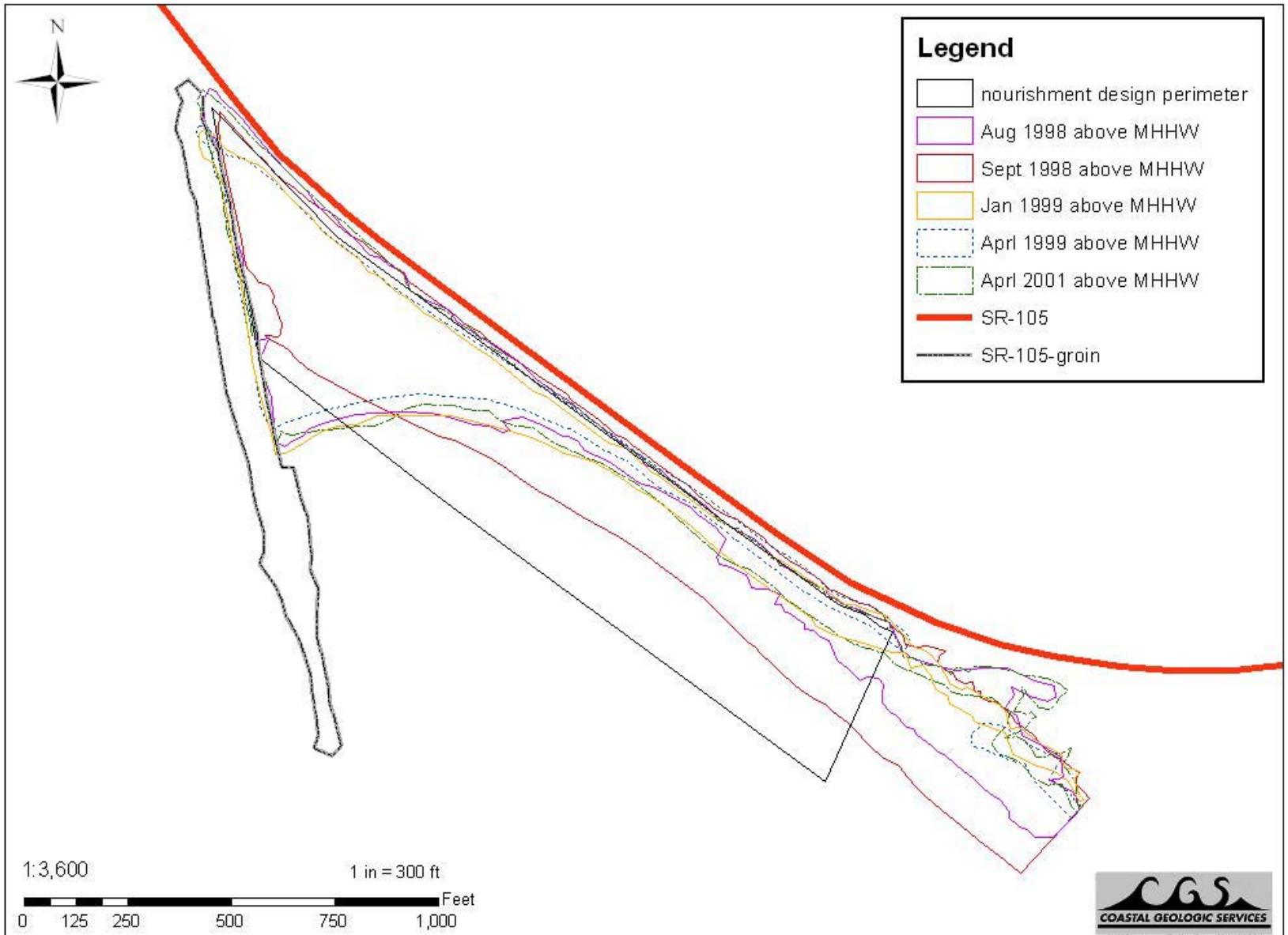


Figure 1. Approximate SR-105 ESP MHHW and supratidal area polygons based on air photos 1998-2001

