DEVELOPMENT AND IMPLEMENTATION OF THE CLIMATE ASSESSMENT AND PROACTIVE RESPONSE INITIATIVE (CAPRI) FOR PUGET SOUND

Draft Final Report | November 2011

prepared for:

National Oceanic and Atmospheric Administration

Damage Assessment, Remediation, and Restoration Program

Seattle, Washington

prepared by:

Industrial Economics, Incorporated

2067 Massachusetts Avenue

Cambridge, MA 02140

and

Research Planning, Inc.

1121 Park Street

Columbia, SC 29201

TABLE OF CONTENTS

EXECUTIVE SUMMARY

1. PURPOSE
   - 1.1 CAPRI Components 2
   - 1.2 Data Sources and Modeling Approach for Climate Change Predictions 3
   - 1.3 Overview of the Vulnerability Index Approach 6

2. FACILITY SCORING
   - 2.1 Overview 11
     - 2.1.1 Identification of Source Data 11
   - 2.2 Threat Subcategory: Degree of Toxicity 12
     - 2.2.1 Contaminant Ranking by NOAA Priority 13
     - 2.2.2 Number of Contaminants 14
   - 2.3 Threat Subcategory: Likelihood of Release 15
     - 2.3.1 Current Status (Site Remediation/Attenuation) 15
     - 2.3.2 Number of Pathways Identified 15
     - 2.3.3 Site Hazard Assessment Rank 15

3. ECOSYSTEM AND SPECIES RELATIVE IMPORTANCE AND SENSITIVITY
   - 3.1 Overview 17
     - 3.1.1 Selection of Ecosystems and Species of Interest 17
     - 3.1.2 Identification of Data Elements 19
   - 3.2 Resource Subcategory: Ecosystem and Species Relative Importance Scoring 21
     - 3.2.1 Ecosystem Relative Importance 21
     - 3.2.2 Species Relative Importance 24
   - 3.3 Resource Subcategory: Ecosystem Contaminant Sensitivity Scoring 27
     - 3.3.1 Ecosystem Sensitivity to Oil Spills 27
     - 3.3.2 Ecosystem Sensitivity to Sediment Contamination 28
   - 3.4 Resource Subcategory: Species Contaminant Sensitivity Scoring 29
     - 3.4.1 Species Sensitivity to Oil Spills 29
     - 3.4.2 Species Sensitivity to Sediment Contamination 29

4. HUMAN USES RELATIVE IMPORTANCE AND SENSITIVITY

4.1 Threat Category Definition 33
4.2 Selection of Human Use Issues of Importance 33
4.3 Human Use Relative Importance Scoring 36
4.3.1 Approach for Assigning Importance Values for Grid Cells from Quantitative Data 36
4.3.2 Decision Rule Approach for Assigning Importance Values for Grid Cells from Non-Numeric Data 37
4.3.3 Combining Human Use Categories Into a Single Importance Score 40
4.3.4 Future Steps for Data Analysis 41

5. CLIMATE CHANGE FACTORS

5.1 Overview 42
5.2 Climate Factor 1: Wetland Habitat Change / Loss 43
5.3 Climate Factor 2: Dry Land Inundation 46
5.4 Climate Factor 3: Air Temperature 49
5.5 Degree of Interaction Between Category Scores and Climate Change Factors 51
5.5.1 Facility Likelihood of Release Interaction with Climate Factors 51
5.5.2 Ecosystem/Species Importance Interaction with Climate Factors 51
5.5.3 Human Use Importance Interaction with Climate Factors 52

6. TECHNICAL APPROACH OF THE CAPRI TOOL

6.1 Introduction 53
6.2 Data Preparation: Compilation and Scoring 54
6.2.1 Compiling Data for Resource/Threat Categories 54
6.2.2 Scoring the Data Elements 54
6.2.3 Compiling Data for Climate Factors 55
6.3 CAPRI Spatial Tools: Creating the Study Area Database 55
6.3.1 Generating the Study Area Grid 55
6.3.2 Assembling Data on the Grid 55
6.4 CAPRI Analysis Tools: Scoring Resource/Threat Categories and Calculating Vulnerability Indices 57
6.5 Scoring the Climate Factors 58
6.6 Scoring Resource/Threat Categories 58
6.7 Calculating Vulnerability Indices 59
6.8 Visualizing and Exporting Results 59

7. RESULTS

7.1 Introduction 63

7.2 Overview of Combined Vulnerability Index Results 63

7.2.1 Summary Statistics 63

7.2.2 Comparative Maps 65

7.3 Exploring the Detailed Results 70

7.3.1 Tabular Results 70

7.3.2 Comparing Results Indices 70

7.4 Applying Results from CAPRI 72

7.4.1 Example Application: CAPRI and Restoration Planning 74

7.4.2 Overview of Options 75

7.4.3 Prevention Options 75

8. NEXT STEPS

8.1 Introduction 77

8.2 Improved Data 77

8.2.1 Ecosystem/Species Data Needs 77

8.2.2 Human Use Needs 78

8.2.3 Facility Data Needs 78

8.2.4 Climate Factor Data Needs 78

8.3 Modification to the Tool 79

8.3.1 Interactions Between Data Elements 79

8.3.2 Interaction within Buffer Zones 79

8.3.3 Enhanced User Controls 79

8.3.4 Zero Versus Null Values 80

8.4 Facilitating Use of Results from CAPRI 80

8.4.1 Expanded Analysis of CAPRI Results within ERMA 81

REFERENCES

EXECUTIVE SUMMARY

The mission of the National Oceanic and Atmospheric Administration (NOAA) Damage Assessment, Remediation, and Restoration Program (DARRP) is to protect and restore coastal and marine resources threatened or injured by oil spills and releases of hazardous substances. The magnitude and timing of the threats posed to coastal and marine resources by oil spills and hazardous substance releases could be directly affected by shifts in environmental conditions attributable to climate change, such as increases in sea level, precipitation, and storm surges. As a means to ensure that it will continue to be able to achieve its mission under these evolving circumstances, DARRP developed the Climate Assessment and Proactive Response Initiative (CAPRI). Central to the Initiative is a framework for developing a "vulnerability index" for a particular coastal region and displaying the relative vulnerabilities of individual sub-regions using a web-based and user-friendly mapping tool.

As a pilot effort, DARRP developed vulnerability indices for four study areas (Snohomish, Duwamish, Nisqually, and Commencement Bay) within the second largest estuary in the United States, Washington's Puget Sound.

CAPRI develops vulnerability indices for study areas through a multi-step analysis process. First, scores are assigned to six categories of important resources and potential threats. The CAPRI framework then examines the interactions between these categories and specific climate change factors and subsequently assigns adjusted category scores. This ultimately enables the calculation of vulnerability indices for a range of climate change scenarios.

VULNERABILITY INDEX: ATTRIBUTE SCORES

To produce a vulnerability index for a particular region, the CAPRI system begins by assigning numerical scores to each of 17 attributes in six categories (generally representing either a "threat" or a "resource", Table ES-1).

For each attribute, assignment of scores occurs for each cell of a spatially explicit grid, the resolution of which is defined by the availability of data specific to the region in question. Scoring occurs on a 0 – 4 scale, with each value corresponding to a defined condition, some of which will be region- or state-specific (Table ES-2).

TABLE ES-1. THREAT/RESOURCE CATEGORIES AND ATTRIBUTES

CATEGORY TYPE	CATEGORY	ATTRIBUTE
Threat	Toxicity of contaminants in facilities that are potential sources of oil spills or hazardous substance releases	1. Contaminant ranking
		2. Number of contaminants
	Likelihood that a spill or release will occur from a facility	3. Current site status
		4. Number of identified pathways
		5. Site hazard assessment rank
Resource	Relative importance of specific ecosystems and individual species	6. Ecosystem attributes
		7. Species attributes
	Sensitivity of ecosystems and species to oil and hazardous substance contamination	8. Ecosystem sensitivity to oil spills
		9. Ecosystem sensitivity to sediment contamination
		10. Species sensitivity to oil spills
		11. Species sensitivity to sediment contamination
	Relative importance of specific human uses of the services that natural resources provide	12. Recreational fishing
		13. Other recreational uses
		14. Commercial fishing
		15. Other commercial uses
	Sensitivity of human uses to oil and hazardous substance contamination	16. Human use sensitivity to oil spills
		17. Human use sensitivity to sediment contamination

VULNERABILITY INDEX: CATEGORY SCORES

The second step in the development of the vulnerability index is the assignment of category scores. These are simply the maximum value among all attribute scores within a category. The result is six category scores, one each for Degree of Toxicity, Likelihood of Release, Ecosystem/Species Relative Importance, Ecosystem/Species Sensitivity, Human Use Relative Importance, and Human Use Contaminant Sensitivity.

VULNERABILITY INDEX: CLIMATE CHANGE FACTORS

The third step in the CAPRI analysis process is an examination of the interaction between certain attribute categories and specific climate change factors. For the Puget Sound pilot, the analysis considers three factors (structural habitat change, inundation from sea level rise, and changes in air temperature) from among the many that could describe changes in environmental conditions resulting from climate change. As with the category attributes, a score is assigned to each grid cell for each climate change factor, with each value corresponding to a defined condition.