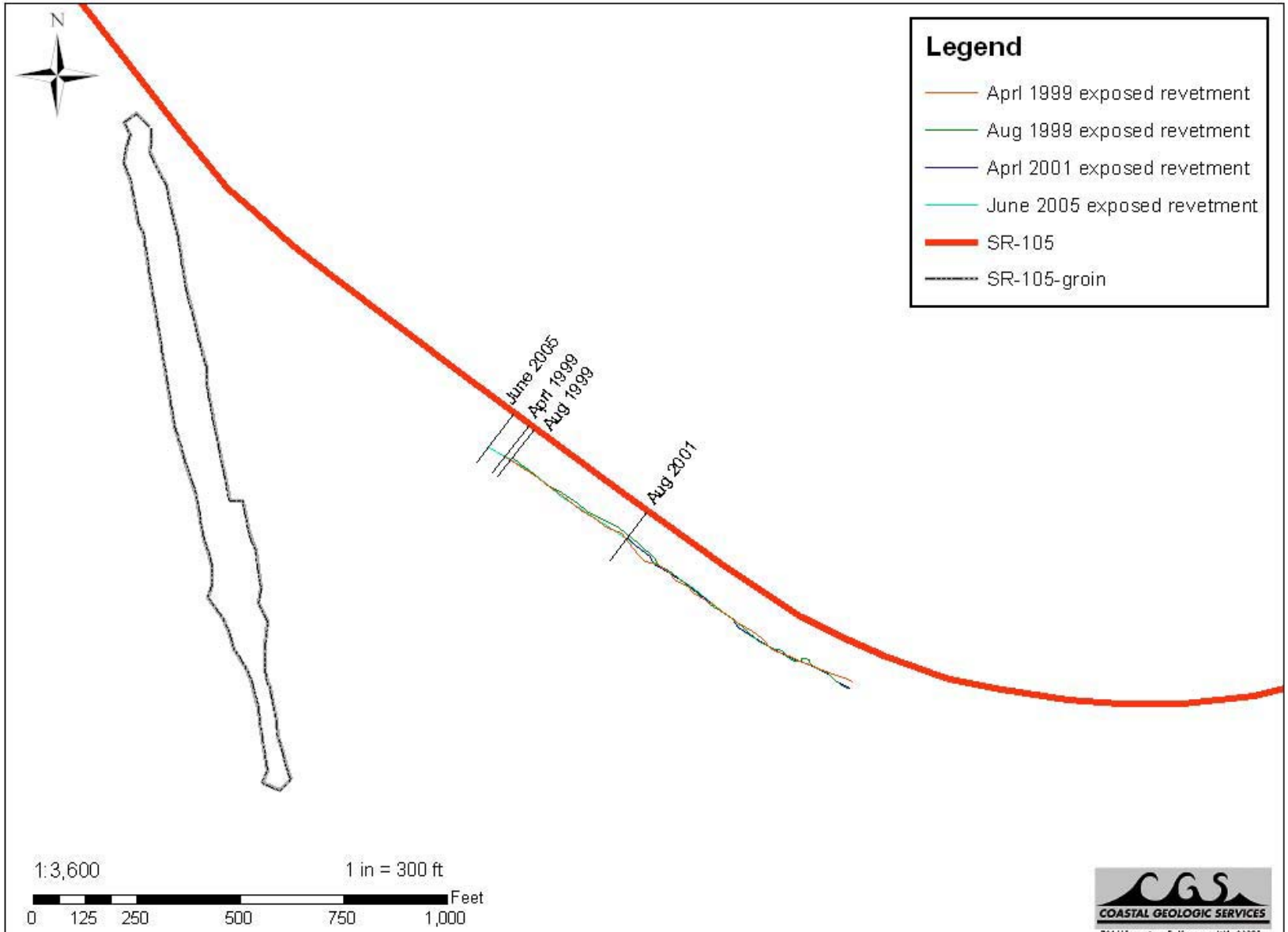
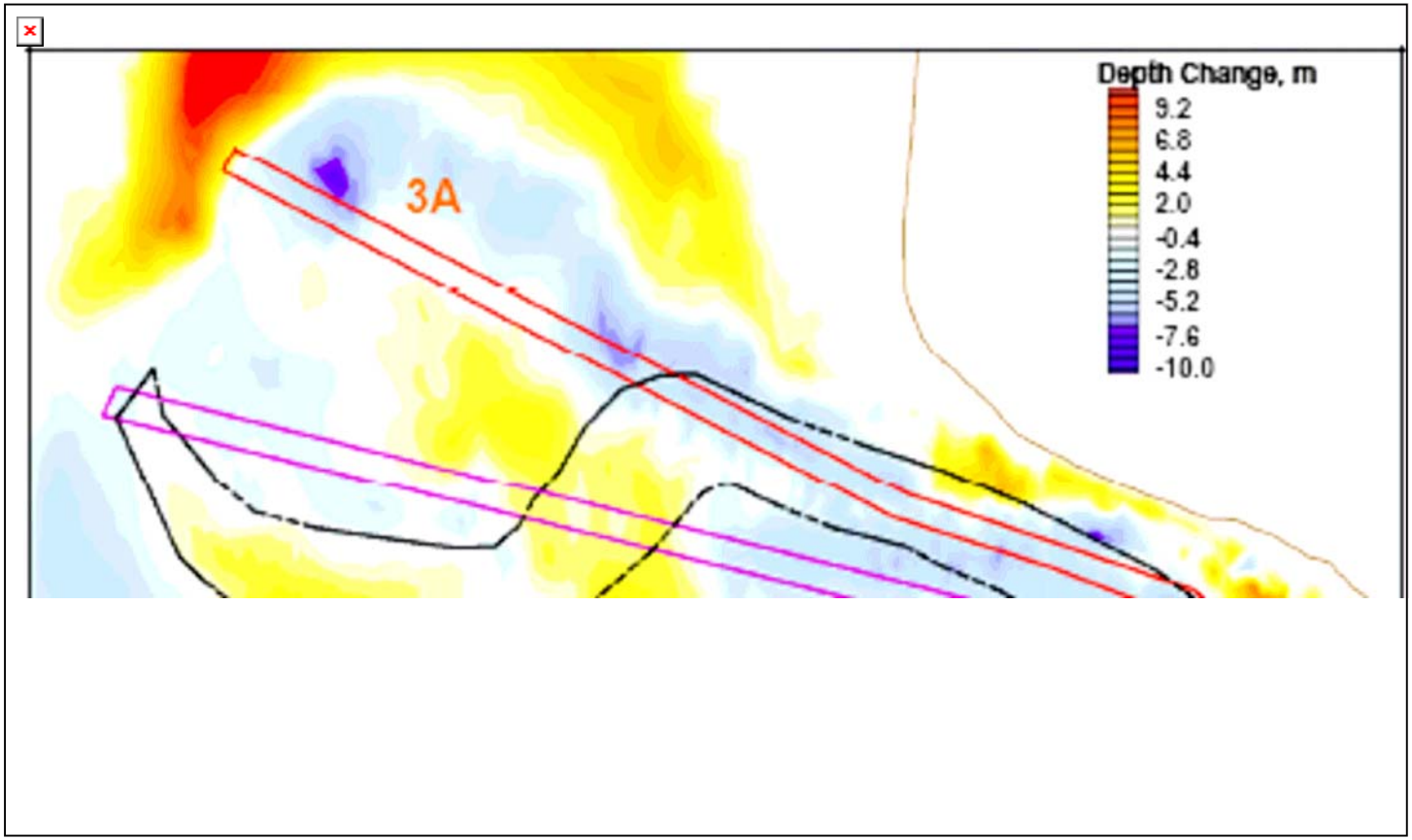