TABLE ES-2. RESOURCE/THREAT CATEGORY ATTRIBUTE DESCRIPTION AND SCORING

ATTRIBUTE	Score				
	0	1	2	3	4
1. Degree Of Toxicity: Contaminant Ranking The score for the contaminant ranking attribute is based on the degree to which facility contaminants bioaccumulate and persist in aquatic food webs. Twenty-four contaminant groups regularly evaluated by Washington State are included.	No data	EPA priority pollutants - metals and cyanides, phenolic compounds, non-halogenated solvents, reactive wastes, corrosive wastes, conventional (organic and inorganic), asbestos, tributyl tin, unexploded ordnance, methyl-*tert*-butyl ether, wood debris, other deleterious substances	Base/neutral/ acid organics, halogenated organics, other metals, radioactive wastes, arsenic	1 of PCBs, pesticides, dioxin, petroleum compounds, PAHs, benthic bioassay failures	>1 of PCBs, pesticides, dioxin, petroleum compounds, PAHs, benthic bioassay failures
2. Degree Of Toxicity: Number Of Contaminants The score for the number of contaminants attribute is based on the degree to which multiple contaminant types are present at a facility.	Zero groups	1 contaminant group	2-5 contaminant groups	6-9 contaminant groups	10-24 contaminant groups
3. Likelihood Of Release: Current Site Status Sites where contaminants have been fully removed (e.g. dredged sites) are expected to have a lower potential for future release than those which still have contaminants on site (e.g., those that have been capped or are relying on natural attenuation). Similarly, sites that have been evaluated as requiring no remedial action are deemed to have a lower likelihood of future release.	Sites deleted from the NPL	Sites with "No Further Action" or "No Remedial Action" decisions	Sites remediated via sediment dredging and removal	NPL proposed sites; Sites remediated via sediment capping and lining or with natural attenuation.	Active NPL sites with no remediation strategies in place

ATTRIBUTE	Score				
	0	1	2	3	4
4. Likelihood Of Release: Number Of Identified Pathways Up to four potential release pathways are identified for each facility: groundwater, surface water, soil, and air. Scoring is assigned based on the number of exposure pathways identified for a site, which should correlate to the extent of potential release.	0 or no data	1 pathway	2 pathways	3 pathways	4 pathways
5. Likelihood Of Release: Site Hazard Assessment Rank The Washington Ranking Method (WARM) score, an estimation of the potential threat posed by a site relative to all other ranked sites in the state, serves as the basis for assigning a CAPRI score. In the WARM system, sites are ranked on a scale of 1 (most concern) to 5 (least concern). Sites that are on the federal National Priorities List (NPL) have a site hazard assessment rank of zero and are scored the same as the sites of highest concern under WARM.	no data	WARM score = 5	WARM score = 4	WARM score = 2 or 3	WARM score = 0 or 1

ATTRIBUTE	Score				
	0	1	2	3	4
6. Ecosystem/Species Relative Importance: Ecosystem Attributes Relative ecosystem importance is assigned based on biodiversity and on ten attributes classified into two types of ecosystem services: regulating and supporting. Regulating services include all the benefits derived from the contribution of ecosystems to large scale regulation processes (e.g., shoreline stabilization). Supporting services refer to all natural processes that maintain direct and indirect goods and services derived from ecosystems (e.g., primary productivity). The number of services provided by a particular ecosystem (eelgrass, salt marsh, tidal flat, etc.) in the study area determines its score.	NA	<3 qualitative service attributes	3-5 qualitative service attributes	6-8 qualitative service attributes	>8 qualitative service attributes
7. Ecosystem/Species Relative Importance: Species Attributes Each of a list of species of interest in the study area is assigned a score based on its status with respect to federal and state fish and wildlife protection regimes (e.g., the Endangered Species Act, the Washington Priority Habitats and Species List).	NA	Species of interest in the study area	Species or groups susceptible to significant population declines due to inclination to aggregate	Federal Species of Concern; State-listed endangered, threatened, or sensitive	Federally listed endangered or threatened species
8. Ecosystem/Species Contaminant Sensitivity: Ecosystem Sensitivity To Oil Spills Ecosystem sensitivity to oil spills is based on the Environmental Sensitivity Index (ESI) classification system. Under the ESI classifications, shoreline ecosystems are scored according to a scale relating to sensitivity to oil, natural persistence of oil, and ease of cleanup (1 is the least sensitive to oiling, 10 is the most sensitive). Subtidal habitats are not classified by ESI and are shown separately.	NA	ESI 1-2; unvegetated subtidal	ESI 3-6	ESI 7-8; kelp and eelgrass	ESI >8

ATTRIBUTE	Score				
	0	1	2	3	4
9. Ecosystem/Species Contaminant Sensitivity: Ecosystem Sensitivity To Sediment Contamination Structural habitats are assigned a sensitivity score for sediment contamination due to waste site releases based on ESI classifications and intrinsic sediment dynamics (potential for accumulation of fine-grained sediments that would be released from contaminated sites).	NA	ESI 1-6	ESI 7-8; kelp	ESI 9-10; unvegetated subtidal, eelgrass	NA
10. Ecosystem/Species Contaminant Sensitivity: Species Sensitivity To Oil Spills For each species of interest, a score indicating sensitivity to oil spills is assigned based on habitat requirements, life history parameters, and professional experience from past oil spill events.	NA	NA	Oil avoidance; subtidal species	Indirect pathway of exposure; nearshore species	Direct pathway of exposure; water-surface species
11. Ecosystem/Species Contaminant Sensitivity: Species Sensitivity To Sediment Contamination For each species of interest, sensitivity to sediment contamination from facilities is based on sediment-uptake pathways and trophic interactions, based on exposure potential. In summary, species sensitivity to contaminated sediments is assumed to be a function of the degree of dependency on sediments and the trophic distance between sediments and the species of interest.		Intertidal diet; broad diet	Fish-based diet; pelagic diet	Benthic-based diet	Nearshore benthic residents and sediment dwellers

ATTRIBUTE	Score				
	0	1	2	3	4
12-15. Human Use Relative Importance: Recreational And Commercial Uses Twelve uses serve as the basis for developing a score for this category: Recreational Fishing Catch Quantities Recreational Shellfish Harvest Quantities Recreational Shellfish Beach Status Shoreline Public Access Shoreline Modifications Presence of Overwater Structures Public Lands: Federal Lands Public Lands: Washington State Parks Public Lands: Indian Lands Aquaculture Production Quantities Commercial Shellfish Growing Status Presence of Ports and Ferry Terminals For the recreational fishing catch, recreational shellfish harvest, and aquaculture production quantities, data at the grid cell level, where available, are binned into five quintiles (i.e., highest 20 percent to lowest 20 percent). The quintiles are assigned scores of 0-4 from smallest quantity to largest quantity. All other uses are assigned scores based on professional judgment. For uses such as access to public lands and to the shoreline, scores are assigned to specific types of land (e.g., Department of Defense-managed, National Park Service) and specific means of access (e.g., private marina, public pier).					
16 And 17. Human Use Contaminant Sensitivity: Sensitivity To Oil Spills Or Sediment Contamination The current version of the CAPRI framework does not incorporate the sensitivity of individual human use category elements to oil spill and hazardous contamination events, but only of the broader human use categories.	NA	NA	NA	Contamination of developed areas, overwater structures, and shoreline infrastructure	Changes in recreational visitation or access; changes in commercial fishing trips or access

Climate change factors are scored on a scale of zero (minimal change) to four (significant change) based on predictions from the literature as well as professional judgment. The CAPRI analysis process further considers two climate change scenarios and four projection years (2025, 2050, 2075, and 2100) in assigning a score to each grid cell.

1. Structural Habitat Change

Scoring of this factor is based on the change in habitat type predicted by the Sea Level Affecting Marshes Model (SLAMM) for each grid cell. The result is a matrix of initial and final conditions (Table ES-3).

TABLE ES-3. STRUCTURAL HABITAT CHANGE SCORING

FINAL CONDITION		DRY LAND (D)	SWAMP (W1)	FRESH-WATER MARSH (W2)	SCRUB / SHRUB MARSH (W3)	SALT OR BRACKISH MARSH (W4)	BEACH (B)	TIDAL FLAT (F)	OPEN WATER (O)
Initial Condition	D	0	4	4	4	4	4	4	4
	W1	--	0	2	1	3	3	3	4
	W2	--	--	0	2	2	3	3	4
	W3	--	--	--	0	2	3	3	4
	W4	--	--	--	--	0	3	3	4
	B	--	--	--	--	--	0	2	4
	F	--	--	--	--	--	--	0	4
	O	--	--	--	--	--	--	--	0

2. Inundation From Sea Level Rise

To estimate an inundation level for each future time period, the CAPRI framework combines three factors that affect the extent to which an area incurs inundation risk from sea level rise. Specifically:

Inundation Level = Sea Level Rise + Tidal Datum Correction – Local Subsidence[1]

For each time step and scenario, those grid cells with elevations below the inundation level are assigned the highest climate score (4), as they are most likely to be flooded at that time step (Table ES-4). However, elevations close to, but still above, the inundation level also incur some measure of elevated flooding risk from storm events. The framework uses the base flood elevation (BFE) across the study area as the unit of elevation to determine proximity to the inundation level.

[1] The formula is typically conveyed as IL = SLR + TD - LS

TABLE ES-4. INUNDATION RISK FROM SEA LEVEL RISE SCORING

SCORE				
0	1	2	3	4
Greater than one base flood elevation unit above inundation level	NA	NA	Within one base flood elevation unit above inundation level	Below Inundation level

3. Changes In Air Temperature

Scoring of this factor reflects the expected types of ecological impacts attributable to each degree of temperature increase, relative to pre-industrial levels, as described in the Intergovernmental Panel on Climate Change's 2007 report, *Climate Change 2007: Impacts, Adaptation and Vulnerability* (Table ES-5). The effects of temperature increase are based largely on the suitability of the ecosystem for its current inhabitants.

TABLE ES-5. CHANGE IN AIR TEMPERATURE SCORING

SCORE				
0	1	2	3	4
0-0.5 ^{o}C projected temperature increase	0.5-1.5 ^{o}C projected temperature increase	1.5-2.5 ^{o}C projected temperature increase	2.5-3.5 ^{o}C projected temperature increase	>3.5 ^{o}C projected temperature increase

VULNERABILITY INDEX: INTERACTION OF CLIMATE CHANGE FACTORS WITH THREATS AND RESOURCES

In the CAPRI framework, climate change is anticipated to lead to increased vulnerability based on interactions with three of the threat/resource categories: likelihood of release, ecosystem/species importance, and human use importance (Table ES-6). To take these interactions into account, the framework assigns an adjusted score to each of these categories based on a set of three scoring matrices reflecting Very High, High, and Low interaction between the climate change factors and the threat/resource categories (Table ES-7). The adjusted category score is the maximum remaining value after application of the interaction matrices. Assignments of interaction levels, and the interaction matrices, are as follows:

CLIMATE CHANGE FACTOR-LIKELIHOOD OF RELEASE INTERACTION

The likelihood of release threat category is expected to be very sensitive to changes in structural habitat and to inundation. Both of these climate change factors could substantially change the likelihood of re-suspension or release of contaminants from soil

or sediment, and could put facility structures at risk. Increased temperature is unlikely to have a significant effect on the likelihood of release at the predicted levels of change.

TABLE ES-6. CLIMATE CHANGE FACTOR INTERACTION WITH THREAT/RESOURCE CATEGORIES

		CLIMATE CHANGE FACTOR		
		HABITAT CHANGE	INUNDATION	TEMPERATURE INCREASE
Threat/Resource Category	Likelihood of Release	Very High	Very High	Low
	Ecosystem/Species Importance	Very High	High	Very High
	Human Use Importance	Very High	Very High	Low

CLIMATE CHANGE FACTOR-ECOSYSTEM/SPECIES IMPORTANCE INTERACTION

Ecosystems and species are very sensitive to changes in habitat, given that the structural habitat defines the ecosystem and the species it can support. Direct effects of climate change include structural habitat change and loss, and subsequent impacts on species utilization and distribution. Indirect impacts include ecosystem impairment from newly released or available contaminants and oil and sediment remobilization from nearby facilities identified as potential sources of contaminants. These predicted impacts can also affect completed and planned restoration projects, and influence the viability of future projects. Sensitivity of dry land to inundation is high, but less significant, since the majority of the targeted ecosystems and species are in open water/intertidal/wetland areas. Increases in air temperature are expected to have very high interactions with ecologically important vegetation and fauna.

CLIMATE CHANGE FACTOR-HUMAN USE IMPORTANCE INTERACTION

Habitat change may significantly affect human uses if it leads to changes in the distribution and/or quantity of species targeted by recreational and commercial fishers. Inundation is expected to have a significant impact on human uses included in the dataset (in the absence of adaptation measures) given the possibility for flooding of recreational and commercial fishing locations (e.g., piers and boat ramps) as well as recreational and commercial access locations. On the other hand, temperature increases are proposed to have a less significant impact on human use activities. While there is expected to be some impact on recreational uses and commercial fishing uses based on potential changes in the distribution of species, other commercial uses, such as ports and ferry terminals and boat ramps, would be expected to have low to no interaction with climate factors.

TABLE ES-7. OUTPUT SCORES BASED ON INTERACTION LEVEL

VERY HIGH INTERACTION						
		Climate Change Factor Score				
		0	1	2	3	4
Threat/ Resource Score	0	0	0	0	0	0
	1	0	1	1	2	2
	2	0	1	2	3	3
	3	0	2	3	4	4
	4	0	2	3	4	4

HIGH INTERACTION						
		Climate Change Factor Score				
		0	1	2	3	4
Threat/ Resource Score	0	0	0	0	0	0
	1	0	1	1	2	2
	2	0	1	2	3	3
	3	0	2	3	3	3
	4	0	2	3	3	3

LOW INTERACTION						
		Climate Change Factor Score				
		0	1	2	3	4
Threat/ Resource Score	0	0	0	0	0	0
	1	0	1	1	1	1
	2	0	1	1	1	1
	3	0	1	1	1	1
	4	0	1	1	1	1

VULNERABILITY INDEX: CATEGORY INDICES AND RESOURCE THREAT INDICES

The fourth step in the CAPRI analysis process is the establishment of a Facility Index, an Ecosystem/Species Index, and a Human Use Index. These category indices reflect the combination of:

- The degree of toxicity score and the likelihood of release score (as adjusted by the climate change factor interaction scores). (“Facility Index”)
- The ecosystem/species sensitivity score and the ecosystem/species relative importance score (as adjusted by the climate change factor interaction scores). (“Ecosystem/Species Index”)
- The human use sensitivity score and the human use relative importance score (as adjusted by the climate change factor interaction scores). (“Human Use Index”)

Application of the Very High interaction matrix, previously used to adjust category scores to account for climate change-induced effects, produces the three category indices.

The CAPRI framework then combines the category indices to produce two "resource threat indices," one that represents the combination of the Ecosystems/Species Index with the Facility Index (the "Ecosystem/Species Facility Index") and one that represents the combination of the Human Use Index with the Facility Index (the "Human Use Facility Index"). In both cases, the same Very High interaction matrix is the basis for determining the index scores.

VULNERABILITY INDEX: COMBINED VULNERABILITY INDEX

As a final step, the CAPRI framework selects the larger of the two resource threat indices and designates that value as the "combined vulnerability index" (CVI). Again, each grid cell within a study area is assigned a CVI.

The complete CAPRI framework for calculating CVIs at the grid cell level, as described above, is illustrated in Figure ES-1.

REPORTING AND VISUALIZING RESULTS

Visualization of CVIs (and supporting VIs) is accomplished through a geospatial decision-support tool, the Environmental Response Management Application (ERMA). ERMA is a user-friendly, web-based platform that allows for easy visualization of results in a geospatial context. ERMA's utility extends to the exploration of data layers that support the calculation of the CVIs (for example, it can display the areas expected to see inundation due to sea level rise given a particular climate change scenario). Stakeholders and communities can utilize ERMA to visualize areas subject to increased risk of releases of hazardous waste and oil, and to inform habitat restoration planning in light of potential impacts.

SAMPLE RESULTS FOR THE PUGET SOUND REGION

Table ES-8 provides an overview of CAPRI results for the four Puget Sound pilot study areas (expressed as the amount of land within each study area that is assigned a particular CVI value). Using 1.5 meter sea level rise climate scenario, one can compare the changes in CVI scores for the four sites over the different analysis years. As expected, the portion of study area that is most vulnerable to the potential release of hazardous waste or oil due to climate change increases as the extent of the climate impacts (e.g., additional land inundation) increases. For example, within the Snohomish study area, the amount of land with higher vulnerability scores is limited to 0.3 percent in 2025 but increases to 0.5 percent in 2100, which corresponds to an increase from approximately 110 acres to 203 acres of land.

TABLE ES-8. COMBINED VULNERABILITY INDEX RESULTS FOR THE 1.5 METER SCENARIO, PUGET SOUND STUDY AREA

STUDY AREA	CVI INDEX SCORE	ANALYSIS YEAR			
		2025	2050	2075	2100
Commencement Bay	Lower (1 & 2)	32.9%	32.5%	32.2%	31.7%
	Higher (3 & 4)	1.4%	1.8%	2.1%	2.6%
Duwamish	Lower (1 & 2)	8.2%	8.1%	8.0%	7.9%
	Higher (3 & 4)	0.8%	1.0%	1.1%	1.1%
Nisqually	Lower (1 & 2)	1.5%	1.4%	1.3%	1.3%
	Higher (3 & 4)	0.5%	0.6%	0.7%	0.7%
Snohomish	Lower (1 & 2)	2.1%	2.0%	1.9%	1.9%
	Higher (3 & 4)	0.3%	0.4%	0.5%	0.5%

Figure ES-2 illustrates CVI results for the Snohomish study area using the 1.5 meter sea-level rise scenario forecast in 2100 (the scenario and year with the largest proportion of land scored as highly vulnerable (score of 3 or 4)). Since the methodology used to develop the CVI is based on vulnerability to facility contamination, maps of CVI scores only show vulnerability (scores greater than zero) in areas with regulated facilities.

The CAPRI framework enables users not only to view the combined vulnerability index values, but also to work back through the analysis structure to identify the drivers of vulnerability for specific areas. For example, Figure ES-3 shows the distribution of index values for the Snohomish study area. As shown, due to the combination of index values through the CAPRI framework, higher vulnerabilities are reflected in the category indices than in the combined resource/threat indices, which represent the co-occurrence of both important resources and facility threats in the same locations. For example, approximately 36 percent of the analyzed area has an Ecosystem/Species Index value greater than zero. Only 13 percent of the analyzed area has a Facility Index value greater than zero. The resources and threats characterized by these index values overlap (and therefore have Ecosystem/Species-Facility Index values) for only 1.8 percent of the analyzed area. Similarly, the overlap between the Human Use Index and Facility Index values greater than zero are minimal (also generating a total of 1.8 percent of land with a non-zero Human Use-Facility Index). There is a small degree of overlap in the areas that are sensitive as determined by the Ecosystem/Species-Facility Index and those from the Human Use-Facility Index. As a result, collectively 2.4 percent of the analyzed area has a CVI greater than zero.

FIGURE ES-1. CAPRI VULNERABILITY INDEX CALCULATION FLOWCHART

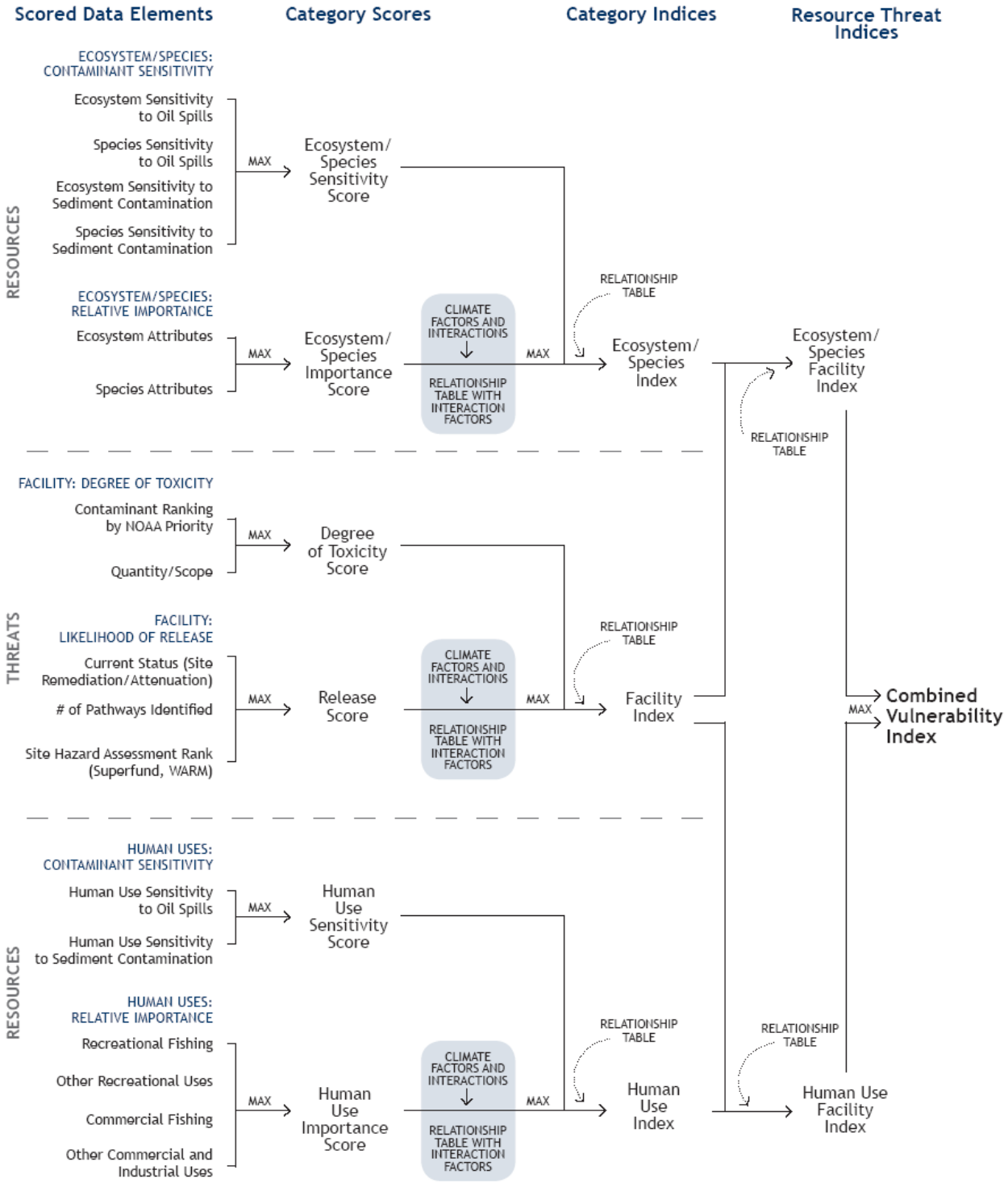


FIGURE ES-2. COMBINED VULNERABILITY INDEX – SNOHOMISH STUDY AREA (1.5 METER SEA LEVEL RISE SCENARIO / 2100)