Figure 4. Exposed revetment near SR-105 ESP 1998-2005


Depth Change, m
9.2
6.8
4.4
2.0
-0.4
-2.8
-5.2
-7.6
-10.0
3A

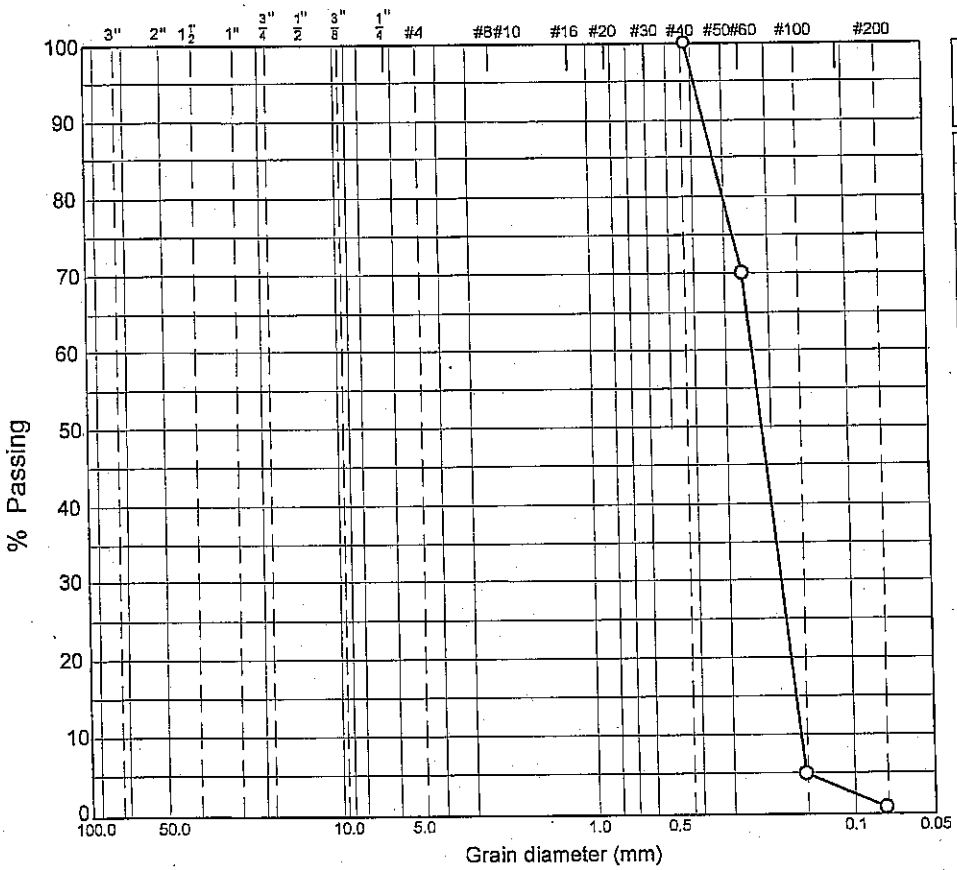
GEOTEST
741 Marine Drive
Bellingham, WA 98225 360 733_7318 888 251_5276 360 733_7418

TEST REPORT
AGGREGATE SIEVE ANALYSIS

PROJECT: **General Services - SR 105**
CLIENT: **Coastal Geologic Services**
AGG. TYPE: **Poorly Graded Sand (SP)**
SOURCE: **MHHW**
LOCATION: **Unknown**
LAB SAMPLE #: **3366**

JOB NO: **5240**
REPORT NO: **S1**
DATE: **6-14-05**
PAGE NO: **1 of 1**
SAMPLE DATE: **6-10-05**
SAMPLED BY: **Client**

GRAIN-SIZE DISTRIBUTION CURVE



Coarse	Fine	Coarse	Medium	Fine
GRAVEL		SAND		

SIEVE SIZE	PASSING %	SPEC. *
1-1/2"	100	
3/4"	100	
3/8"	100	
#4	100	
#10	100	
#20	100	
#40	100	
#60	70	
#100	5	
#200	0.6	

Specification:

TEST PROCEDURES:
Dry Sieve: ASTM C136
Wet Sieve: ASTM C117

Comments:

Copies: Client

Submitted By: Grant Richardson
Technical Director

JUN 16 2005

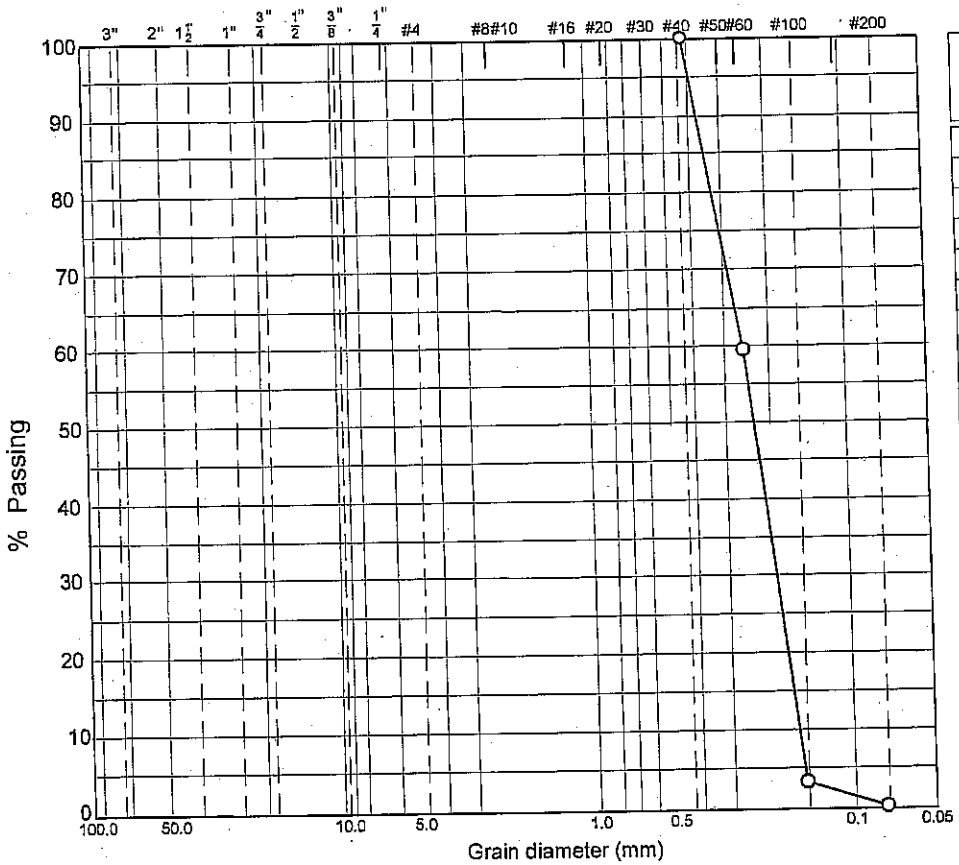
GEOTEST
741 Marine Drive
Bellingham, WA 98225 360 733_7318 888 251_5276 360 733_7418

TEST REPORT
AGGREGATE SIEVE ANALYSIS

PROJECT: **General Services - SR 105**
CLIENT: **Coastal Geologic Services**
AGG. TYPE: **Poorly Graded Sand (SP)**
SOURCE: **NOUR-E**
LOCATION: **Unknown**
LAB SAMPLE #: **3367**

JOB NO: **5240**
REPORT NO: **S2**
DATE: **6-14-05**
PAGE NO: **1 of 1**
SAMPLE DATE: **6-10-05**
SAMPLED BY: **Client**

GRAIN-SIZE DISTRIBUTION CURVE



Coarse	Fine	Coarse	Medium	Fine
GRAVEL		SAND		

SIEVE SIZE	PASSING %	SPEC. *
1-1/2"	100	
3/4"	100	
3/8"	100	
#4	100	
#10	100	
#20	100	
#40	100	
#60	59	
#100	3	
#200	0.3	

Specification:

TEST PROCEDURES:
Dry Sieve: ASTM C136
Wet Sieve: ASTM C117

Comments:

Copies: Client

Submitted By: Grant Richardson
Technical Director

JUN 16 2005

Appendix C – Fairbanks Environmental Services, Inc. Report

Beach Nourishment for Erosion Control With Emphasis on SR-105/ Washaway Beach Emergency Stabilization Project Biological Considerations

June, 2005

Prepared for:
Northern Economics Inc. &
Washington State Department of Transportation

Prepared By:
Chris Fairbanks
Fairbanks Environmental Services, Inc.

Identification of Sensitive Habitat and Species

Resources for identifying sensitive habitat and species

- USFWS (birds, butterflies, amphibians, wildlife, bull trout)
- NOAA-Fisheries (salmon, marine mammals, sea turtles)
- WDNR Natural Heritage Program (plants)
- WDFW Priority Habitats and Species Program (all fish and wildlife species)
- County critical areas maps (physical features flooding, geohazards, wetlands)

Priority habitat and species that are protected by county ordinances, state or federal laws can be identified through a number of sources. Most counties in Washington State have a Critical Areas Ordinance that has identified and mapped sensitive habitat, wetlands and geo/flooding hazards. These maps are generally available on line through each county's planning and development departments. Washington State Department of Fish and Wildlife (WDFW) Priority Habitat and Species Program maintain a database of delineated habitat and species observations. Maps and metadata descriptions are available on request through their website (Table 1). These maps are generally inclusive of federally listed endangered species and show areas where additional conservation and protection measures must be considered for certain species such as northern spotted owl.

Table 1. Sources for information of critical areas, priority species and habitats and ESA listed species.

AGENCY	JUSISDICTION	RESOURCE	WEBPAGE
Local planning and development	County	Critical and hazardous areas maps	Local government webpage
WDFW Priority Habitat and Species Program	Washington State animal species	Site specific database of observations of state listed species	http://wdfw.wa.gov/hab/phslist.htm
WDNR Natural Heritage Program	Washington State plant species	Sensitive plants observed by county	http://www.dnr.wa.gov/nhp/index.html
NOAA-Fisheries	ESA listed marine species	Listed species by inland waters and coastal waters	http://www.nwr.noaa.gov/esalist.htm
USFWS	ESA listed terrestrial and freshwater species	Listed species by county	http://westernwashington.fws.gov/se/SE_ List/endangered_Species.asp

Information for sensitive plant species listed by each county is available from the Washington State Department of Natural Resources (WDNR) Natural Heritage Program at their website (Table 1). State listed sensitive plants are also inclusive of federally listed sensitive plant

species. The location for populations of plants is not given through the website; however, information about the plants' ecology provided will give resource managers an indication of the environment where sensitive plants may be found and if site-specific surveys should be completed. Animals listed under the Endangered Species Act (ESA) are protected either by NOAA-Fisheries for marine species or by US Fish and Wildlife Services (USFWS) for terrestrial and freshwater species. USFWS maintains a website where ESA species are listed by counties in Washington State and NOAA-Fisheries maintains a list of marine ESA species that may be found in the inland waters and coastal waters of Washington State (Table 1).