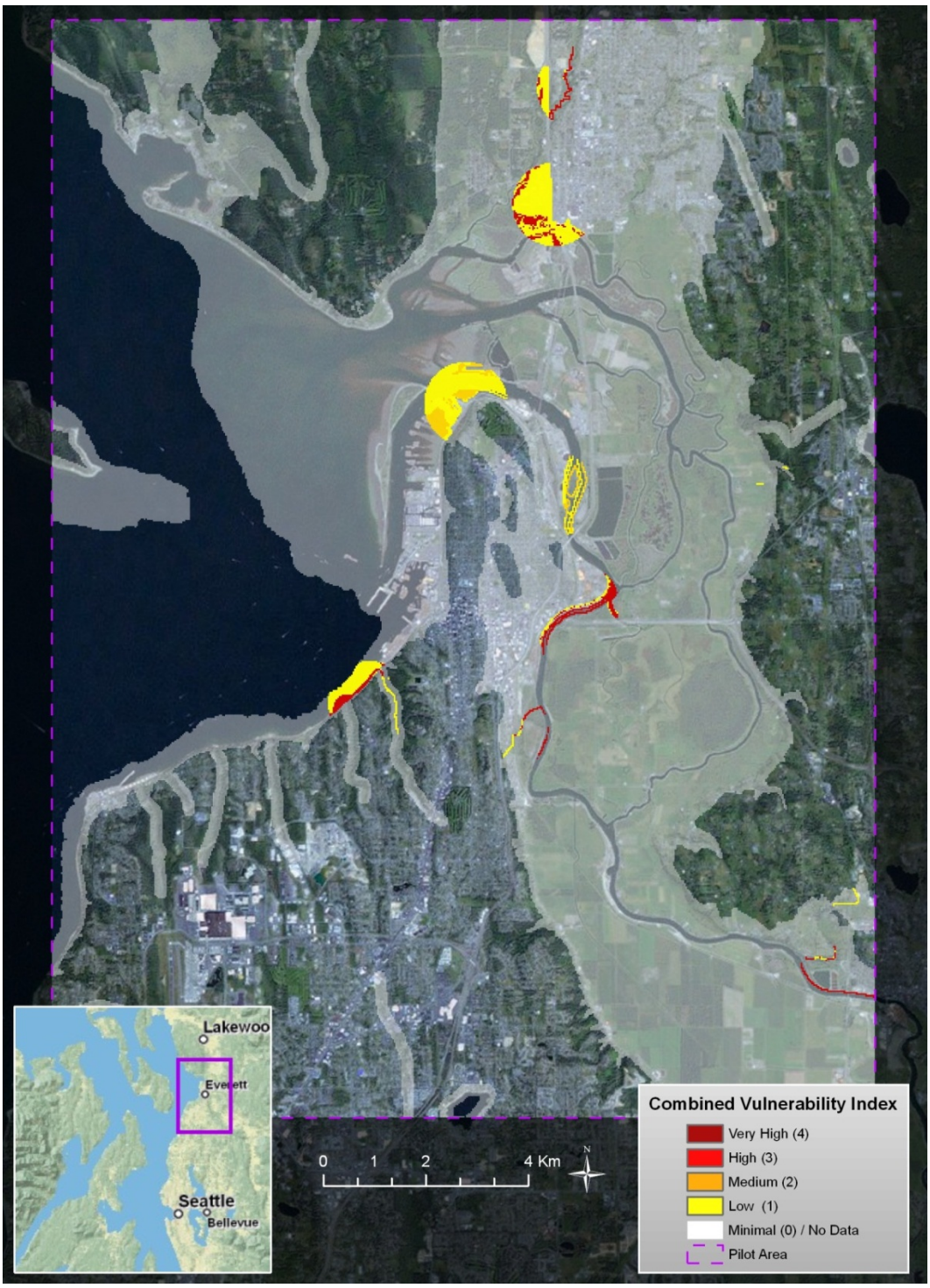


FIGURE ES-3. VULNERABILITY INDEX DISTRIBUTIONS FOR SNOHOMISH STUDY AREA (1.5 METER SEA LEVEL RISE SCENARIO / 2100)

Category Indices

	No Score	One	Two	Three	Four
Ecosystem/Species VI	64.4%	5.0%	24.0%	0.8%	5.9%
Facility Threat VI	87.2%	11.2%	0.3%	0.3%	1.1%
Human Use VI	65.9%	30.5%	0.0%	3.5%	0.0%

Resource-Threat Indices

	No Score	One	Two	Three	Four
Ecosystem/Species-Facility VI	98.2%	1.1%	0.3%	0.0%	0.4%
Human Use-Facility VI	98.2%	1.6%	0.0%	0.0%	0.2%

Combined Vulnerability Index

No Score	One	Two	Three	Four
97.6%	1.6%	0.3%	0.0%	0.5%

APPLYING CAPRI RESULTS

The CAPRI framework provides NOAA and its partners with information needed to plan for and adapt to the potential impacts of climate change. At a first pass, the results illustrate areas most vulnerable to impacts from identified facilities as a result of climate change and provide valuable information on response priorities. Through the drill-down options available in ERMA, the user can identify the resources and threats that are driving the vulnerability index for that location, and then identify appropriate adaptation or response options to address or minimize the vulnerabilities.

NEXT STEPS

The Puget Sound pilot study reflects the initial development of the CAPRI framework for evaluating contaminant impacts in the coastal zone attributable to climate change. This framework provides a flexible structure for conducting screening level vulnerability analyses that can be applied to coastal areas across the nation. While the current CAPRI framework provides valuable information on climate vulnerability, the results are limited by data availability. The pilot development process has helped to identify categories for which new or improved data would be particularly beneficial, as well as potential enhancements to, and further applications of, the CAPRI framework.

Data Needs

- Many hazardous materials stored at facilities are not classified as waste. Further investigation into methods for incorporating data collected under programs such as the Toxics Release Inventory could provide additional robustness to the suite of identified facilities that pose potential threats.
- Additional datasets that focus on upland and subtidal areas would increase the coverage of potentially vulnerable ecosystems beyond the current focus on the nearshore environment.
- Ecosystem and species sensitivity to threats other than oil spills and sediment contamination (e.g., groundwater contamination) could be a useful addition to the framework.
- The Puget Sound pilot did not incorporate information on the sensitivity of human uses to contamination. If appropriate data are identified in the future, information on the spatial distribution of human use sensitivity would fit directly within the CAPRI framework.
- Incorporation of additional climate change factors (e.g., stream flow, water temperature) would broaden the suite of impacts addressed. These additional climate change factors may also prove to be key drivers of vulnerability in areas where inundation (either of wetland or upland) is less of a threat.

Potential Framework Enhancements:

- The CAPRI structure could more closely link specific categories of threats and resource sensitivities to obtain scores and index values specific to a type of contamination.
- The user could have greater control in the process of determining vulnerabilities. As a screening tool, the framework uses the maximum value of vulnerability at each step. As additional datasets are added to the framework and individuals seek to explore the data in different ways, modifications might include allowing users to limit the analysis (i.e., the generation of indices) to a subset of the elements, or allowing users to further adjust the relationship table used to control the process in which resources and threats are integrated into a single indicator (i.e., index) of vulnerability.
- Further investigation is warranted into how best to differentiate null values (resulting from a lack of information) from true zero values.
- Links to NOAA climate adaptation resources currently under development (e.g., the Coastal Climate Adaptation program), as well as to programs relevant to study areas (e.g., Washington Climate Change Impacts Assessment for Puget Sound assessments) could be included within ERMA.
- While the drivers of specific vulnerabilities can be identified by drilling down in ERMA, this is a potentially cumbersome task that would need to be repeated multiple times. The creation of a reporting tool in ERMA that shows the drivers for particular areas would facilitate evaluation and potential responses to vulnerabilities.
- To facilitate use of CAPRI's results in climate impact prevention and adaptation, ERMA could be further expanded to characterize the vulnerability of specific areas such as existing or potential restoration sites.
- Habitat restoration efforts that NOAA and other federal, state, and local groups undertake as part of ongoing ecological protection and natural resource damage responses could be aided by the identification of the most vulnerable habitats and/or uses in particular regions and sub-regions, as determined by the CAPRI framework.

1. PURPOSE

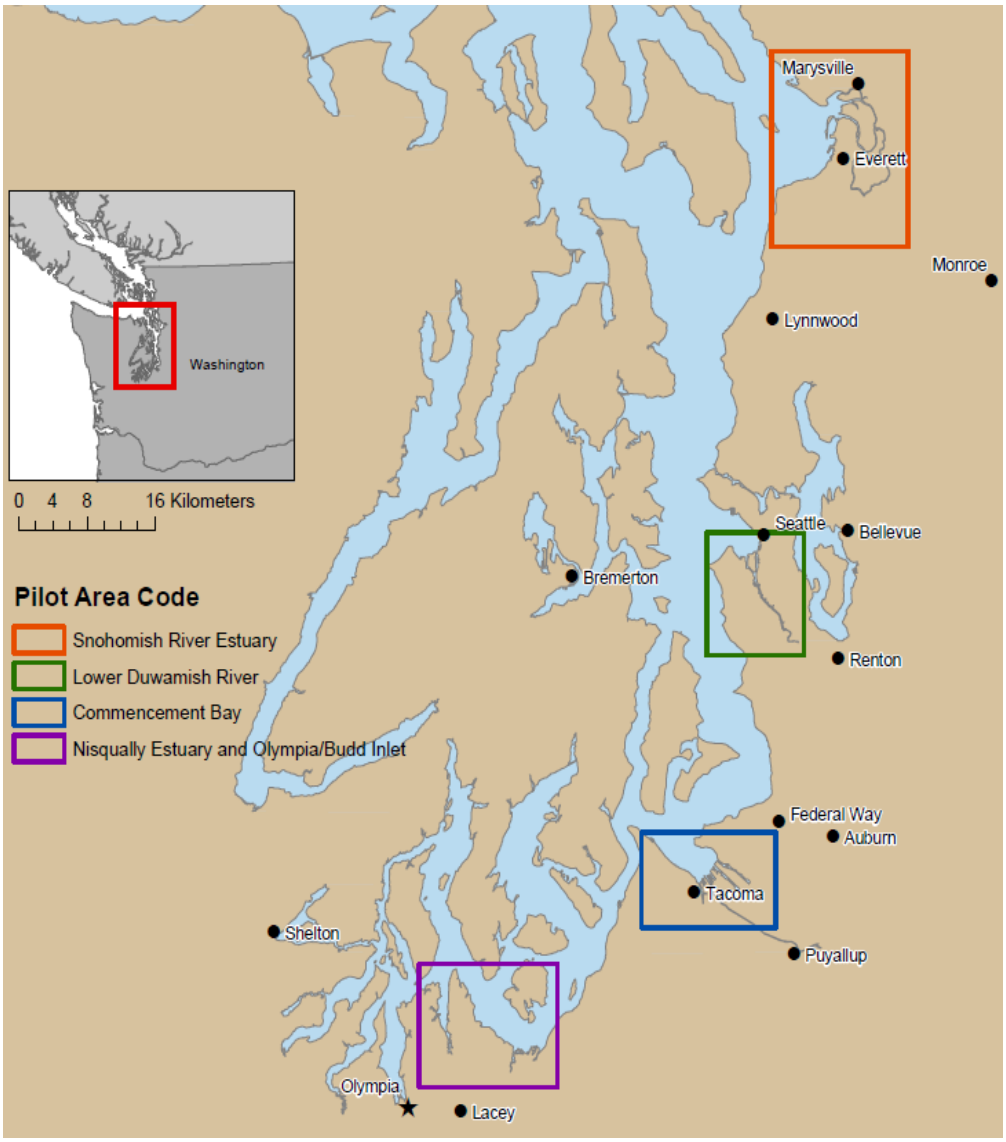
Climate change already affects the United States and its coastal waters. The impacts include rising temperature and sea level, retreating glaciers, earlier snowmelt, heavier rains, thawing permafrost, lengthening growing seasons, lengthening ice-free seasons in the ocean and on lakes and rivers, and alterations in river flows. These changes are projected to grow (Global Climate, 2009). Sea-level rise, increased precipitation, and storm surge place many U.S. coastal areas at increasing risk of erosion and flooding. Such impacts increase the potential for releases of hazardous waste and oil, injuring sensitive ecological communities and impairing human use of coastal resources.

The mission of NOAA's Damage Assessment, Remediation and Restoration Program (DARRP) is to protect and restore coastal and marine resources threatened or injured by releases of hazardous substances, including oil spills. In response to climate change, DARRP has developed the Climate Assessment and Proactive Response Initiative (CAPRI) to provide a tool to evaluate contaminant impacts in the coastal zone related to climate change. By assessing the potential for climate change-related contaminant releases and their predicted impacts to coastal resources, NOAA and other local, state, regional, and federal decision makers will be able to better prepare for and adapt to climate change. This paper describes the framework for a screening-level vulnerability analysis that can be applied to coastal areas across the nation.

The pilot application of the CAPRI framework focuses on Washington State's Puget Sound, the second largest estuary in the United States. The pilot comprises four study sites: Snohomish, Duwamish, Nisqually, and Commencement Bay (Figure 1-1). These coastal study sites are selected based on prior analyses of sea-level rise impacts which indicate likely areas of vulnerability (NWF, 2007). Both local and national datasets are used to develop the vulnerability index. The data availability will vary in different regions, based on local information sources, but the framework will remain the same. Thus, the CAPRI framework is intended to provide a national model that can be adapted to the unique data available in a particular region or coastal area.

Due to limitations in terms of time, scope (budget constraints), and data availability, some aspects of the framework were not fully developed in the pilot. These limitations will be discussed, along with recommendations for further development of the pilot.

FIGURE 1-1. PUGET SOUND STUDY AREA



1.1 CAPRI COMPONENTS

The CAPRI framework encompasses four major components:

- Assessment of climate change impacts, resources, and contaminant threats;
- Development of a spatially-based vulnerability index;
- Use of the Environmental Response Management Application (ERMA) for visualization and analysis of data layers and results; and,
- Identification of effective prevention, response, and restoration options.

The foundation of CAPRI is the development of a vulnerability index. The index integrates regional climate change predictions, threats of hazardous releases, and resources of concern. The index generates a suite of indices based on these data sources. The primary index provides a score for the vulnerability of a particular area to climate related contaminant releases. The vulnerability index framework is shown in Figure 1-2.

Multiple data streams populate a vulnerability index for a particular study area. Climate change impacts are an integral part of the index. Examples of climate change data include forecast changes in sea level rise, stream flow, precipitation, and temperature. Climate change data from multiple models are available at the global scale, while some areas may have models available at the sub-continental or regional scale. Resources of concern include natural resources and the human use of those resources. Examples of natural resources in coastal areas are marsh and other types of habitat, estuarine fish, or marine mammals. For human use, resources include recreational beach use or different types of fishing. Datasets that describe state and federal hazardous waste sites and oil facilities and infrastructure are also essential. All of these data are used as inputs into the vulnerability index (Figure 1-2).

The vulnerability index outcomes are displayed in an online mapping tool, the Environmental Response Management Application (ERMA). ERMA is a user-friendly, web-based platform, which allows for easy visualization of results in a geospatial, or mapping, context. Levels of vulnerability are shown through color coding, low (yellow) to very high (dark red). ERMA will allow stakeholders and communities to visualize and prioritize potential increased risks of releases of hazardous substances and oil. Users can also visualize the full suite of indices and look at different relationships such as climate change impacts on natural resources or human uses with or without contaminant impacts. The CAPRI framework provides users with information needed to plan for and adapt to the potential impacts of climate change. Prevention, adaptation, and management measures are potential options. Prevention entails efforts to reduce the likelihood of exposure from existing or future facilities. Adaptation includes ecosystem and/or human use improvement projects which protect current resources, increase resilience, or replace lost resources. Management entails prioritization of actions to reflect local priorities, financial constraints, and regulatory processes.

1.2 DATA SOURCES AND MODELING APPROACH FOR CLIMATE CHANGE PREDICTIONS

To predict the ecological and human use impacts of climate change, NOAA relies first on likely climate change scenarios. Since 1988, the Intergovernmental Panel on Climate Change (IPCC) has provided scientific assessments of the most current scientific, technical, and socioeconomic information relevant to climate change. The IPCC has released a series of assessment reports over the past two decades. Published in 2007, the IPCC's Fourth Assessment Report contains the latest findings on climate change science and projections for the 21st century.

The IPCC's projections of global climate change are driven primarily by two factors:

1. changes in global greenhouse gas and sulfur emissions, and
2. climate sensitivity to increased greenhouse gas concentrations.

Changes in greenhouse gas and sulfate aerosol emissions are influenced by population growth, socioeconomic development, energy sources, and technological progress. In order to represent a range of future conditions in its climate modeling, the IPCC uses a range of assumptions, corresponding to a range of emission scenarios. The CAPRI analysis for Puget Sound relies predominantly on the IPCC's A1B emissions scenario forecast conditions applied at the regional scale in order to represent reasonable worst case conditions. A1B assumes a balanced mix of fossil and non fossil fuel energy, with technology improvements, and projects a future where technology is shared between developed and developing nations in order to reduce regional economic disparities. A1B lies near the high end of the spectrum for future greenhouse gas emissions, particularly through mid-century (IPCC, 2000).

Various global climate models (GCMs) use the emissions scenarios from the IPCC, but the resolution is very coarse on these models due to the large area covered. For regional climate forecast conditions for the Puget Sound pilot, NOAA used outputs from the University of Washington's Climate Impact Group (UW-CIG). UW-CIG was one of eight Regional Integrated Sciences and Assessment (RISA) teams funded by NOAA to study regional impacts of climate variability and climate change in the U.S.[2] RISAs, UW-CIG and similar programs may be a source of climate forecast data for other regions where this framework may be applied.

UW-CIG has analyzed simulations of future Pacific Northwest climate using twenty GCMs run with the A1B and B1 emissions scenarios from the Fourth IPCC Assessment (IPCC, 2007). These simulations are designed to model the physical processes leading to climate change on the global scale. The models can show differences in the rate of climate change at different locations, but only on the continental scale. A source of uncertainty with GCMs at finer resolutions is the inability to capture prominent features at the regional level. For example, mountain ranges and estuaries are not incorporated into GCMs, but can be important influences on smaller than continental scales. In order to improve predictions, UW-CIG utilized a new approach to evaluating climate change projections for the Pacific Northwest. Reliability Ensemble Averaging, or REA, weights regionally-averaged GCM simulations relative to each model's ability to replicate 20th century Pacific Northwest climate. The GCMs are calibrated using regional climate data, thereby improving forecast conditions. Resolution is also on a finer scale than GCMs.

[2] The Northwest RISA has been relocated to Oregon State University.