Pacific Salmon

Seven species of Pacific salmon and trout are managed by WDFW. Two of these species, Puget Sound chinook salmon and Puget Sound/coastal bull trout are listed as threatened under ESA with proposed critical habitat designations. The general life cycle of these fish is to emerge from eggs laid in the gravel beds of freshwater streams and rear in streams ponds or lakes for a period of weeks to one year, dependant on the species, and then to migrate downstream to the estuaries. After a period of acclimation and rapid growth in the estuaries and marine nearshore, the fish spend two to six years in the marine waters. Some fish will remain residents in the Puget Sound and some fish will rear offshore in the ocean. Juvenile salmon use the shorelines as migration routes and the shallow slope of the nearshore provides refuge from larger bodied predators (Williams and Thom 2001).

Several salmon and trout stocks of the Columbia River and its tributaries are also listed as threatened under ESA. Individual fish from these stocks may utilize the coastal bays and estuaries of Washington State, and these fish populations should be considered during the design and permitting phase of coastal projects.

Modification of shorelines such as beach nourishment or engineered structures may benefit salmon by improving shallow water habitat that is used by juvenile salmon for migration, rearing and predator avoidance, or may cause negative impacts. In a review of relevant literature, Williams and Thom (2001) present the following list of salmon habitat attributes that nearshore modification may affect.

- Migration; juvenile and adult salmon use the shorelines as migration routes between habitat units.
- Nursery; juvenile salmon use the shallow nearshore for rearing and predator avoidance.
- Juvenile food production and feeding; Shallow water habitat and vegetation in freshwater, estuarine, and marine waters provide rich feeding stations.
- Adult food production; baitfish use intertidal habitat for spawning and rearing. Surf smelt use upper intertidal gravel beaches, sand lance use sandy beaches in the upper intertidal zone and Pacific herring use marine vegetation in the nearshore. Sandy beaches of the outer coast are also rich with prey items such as amphipods and ghost shrimp.
- Residence; nearshore habitat provides refuge habitat for juvenile salmon.
- Physiological transition; juvenile and adult salmon use estuaries and nearshore habitat to transition between freshwater to marine life stages.

Species of commercial and recreational interests

The marine nearshore is a critical habitat of numerous species of shellfish, crustaceans, baitfish, and groundfish. These species are important components of the nearshore food webs as prey items or as predators or scavengers at various stages of their life. Oysters, clams, crab and shrimp are important resources for commercial and recreational harvesters and are dependant on nearshore habitat as larvae or adults. Baitfish including surf smelt, sand lance and herring are an important component of juvenile and adult salmon diet. Baitfish spawn and rear in the shallow nearshore and are prey items to salmon throughout their life cycle. Groundfish include Pacific cod, lingcod, walleye pollock, Pacific hake, flatfish and rockfish. Though the adult cod, pollock and hake reside in deeper water, the larvae and juvenile fish use shallow nearshore or estuarine habitat for rearing. Juvenile flatfish also use nearshore, estuaries and river deltas for rearing. Rockfish reside along rocky reef habitat and give live-birth in shallow water nearshore. The larval fish are free swimming and use shallow areas with vegetation for rearing and refuge.

Potential impacts from beach nourishment

Beach nourishment mimics coastal processes by providing a source of sediment for building beaches and net-shore drift. Where sediment supply has been interrupted, nourishment projects may benefit the ecosystem by serving as a sacrificial sediment source preventing erosion of nearshore habitat. Armoring the shoreline and building hard structures to protect roadways and other infrastructure can interrupt coastal processes such as natural erosion of bluffs and net-shore drift. Beach nourishment can serve as a sacrificial feature to reduce erosion of natural features and providing sediment for down-drift beaches (Williams and Thom 2001). Impacts of beach nourishment intended to improve habitat features may also have negative secondary impacts. Potential negative impacts as a result of beach nourishment include:

- Burial of habitat and benthic communities;
- Increased turbidity;
- Modification of sediment grain size;
- Modification of tidal elevation and beach slope;
- Loss of marine vegetation;
- Habitat degradation in borrow site.

Burial

Placement of imported sediment on intertidal habitat will bury the existing populations of benthic organisms and their habitat. Depending on the life history of the species, recovery rates will vary. Benthic populations in shallow intertidal habitat within estuarine beaches are less tolerant of burial than those of more energetic environments (Nordstrom 2005). Peterson et al. (2000) found that densities of ghost crab and an intertidal clam found on beaches of North Carolina were lower by 86-99% 5 to 10 weeks after two nourishment projects were completed and that the ghost crab density was reduced by 35-37% after bulldozing sediments on a separate beach. Ray (2001) found that recovery of intertidal fauna was complete within 2 to 6.5 months at mean low water at beach nourishment sites in New Jersey. Recovery rates were believed to be dependant on seasonal differences in population abundances and when the nourishment project was completed. Benthic populations will likely recover quickly where the fill material is equivalent to the native sediment and an adjacent seed population is ripe with spawn.