OBSERVED AND PREDICTED CHANGES IN PUGET SOUND CLIMATE

In the Pacific Northwest region, the annual average temperature rose about 1.5°F over the past century, with some areas experiencing increases up to 4°F. In the 21st century the region's average temperature is projected to increase 3 to 10°F, a dramatic increase in the rate of warming. The predictions vary by the emissions scenario selected. Annual precipitation changes may be small, but the patterns will shift. For example, the region will likely experience increases in winter precipitation and decreases in summer precipitation. These projections are less certain than temperature estimates. Changes in snowpack, stream-flow timing and magnitudes, and sea level have already been observed (Global Climate, 2009). The following are anticipated impacts of climate change in Pacific Northwest coastal areas:

- Increased coastal erosion and beach loss due to rising sea levels
- Increased landslides due to increased winter rainfall
- Permanent inundation of coastal areas
- Increased coastal flooding due to sea level rise
- Increased winter stream flow in interior and coastal watersheds
- Increased stress on salmon and other coldwater species as a result of rising water temperatures, declining summer stream flows, and increased intensity and frequency of winter floods.

In addition to predictions from UW-CIG's climate change forecasting, NOAA used modeled results of the impacts of sea level rise on coastal areas. The National Wildlife Federation (NWF) conducted an analysis to determine potential impacts of sea level rise on key coastal habitats in the Pacific Northwest. NWF used the Sea Level Affecting Marsh Model (SLAMM) 5.0, which simulates the dominant processes involved in wetland conversions and shoreline modifications during long-term sea-level rise (Glick et al., 2007). Initial development of SLAMM occurred in the 1980s (Park et al., 1986), and model development continues through support from EPA and non-profit groups. Various government and non-profit groups are currently using this model to characterize potential impacts of accelerated sea level rise on coastal ecosystems. For example, the U.S. FWS is applying SLAMM to all of its coastal refuges in order to prioritize response actions, and the Nature Conservancy is using SLAMM to characterize vulnerability on the large tracts of coastal land which it owns. Recent research by Craft et al. (2009) used SLAMM to forecast the effects of marsh inundation on tidal marsh ecosystem services at selected sites along the Georgia coast. SLAMM can be applied throughout the coastal United States.

The SLAMM analysis relied on the A1B scenario in model runs from the IPCC's Third Assessment Report (IPCC, 2001), as the IPCC's Fourth Assessment Report was not yet available. However, the Third Assessment A1B mean and maximum scenarios used in SLAMM 5.0 fall within the estimated range for the Fourth Assessment values. Recent studies suggest that sea level might rise faster than reported in either IPCC Assessment Report due to much faster melting of Greenland and Antarctica ice fields in the past few years (Rignot and Kanagaratnam, 2006; Rahmstorf, 2007). To account for this possibility, additional scenarios were run assuming 1 meter, 1.5 meters, and 2 meters of global average sea-level rise by the year 2100. The A1B-max scenario was scaled up to produce these bounding scenarios. The Puget Sound pilot utilizes the 1.5 meter scenario, as well as the A1B maximum scenario.

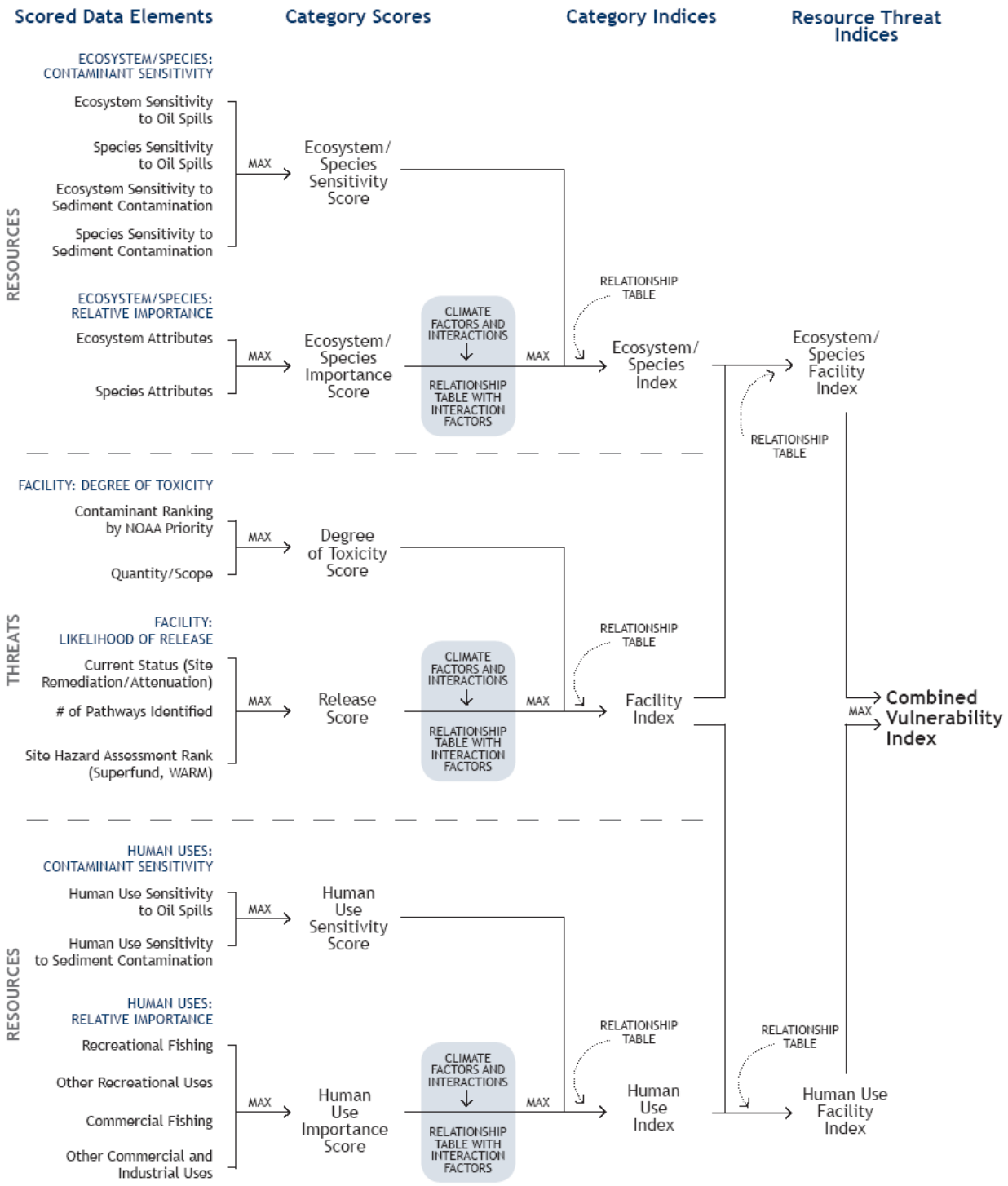
1.3 OVERVIEW OF THE VULNERABILITY INDEX APPROACH

The projected impacts of climate change are integrated with resources and threats to produce a vulnerability index. This spatially-based vulnerability index (VI) integrates climate change impacts, the threat of potential oil and contaminant releases, and the resulting risks to resources of concern. These resources of concern are organized into ecosystems/species (e.g., habitat type, species present) and human uses (e.g. commercial fishing, recreational beach use). Integration occurs on a spatial basis, the scale of which will vary according to the data available within a particular region. The spatial scale for the Puget Sound pilot is a 30-by-30 meter square grid cell.

The vulnerability index requires spatially discrete datasets, which come from multiple national and local sources. Many of the data types that rely on local information in the pilot project are also available in other regions for attributes such as land use/land cover, flood maps, and state priority habitat listings. This approach allows for the flexibility to apply nationwide data sources as well as regional data sets that might be available to document climate change, contaminant sources, ecosystems, species, and human uses within the specified coastal area. When more than one dataset is available for an attribute, multiple datasets can be used

Figure 1.2 illustrates the vulnerability index calculation process. The left column illustrates natural resource and facility (contaminant source) attributes. Climate change factors and potential releases from facilities will impact the vulnerability of ecosystems/species and human uses. However, climate factors will only influence some of the attributes of the natural resources and facilities, while other attributes will not be affected.

FIGURE 1-2. CAPRI VULNERABILITY INDEX CALCULATION FLOWCHART



The climate change factors selected for the Puget Sound pilot are wetland habitat conversion, dry land inundation, and air temperature (Section 2). Other climate factors such as changes in stream flow may be integrated at a later date contingent upon data availability. Climate factors are scored based on risk, i.e. the severity of the predicted effects.

The threat from facilities is scored based on two factors: the degree of toxicity of hazardous materials present at the facility and the likelihood of releases (Section 3). Degree of toxicity is represented by ranking of contaminant classes of concern to NOAA, and by relative quantity or scope of contamination at the facility. Likelihood of release is defined by current status in the cleanup process, number of pathways identified for contaminants to reach natural resources (or to leave source areas), and the site hazard assessment rank.

Ecosystems/species and human uses are each scored based on two factors: sensitivity to contamination and relative importance (Sections 4 and 5). Importance values are based on the relative benefit derived from different ecosystems/species or human uses. For example, ecosystems are valued based on ecological services provided. The importance scores correspond to the relative resource value of these areas and provide a means for prioritization.

The data on climate factors, resource categories, and facility threats are scored on a scale of zero to four as shown in Figure 1-3. The scoring process for each data type is discussed in sections 2 through 5.

FIGURE 1-3. DATASET SCORING METHOD

Dataset	Score				
	0	1	2	3	4
Climate factors	Minimal Risk	Low Risk	Medium Risk	High Risk	Very High Risk
Resource categories	Minimal Importance	Low Importance	Medium Importance	High Importance	Very High Importance
	Minimal Sensitivity	Low Sensitivity	Medium Sensitivity	High Sensitivity	Very High Sensitivity
Facility Threats	Minimal Likelihood of Release	Low Likelihood of Release	Medium Likelihood of Release	High Likelihood of Release	Very High Likelihood of Release
	Minimal Toxicity	Low Toxicity	Medium Toxicity	High Toxicity	Very High Toxicity

For each of the facility and resource categories, the attribute with the highest score serves as the overall score for that category. This approach is used to appropriately screen threats, rather than masking potential risks in an average value. Evaluation of the risk determinant would take place during visualization in ERMA. For example, in the degree of toxicity category, if quantity/scope scores as a 3 and contaminant ranking scores as a 4, the contaminant ranking score (4) will serve as the overall score to represent degree of

toxicity from that facility. The attribute with the maximum score value in each category is then brought forward in the analysis (see Figure 1-2, Category Scores column).