Turbidity

Nearshore and estuarine water is naturally turbid, and the level of turbidity is variable depending on terrestrial sources, wind, waves and plankton production (Greene 2002; Nightingale and Simenstad 2001). Turbidity as a result of dispersed sediment is generally limited to the swash zone near a beach nourishment project, and the concentration of fine sediment drops off in the surf zone and nearshore bottom water (Greene 2002). Increased turbidity may alter behavior of salmonids; however, these highly mobile species are able to avoid sediment plumes (Nightingale and Simenstad 2001). Some species may benefit from increased turbidity with increased success of prey capture or predator avoidance, though other species are stressed from turbidity (Greene 2002). An increase of turbidity as a result of a project is generally a short-term impact, though where fill material has excessive clay and silt components, the impact may persist (Greene 2002).

Modification of sediment grain size

Selection of fill material should match the native beach material as much as possible, be free of contaminants, and have low silt and clay fractions (Williams and Thom 2001; Nordstrom 2005). Beach nourishment is often accomplished with "beneficial use" of dredge spoils where non-native sediment is used for fill that does not match the grain size of the native material (Nordstrom 2005). Bilodeau and Bourgeois (2004) concluded that the recolonization of the borrowing ghost shrimp *Callichirus islangrande* was impeded by a significant proportional increase of silt/clay component. At two sites of their study, the ghost shrimp was extirpated for the two-year period of their study. In Grays Harbor, oyster shells were placed on a mud bottom to enhance Dungeness crab settlement and Williams (1994) found that the modification of sediment significantly altered the benthic community composition. Juvenile salmon and bait fish prey items such as harpacticoid copepods are more abundant in marine vegetation habitat, and sediment that is suitable for attachment of marine algae may have a beneficial impact for production of these species (Simenstad et al. 1991).

Surf smelt and sand lance utilize the appropriate substrate in the upper intertidal zone for spawning and are important prey items for juvenile and adult salmon (Pentilla 2000; Cederholm et al. 2000). Modifying the grain size of the substrate of the upper beach where surf smelt and sand lance have been documented may reduce the area of appropriate spawning habitat for these fish and thus reduce the prey resource for salmon.

A change in the compaction and shear resistance of the beach may also result of modification of sediment grain size and a change in the physical features of habitat will alter the biological community structure (Greene 2002).

Modification of tidal elevation and beach slope

Shallow water along estuaries and the nearshore provides a structurally complex habitat that is used by juvenile salmon during their outmigration to sea for rearing, forage and avoidance of predators (Williams and Thom 2001). Placement of sediment alters the existing beach contour

and moves the beach waterward (Shipman 2001). Modification of tidal elevation and beach slope would impact the existing physical habitat used by juvenile salmon and the existing benthic communities. Design considerations of beach nourishment projects should consider habitat area within tidal elevation zones and beach slope. Enhancement of physical habitat for the benthic community and juvenile salmon could provide an ecosystem benefit where coastal processes have been interrupted and habitat has been degraded.

Loss of marine vegetation

Coastal wetlands, estuaries and nearshore support a variety of vegetation that is a key element in the marine ecosystem and the loss of over 70 percent of these habitats in Puget Sound has contributed to the declines in salmon population (Williams and Thom 2001). Density of prey items for juvenile salmon and baitfish are significantly higher in vegetated habitat compared to bare sand and silt (Simenstad et al. 1991), and therefore any loss of marine vegetation would be detrimental. Beach nourishment projects that enhance the physical habitat and use sediment that is appropriate for colonization of marine vegetation may be considered beneficial by regulating agencies.

Habitat degradation in borrow site

Removal of sediment may also result in negative environmental impacts at borrow sites (Nordstrom 2005). This issue however is not within the scope of this document but should be considered during the planning and permitting process.

Table 2 below lists each impact discussed above with habitat resources that may be affected with a potential impact value or cost to the nearshore ecosystem with a brief justification for the cost. In general, it is difficult to assign a dollar cost without detailed project plans. The potential impact values are relative to each other and somewhat subjective.

Table 2 Potential impacts of beach nourishment on habitat resources

IMPACT	RESOURCE	CONSIDERATIONS	POTENTIAL FOR IMPACT	JUSTIFICATION
Burial of benthic habitat	Epibenthic invertebrates	Use sediment equivalent to native beach material	Moderate-low	Relative quick recovery
	Eelgrass	Use sediment equivalent to native beach material	High	Slow recovery
	Marine algae	Use sediment equivalent to native beach material	Moderate	Moderate to quick recovery
	Salmon – migration	Maintain or lower beach slope, avoid blocking migration corridors	Moderate-high	Low slope beach and continuous migration corridors aid predator avoidance.
	Salmon – rearing habitat	Avoid impacts to marine vegetation	Moderate-high	Marine vegetation is high value habitat for rearing habitat.
	Salmon - food production	Avoid impacts to marine vegetation and native beach material	Moderate-high	Marine vegetation is high value habitat for food production.
	Salmon – transition habitat	Avoid blocking access between estuaries and freshwater.	High	Salmon require free access up and down natal and non-natal streams
Increased turbidity	Epibenthic invertebrates	Use clean sediment with low clay/silt component, avoid burial.	Low	Temporary impact
	Eelgrass	Use clean sediment with low clay/silt component, avoid burial.	Moderate-low	Temporary impact
	Marine algae	Use clean sediment with low clay/silt component, avoid burial.	Moderate-low	Temporary impact
	Salmon – migration	Use clean sediment with low clay/silt component	Moderate	Temporary impact
	Salmon – rearing habitat	Use clean sediment with low clay/silt component	Moderate	Temporary impact
	Salmon - food production	Use clean sediment with low clay/silt component	Moderate	Temporary impact
	Salmon – transition habitat	Use clean sediment with low clay/silt component	Moderate	Temporary impact
Modification of sediment grain size	Epibenthic invertebrates	Select grain size to increase invertebrate production	Moderate-high	Epibenthic invertebrates are an important food source for juvenile salmon and crab.
	Eelgrass	Avoid impacts to eelgrass	High	Eelgrass require fine sediment
	Marine algae	Use equivalent to more coarse material	Moderate	Marine algae grows in a wide range of sediment material
	Salmon – migration	Maintain or lower beach slope, avoid blocking migration corridors	Moderate	Grain size less important that slope beach and continuous migration corridors.

IMPACT	RESOURCE	CONSIDERATIONS	POTENTIAL FOR IMPACT	JUSTIFICATION
	Salmon – rearing habitat	Avoid impacts to marine vegetation	Moderate-high	Marine vegetation is high value habitat for rearing habitat.
	Salmon - food production	Avoid impacts to marine vegetation and native beach material	Moderate-high	Marine vegetation is high value habitat for food production.
	Salmon – transition habitat	Avoid blocking access between estuaries and freshwater.	High	Salmon require free access up and down natal and non-natal streams
Modification of tidal elevation and beach slope	Epibenthic invertebrates	Avoid loss of benthic habitat	Moderate	Epibenthic invertebrates are an important food source for juvenile salmon and crab.
	Eelgrass	Avoid impacts to eelgrass	High	Eelgrass grows in on low slope and narrow depth range.
	Marine algae	Avoid loss of algae habitat	Moderate	Marine algae grows in a wide range of sediment material
	Salmon – migration	Maintain or lower beach slope, avoid loss of migration area	Moderate-high	Low slope beach and continuous migration corridors aid predator avoidance.
	Salmon – rearing habitat	Avoid impacts to marine vegetation and loss of habitat area	Moderate-high	Marine vegetation is high value habitat for rearing habitat.
	Salmon - food production	Avoid impacts to marine vegetation and loss of habitat area	Moderate-high	Marine vegetation is high value habitat for food production.
	Salmon – transition habitat	Avoid blocking access between estuaries and freshwater.	High	Salmon require free access up and down natal and non-natal streams
Loss of marine vegetation	Epibenthic invertebrates	Select grain size to increase invertebrate production	High	Marine vegetation has higher density of epibenthic invertebrates that are an important food source for juvenile salmon and crab.
	Eelgrass	Minimize impacts to eelgrass	High	Eelgrass is an important component of the nearshore ecosystem.
	Marine algae	Minimize impacts to marine algae	Moderate-high	Marine algae are an important component of the nearshore ecosystem.
	Salmon – migration	Maintain or lower beach slope, avoid blocking migration corridors	High	Marine vegetation is important refuge for juvenile salmon
	Salmon – rearing habitat	Avoid impacts to marine vegetation	High	Marine vegetation is high value habitat for rearing habitat.
	Salmon - food production	Avoid impacts to marine vegetation and native beach material	High	Marine vegetation is high value habitat for food production.
	Salmon – transition habitat	Avoid blocking access between estuaries and freshwater.	Moderate-high	Salmon require free access up and down natal and non-natal streams

SR 105 Project

The nearshore environment at Washaway Beach is very dynamic due to high-energy waves, wind and water currents in North Channel. Chinook salmon, chum salmon, coho salmon, steelhead trout, and sea-run cutthroat trout use the area for migration during both the adult and juvenile life stage (FHA and WSDOT 1997). Ghost shrimp burrows were observed in the Project area during a recent field trip and razor clams are abundant in the west shoals. The salmon stocks that use the coastal watersheds of Washington have not been listed under ESA; however, five stocks of Columbia River salmon and trout and coastal bull trout may utilize Willapa Bay and the Project Area during some part of their life cycle. Table 3 lists the ESA listed species that may occur in the SR 105 Project Area. Table 4 lists the species and stock of salmon that spawn in tributaries to Willapa Bay and that would likely utilize the shallow water habitat of Washaway Beach. The direct and indirect impacts that a beach nourishment project at Washaway Beach will have on these listed species would be addressed in a Biological Assessment that would be required as part of the permitting process.

Table 3. United State Endangered Species Act listed species for Pacific County and Coastal waters of Washington State.

Species[1]	Federal Status[2]	Jurisdiction
Bald eagle (*Haliaeetus leucocephalus*)	T	USFWS
Brown pelican (*Pelecanus occidentalis*)	E	USFWS
Marbled murrelet (*Brachyramphus marmoratus*)	T	USFWS
Northern spotted owl (*Srtix occidentalis caurina*)	T	USFWS
Western snowy plover (*Charadrius alexandrinus nivosus*)	T	USFWS
Short-tailed albatross (*Phoebastria albatrus*)	E	USFWS
Oregon silverspot butterfly (*Speyeria zerene hippolyta*)	T	USFWS
Green sea turtle (*Chelonia mydas*)	T	USFWS
Olive Ridley sea turtle (*Lepidochelys olivacea*)	T	USFWS
Leatherback sea turtle (*Dermochelys coriacea*)	E	NOAA-Fisheries
Loggerhead sea turtle (*Caretta caretta*)	T	NOAA-Fisheries
Bull trout (*Salvelinus confluentus*)	T	USFWS
Blue whale (*Balaenoptera musculus*)	E	NOAA-Fisheries
Humpback whale (*Megaptera novaeangliae*)	E	NOAA-Fisheries
Fin whale (*Balaenoptera physalus*)	E	NOAA-Fisheries
Sei whale (*Balaenoptera borealis*)	E	NOAA-Fisheries
Sperm whale (*Physeter macrocephalus*)	E	NOAA-Fisheries
Steller sea lion (*Eumetopias jubatus*)	T	NOAA-Fisheries

1. List from USFWS: http://westernwashington.fws.gov/se/SE_List/Pacific.htm
   NOAA Fisheries: http://www.nwr.noaa.gov/esalist.htm
2. Status: **T**hreatened or **E**ndangered.