The next component of the analyses is calculating the effects of climate change in conjunction with specific facility and resource category values (likelihood of release and importance, respectively). If facilities or resources are "more likely to be released" or "more important", then one would be more concerned if climate change impacts occur in those locations. While the ecosystem/species/human use importance score interacts with the climate change value in this analysis, the sensitivity of the resource to contamination does not vary with the climate change factors (e.g., if a species is very sensitive to PCBs, it remains at the same level of sensitivity regardless of changes in temperature). Similarly, the toxicity of hazardous materials present at facilities is independent of climate change. The analysis process is described in more detail in Section 6.

Climate factors interact with the resource importance scores and facility likelihood of release score as shown in the shaded boxes in Figure 1-2. Climate change factors will differ in the extent to which they impact a facility or a resource due to the level of interaction, or relevance. For example, temperature increases may have a significant impact on ecological resources, but have a limited impact on threats from facilities. The numerical results of the interactions are calculated using a series of relationship tables. These tables are similar to the result of taking an average of the two factors, and then taking into account whether the interaction is likely to be significant. (Further details are provided in Section 6.) Relationship tables are developed based on low, high, and very high levels of interaction between the climate factor and the scored facility or resource category. The highest score from the climate-resource or climate-threat interaction is brought forward for the next set of calculations.

The remaining three categories, facility degree of toxicity, ecosystem/species sensitivity, and human use sensitivity are incorporated in this series of calculations, resulting in a suite of indices (Figure 1-2, Category Indices column). For facilities, the output of the climate factor/interaction table is combined with the facility degree of toxicity score, using the relationship table. The outcome is a facility threat vulnerability index (VI), a spatial representation of the vulnerability of a facility release due to climate change impacts. For ecosystems/species, the output of the climate factor/interaction is combined with the ecosystems/species sensitivity score, resulting in the ecosystem/species VI. For human use, the climate factor/interaction output is combined with the human use sensitivity score, resulting in the human use VI. The resource VIs are spatial representations of the vulnerability of chemically-sensitive ecological or human use resources to climate change impacts (independent of the actual risk of contamination).[3]

The next set of calculations integrates the facility threat VI with the resource VIs (Figure 1-2, Vulnerability Indices column). Relationship tables are again utilized to combine scores. The facility threat VI is applied in separate relationship tables to the

[3] An interim layer that includes only the interaction between the climate factors and the resource importance (i.e., that does not include resource sensitivity to contamination) may also be developed at a later date.

ecosystem/species VI and the human use VI. The result is an ecosystem/species facility VI and a human use facility VI. These VIs are spatial representations that integrate the sensitivity of ecological or human use resources to the potential presence of hazardous waste or oil due to climate change impacts.

These VIs are incorporated to develop a combined vulnerability index (CVI) at the grid cell level. Human uses and ecological resources are evaluated for risk within the spatial extent of facilities and their respective areas of influence. The CVI characterizes the potential risk from potential contaminant releases due to climate change to resources of concern in a specific location. Section 6 discusses the CVI results for Puget Sound.

The results of the CVIs and supporting VIs will be presented in a geospatial decision-support tool platform, the Environmental Response Management Application (ERMA). ERMA is a user-friendly, web-based platform that allows for easy visualization of results in a geospatial context. Underlying data layers used in the analysis as well as complementary data sets can be explored. This platform allows for integration and synthesis of static and real-time information. Stakeholders and communities can utilize ERMA to visualize areas subject to increased risk of releases of hazardous waste and oil, and to inform habitat restoration planning in light of potential impacts.

2. FACILITY SCORING

2.1 OVERVIEW

Standard site risk assessment techniques use a three-part approach to determine the threat posed by a facility: degree of toxicity of potential releases (hazard identification), likelihood of release (source characterization), and potential receptors affected by a release (exposure assessment). EPA's guidelines on ecological risk assessment and site preliminary assessments (USEPA, 1998; USEPA, 1991), as well as the Washington State Ranking Method (WARM), use this three-part approach. For clarity, these terms are defined as follows:

- Hazard identification: refers to the stressor's potential for causing adverse effects as a result of its specific characteristics (e.g., toxicity);
- Source characterization: refers to site characteristics and site specific attributes which may facilitate the presence or release of environmental contaminants (e.g., current remediation status); and
- Exposure assessment: refers to the potential or anticipated exposure of receptors to environmental contaminants (e.g. presence of sensitive ecosystems or bioresources within the sphere of influence of the facility).

With CAPRI, NOAA directly scores two of these factors (degree of toxicity and likelihood of release) for facilities; the tool assesses the third (potential receptors) by representing the locations of threats and resources on a geospatial basis. Within the Puget Sound pilot, the facilities evaluated for hazard scoring include Superfund sites, state cleanup facilities, oil infrastructure, and other state-regulated facilities. Federal and state databases provide the basis for scoring the facilities' toxicity and likelihood of release. The exposure assessment utilizes 0.5 mile buffer zones around facilities to represent the most probable area of exposure (given that most of the facilities are identified only as points).[4]

2.1.1 IDENTIFICATION OF SOURCE DATA

The analysis currently relies on data from both federal and state sources. Sites from EPA's National Priority List (NPL) are combined with data on state-listed sites into a single data layer depicting locations of hazardous sites (Table 3-1).[5] Contaminant data for

[4] The Puget Sound Initiative uses an 800m (0.5 mi) distance from Puget Sound to identify priority sites, which has been implemented as a buffer radius in the CAPRI pilot.

[5] NOAA recognizes that this pilot uses a somewhat limited definition of hazardous sites. Other types of facilities and other datasets (RCRA sites, other regulated facilities) could be included in future analyses.

these NPL and state facilities are available from Washington State databases. While the details contained within any state layers would vary from region to region, the expectation is that similar types of characterizations and data are available. The two major data sources for contaminant data in Washington State are the following:

- **CSCSList (Confirmed & Suspected Contaminated Sites) Report/dataset:** This is a Washington State Department of Ecology report that contains information about sites that are undergoing cleanup and sites that are awaiting further investigation and/or cleanup. Sites on the State's Hazardous Sites List are included in this data set.
- **ISIS (Integrated Site Information System) Data**[6]: Washington State's Toxics Cleanup Program works to clean up contaminated properties throughout the state. The program uses ISIS to prioritize its work and track progress in cleaning up contaminated sites. The ISIS Web reporting portal provides a selection of standard reports and the ability to quickly and easily retrieve a subset of data for a particular area of interest.

Seven types of facilities are included in the analysis for Puget Sound, based on available data layers (Table 2-1). Risk-ranking attributes for oil-facility information (other than that already available through the Department of Ecology) have not been added to the analysis as the data were not available at the time of the pilot study. The available data for facilities are primarily point data; however, digitized aquatic footprints are available for sediment contamination related to certain NPL sites. Both the facility buffer and any applicable digitized footprint are used to identify grid cells potentially affected by a facility.

2.2 THREAT SUBCATEGORY: DEGREE OF TOXICITY

For facilities, the degree of toxicity score is the maximum of two data attributes: the type of contaminants present and the number of identified contaminant groups in surrounding media. This score is applied to all grid cells within the buffer zone of the facility. If multiple facility buffers overlap in a given grid cell, the maximum degree of toxicity score is used. This is not a climate-adjusted factor; the degree of toxicity is expected to remain constant regardless of climate.

[6] The State of Washington has rolled ISIS into a system called Environmental Information Management, or EIM. For more information on EIM, visit http://www.ecy.wa.gov/eim/index.htm

TABLE 2-1. FACILITY TYPES IDENTIFIED FOR PUGET SOUND

DATA LAYER NAME	DESCRIPTION
Superfund (NPL) Facilities	Facilities that are listed on NPL
Hazardous Waste Treatment Storage and Disposal Facility (HWTSDF)	State designation for facilities that treat store or dispose hazardous waste
Independent Cleanup Site (INDPNDT)	Sites undergoing remedial action without Washington State's Toxics Cleanup Program oversight or approval and not under an order or decree
LANDFILL	A state designation of a disposal facility or part of a facility at which solid waste is placed in or on land and which is not a land treatment facility
Oil Facilities with a Contingency Plan (CPLAN)	Oil handling facilities that are required to file oil spill contingency plans. An oil handling facility can be classified as a structure, equipment, pipeline, or device located on or near navigable waters of the state that transfers oil in bulk to or from a tank vessel or pipeline and is used for producing, storing, handling, transferring, processing, or transporting oil in bulk
SEDMENT	A sediment site is a location of interest to Washington state at which sediment chemical and/or biological data has been obtained and evaluated for potential impacts to human health or the environment. Sediment sites may exist beneath or are associated with freshwater, marine and estuarine bodies of water. Sediment sites may or may not be linked to a known land-based facility
State Cleanup Sites (SCS)	Sites under the purview of the Washington State Toxics Cleanup Program and subject to state regulations. Regulations include Model Toxics Control Act or its predecessors
Note: Layer descriptions from WA Department of Ecology http://www.ecy.wa.gov/services/gis/data/enviro/interactions.htm	

2.2.1 CONTAMINANT RANKING BY NOAA PRIORITY

Contaminants or contaminant groups present at a given facility are identified in the federal (NPL) and state (CSCSList) databases. A priority ranking for contaminants was created based on bioaccumulation and persistence of contaminants in aquatic food webs. This data element or attribute is scored according to the contaminants identified for the facility. If no facility is present, the score is a zero. The scoring by contaminant groups is presented in Table 3-2, showing the 24 contaminant groups identified by Washington State.

The federal and state datasets do not contain contaminant concentrations. Some data are available from HRS/WARM rankings for individual sites. However, these data are not collated or validated, and are not consistent with respect to date of analysis (i.e., samples may be taken for pre-assessment, during remediation; and/or post-restoration). Data sources that describe the current contamination levels at sites would provide a more comprehensive assessment.

2.2.2 NUMBER OF CONTAMINANTS

While the analysis would ideally include the magnitude of contamination present, these data are available in very limited circumstances. Therefore, the number of contaminants is used as a proxy at this time. The total number of Washington State's 24 identified contaminant groups that are present at the site are used to score the site. While this approach would somewhat minimize the potential hazard of single-contaminant, high impact incidents (e.g., oil spills, PCB releases), a more appropriate data layer has not been identified. The highest priority contaminants receive high scores under the contaminant score. Additionally, the potential for certain acute incidents (e.g., offshore oil spills) are not reflected in the available facility data.

The current method of approximating scope by the number of chemicals present is somewhat limiting. These limitations, in addition to the screening function that the tool provides, are the driving force behind the use of the maximum resource/threat scores from each category. Future refinements to this tool could focus on allowing user-defined choices for scoring and selection of target data sets.