Table 4. Willapa Bay salmon and trout stocks with Washington State status.

Species	Stock Name	WRIA	1992 State Status	2002 State Status
Chinook	North River/Smith Creek Fall Chinook	24	Depressed	Depressed
Chinook	Willapa Fall Chinook	24	Not Rated	Healthy
Chinook	Naselle Fall Chinook	24	Not Rated	Depressed
Chum	North River Fall Chum	24	Healthy	Healthy
Chum	Willapa Fall Chum	24	Healthy	Unknown
Chum	Palix Fall Chum	24	Healthy	Healthy
Chum	Nemah Fall Chum	24	Healthy	Unknown
Chum	Naselle Fall Chum	24	Healthy	Healthy
Chum	Bear River Fall Chum	24	Healthy	Unknown
Coho	North River/Smith Creek Coho	24	Not Rated	Healthy
Coho	Willapa Coho	24	Not Rated	Healthy
Coho	Palix/Niawiakum Coho	24	Not Rated	Healthy
Coho	Nemah Coho	24	Not Rated	Healthy
Coho	Naselle Coho	24	Not Rated	Healthy
Coho	Bear River Coho	24	Not Rated	Healthy
Steelhead	North River/Smith Creek Winter Steelhead	24	Unknown	Healthy
Steelhead	Willapa Winter Steelhead	24	Healthy	Healthy
Steelhead	Palix Winter Steelhead	24	Unknown	Healthy
Steelhead	Nemah Winter Steelhead	24	Unknown	Healthy
Steelhead	Naselle Winter Steelhead	24	Healthy	Healthy
Steelhead	Bear River Winter Steelhead	24	Unknown	Healthy
Cutthroat	North/Smith Cr/Cedar – native stock; wild spawning	24		Unknown
Cutthroat	Willapa – native stock; wild spawning	24		Unknown
Cutthroat	Mid-Willapa Bay – native stock; wild spawning	24		Unknown
Cutthroat	Naselle/Bear – native stock; wild spawning	24		Unknown
Bull trout	No native stock identified in Willapa Bay			

Table 5. Washington State Department of Fish and Wildlife Priority Habitat and Species that have been identified within one mile of SR105 Project Site (WDFW 2005)

Species	State status
Dungeness crab (*Cancer magistar*)	Commercial
Bald Eagle nest	Threatented
Harbor seal (*Phoca vitulina*) haul out and pupping site	Monitor
Shorebird concentrations – large concentrations	
Habitat	
Coastal salt marsh and brackish marsh	
Cliffs and bluffs	

Table 6. Washington State Dept of Natural Resources Natural Heritage Program list of sensitive plants that occur in Pacific County with federal status

Common Name	*Scientific Name*	*State Status*	*Federal Status*
Coyotebush	*Baccharis pilularis*	T	
Frigid Shootingstar	*Dodecatheon austrofrigidum*	E	SC[1]
Pink Fawn-lily	*Erythronium revolutum*	S	
Queen-of-the-forest	*Filipendula occidentalis*	T	SC
Floating Water Pennywort	*Hydrocotyle ranunculoides*	S	
Bog Clubmoss	*Lycopodiella inundata*	S	
Northern Grass-of-parnassus	*Parnassia palustris var. neogaea*	S	
Loose-flowered Bluegrass	*Poa laxiflora*	T	
Ocean-bluff Bluegrass	*Poa unilateralis*	T	
Great Polemonium	*Polemonium carneum*	T	
Bear's-foot Sanicle	*Sanicula arctopoides*	E	

1. Species of concern

Current Conditions

A site visit was conducted on June 9, 2005 during a –1.2 ft low tide relative to mean lower low water (MLLW) to assess the current habitat conditions of the site. The exposed beach had a low slope that is beneficial for juvenile salmon; however, mean higher high water (MHHW) appeared to be about 3 ft above the toe of the SR 105 revetment at the most exposed point. Shallow water habitat that is important for juvenile salmon would not be available during tide events above +5.5 ft MLLW. The beach was populated with amphipods observed on the beach surface and ghost shrimp as determined by their numerous borrows. The constructed groin and barb structure did not appear to provide salmon predators with advantageous habitat as documented through predator populations and stomach contents (Miller et al. 2002). The current conditions do not provide the shallow water nearshore habitat that is beneficial for juvenile salmon when the tide elevation is greater than +5.5 ft MLLW.

Surf smelt and sand lance spawning has not been documented by WDFW in the project area but this may be due to the lack of information from site specific surveys rather than absence of appropriate spawning habitat (Penttila, pers. comm.). These fish are present at the project site and were captured with a variety of other fish in beach seine samples as part of a fish utilization and behavior study at the project site (Miller et al. 2002).

Recommendations

Beach nourishment projects should be designed to mimic natural coastal processes as much as possible. A continuous contribution of fill material to a sediment-starved beach would allow a sacrificial protection of shoreline features at the same time interval of erosion events.
A continuous sediment supply would maintain nearshore habitat with less impact as opposed to

large volumes of sediment placed on a beach at greater time intervals that would bury the existing benthic community and displace the shallow water habitat. The beach nourished with a large volume of sediment would erode between the nourishment intervals which may have impacts to the physical habitat, beach profile and benthic community.

If a large volume of sediment were eroded during a short period by a series of seasonal storms, then a larger volume of beach nourishment material may be needed. If the material were placed within a few months of erosion, then impacts to the biological resources of the beach would be minimized. However, if a large volume of sediment were placed on the beach after the biological communities were reestablished, then the impacts would be greater.

Citations

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