TABLE 2-2. DEGREE OF TOXICITY SCORING

Data Element	Score				
	0	1	2	3	4
Contaminant Score by NOAA/WA State Priority	No data	EPA priority pollutants - metals and cyanides, phenolic compounds, non-halogenated solvents, reactive wastes, corrosive wastes, conventional (organic and inorganic), asbestos, tributyl tin, unexploded ordnance, methyl-*tert*-butyl ether, wood debris, other deleterious substances	Base / neutral / acid organics, halogenated organics, other metals, radioactive wastes, arsenic	1 of PCBs, pesticides, dioxin, petroleum compounds, PAHs, benthic bioassay failures	>1 of PCBs, pesticides, dioxin, petroleum compounds, PAHs, benthic bioassay failures
Quantity/ Scope	Zero groups	1 contaminant group	2-5 contaminant groups	6-9 contaminant groups	10-24 contaminant groups

2.3 THREAT SUBCATEGORY: LIKELIHOOD OF RELEASE

This subcategory captures specific facility attributes that may facilitate the mobilization and migration of contaminants present at the site and describes specific activities that may either impede or facilitate unintended release of contaminants. The likelihood of release score is the maximum of three scored data elements: current status, as defined by site remediation or attenuation actions; the number of exposure pathways; and the federal or state hazard ranking. This score is applied to all grid cells within the buffer zone of the facility. If multiple facility buffers overlap in a given grid cell, the maximum degree of toxicity score is used. The likelihood of release is affected by climate change, and a discussion of the relationship tables associated with each climate change factor is included at the end of this section.

2.3.1 CURRENT STATUS (SITE REMEDIATION/ATTENUATION)

Site remediation actions determine the potential for releases. Sites where contaminants have been fully removed (e.g. dredged sites) are expected to have a lower potential for future release than those which still have contaminants on site (e.g. those that have been capped or are relying on natural attenuation). Similarly, sites that have been evaluated as requiring no remedial action are deemed to have a lower likelihood of future release. While a given facility may have multiple statuses, the highest score is assigned to the facility to identify the maximum threat associated with that site.

2.3.2 NUMBER OF PATHWAYS IDENTIFIED

Up to four potential release pathways are identified for each facility: groundwater, surface water, soil, and air. Scoring is assigned based on the number of exposure pathways identified for a site, which should correlate to the extent of potential release. Sites with multiple pathways for release have a greater potential vulnerability to climate change within this framework.

2.3.3 SITE HAZARD ASSESSMENT RANK

At both the federal and the state level, facilities are given a hazard assessment ranking. For NPL sites, this is the Hazard Ranking System (HRS) score initially calculated to determine site eligibility. The HRS score (>28.50 for NPL sites) is a measure of relative risk posed by the site.

This score is based on four exposure pathways:

- Ground water migration (drinking water)
- Surface water migration (drinking water, human food chain, sensitive environments)
- Soil exposure (population, sensitive environments)
- Air migration (population, sensitive environments).

Scores for each of these pathways are related to risk factors based on site specific conditions:

- Likelihood of release of hazardous substances into the environment
- Waste properties (toxicity and waste quantity)
- Sensitive targets affected by the release (human and ecological).

For Washington State, the comparable methodology is the Washington Ranking Method (WARM). The state's Model Toxics Control Act (MTCA) requires sites to be ranked relative to each other to guide the Department of Ecology's use of cleanup resources. The WARM score is an estimation of the potential threat posed by a site relative to all other ranked sites in the state. Sites are ranked based on their risks to human health and the environment. Sites are ranked on a scale of 1 (most concern) to 5 (least concern).

While these scores incorporate both degree of toxicity and exposure assessment, including this data element is important given the extent of site-specific data in each HRS or WARM score. The extensive data collection and analyses conducted for each site are a valuable source of information that is not recorded in any of the databases available for this project (e.g. individual site characteristics such as contaminant hydrophobicity, sediment transport, site stability, etc.). However, NOAA does not rely exclusively on this dataset, since much of the information is collected during the pre-assessment phase for a given site, and not necessarily updated throughout the site remediation/investigation process.

Sites that are on the NPL have an HRS > 28.5 (corresponding site hazard assessment rank of 0) and are scored the same as the sites of highest concern under WARM. The remaining state facilities are scored based on their WARM ranking, as shown in Table 2-3.

TABLE 2-3. LIKELIHOOD OF RELEASE SCORING

Data Element	Score				
	0	1	2	3	4
Current Status on NPL or Washington state listing	Sites deleted from the NPL	Sites with "No Further Action" or "No Remedial Action" decisions	Sites remediated via sediment dredging and removal	NPL proposed sites; Sites remediated via sediment capping and lining or with natural attenuation.	Active NPL sites with no remediation strategies in place
# of Pathways Identified	0 or no data	1	2	3	4
Site Hazard Assessment Rank	no data	5	4	2 or 3	0 or 1

3. ECOSYSTEM AND SPECIES RELATIVE IMPORTANCE AND SENSITIVITY

3.1 OVERVIEW

For this analysis, resources are divided into ecosystem/species resources and human use resources. This section addresses the methods for scoring the ecosystem and species resources for each grid cell. The ecosystems and species expected in each grid cell are evaluated for their relative importance and for their sensitivity to contamination. The relative importance evaluation uses presence of the resource combined with the societal values placed on that resource (*e.g.*, scarcity, role as a cornerstone species, ecological services attributed to that ecosystem). This value is sensitive to climate change: to prioritize efforts, NOAA is more concerned when climate change affects higher-valued resources.

In addition to relative importance, CAPRI also considers ecosystem and species contaminant sensitivity. For the CAPRI pilot, NOAA evaluates the potential impacts of two types of contaminants that are likely to affect natural resources and that have available data: oil spills and contaminated sediments. Additional contaminant sources that may be considered in the future include groundwater and surface water discharges and releases from pipes and tanks, with resulting impacts to soils, groundwater, surface water, and sediment.[7] At the ecosystem level, contaminant sensitivity consists of anticipated changes to structural habitat and to the ability of the ecosystem to continue providing ecological services as a result of contaminant exposure. At the species level, sensitivity is identified through review of habitat requirements and life history parameters to determine how each species may be sensitive to contaminant exposure.

In this section, NOAA provides a framework for assigning scores for ecological importance and sensitivity for coastal ecosystems and species within a “baseline” context (i.e., their current state, absent future climate change impacts).

3.1.1 SELECTION OF ECOSYSTEMS AND SPECIES OF INTEREST

NOAA considered the various structural elements of the Puget Sound coastal and inland water systems. Coastal and nearshore ecosystems are primary locations for NOAA trust resources. For the Puget Sound pilot, efforts are focused primarily on these ecosystems, but the process could be expanded to include differentiation in upland habitats. Ecosystems considered for this project include:

[7] Additional facilities/hazards (i.e. risks from routine storage and use of hazardous materials) may be considered in future iterations.

- Kelp
- Eelgrass
- Salt marshes (sloughs, salt, brackish, and transitional marshes)
- Fresh marshes (inland and tidal marshes, swamp and tidal swamp)
- Beaches (estuarine and ocean)
- Intertidal flats (mud and sand)
- Intertidal rocky shores
- Subtidal (mud, sand, or rocky)

The data elements for categorizing each model grid cell into an ecosystem type are found in the Puget Sound Environmental Sensitivity Index data and in the Washington State ShoreZone dataset. The relationship to the habitat change categories from SLAMM (the habitat climate factor) is shown in Table 3-1. Because SLAMM does not differentiate subtidal habitats, kelp and eelgrass zones are in addition to those noted in Table 3-1. While the Puget Sound pilot does not address additional subtidal/intertidal habitats, future expansion could address additional submerged aquatic vegetation, oyster reefs, delineation of subtidal areas by depth and substrate, and delineation of upland structural habitats.

Species in Puget Sound that were of federal or regional importance were identified based on Washington State's Priority Habitats and Species (PHS) list and available digital data from the Puget Sound Environmental Sensitivity Index and Washington Department of Fish and Wildlife (WDFW). During scoping for this project, NOAA identified a large number of species or species groups of interest. Final selections from this list are made based on availability of data and similarity or overlap between distributions and sensitivity. Species and species groups considered for this project are listed in Table 3-1.

Some of the species or species groups considered for the project were unable to be carried through to the analysis. Species-level clam distributions are not available through the ESI or WDFW maps; however, hard-shell and soft-shell clams are included in the ESI maps for Puget Sound. Additionally, recreational and commercial shellfishing areas are covered in the human use category, which will highlight the sensitivity of these areas. While the pinto abalone is a NOAA Species of Concern, distribution data for the species are not available. The southern resident killer whale has critical habitat designated for all of Puget Sound, which eliminates any geospatial differentiation in vulnerability. Bird groupings in Table 3-1 reflect the presentation in the ESI data for Puget Sound. Birds may be mapped either by species or by species group, depending on the available underlying data. The species noted in each species group are those that have some individual data available.

TABLE 3-1. IDENTIFIED SPECIES OF INTEREST FOR STUDY AREA

Fish: Salmon (coho, Chinook [spring-fall], pink, chum [summer-winter], sockeye) Steelhead [summer-winter] Native char (bull trout) Pacific herring Rock sole Pacific sandlance English sole[1] Rockfish[1]	***Marine Mammals:*** California sea lion Southern resident killer whale[2] Steller sea lion Harbor seal
Birds: Alcids (ancient murrelet, murre, pigeon guillemot, rhinoceros auklet) Diving birds (cormorant, Pacific loon, common and red-throated loon, western grebe) Waterfowl (bufflehead, goldeneye, harlequin duck, long-tailed duck, scaup, scoter) Gulls and terns Shorebirds Raptor (bald eagle) Wading birds (great blue heron)	***Invertebrates:*** Dungeness crab Red rock crab Pandalid shrimp Geoduck Pinto Abalone[1] Hard-shell clams[3] Native littleneck clam[1] Butter clam[1] Olympia oyster[1] Pacific oyster[3] Soft-shell clams[3] Sea urchins[3]

1. NOAA has not identified geospatial data for these species in Puget Sound.
2. The critical habitat for the southern resident killer whale in Puget Sound covers the entire waterbody.
3. For these species or species groups, integration of ESI and WDFW datasets, as well as PHS criteria, may be conducted in a future version of this tool.

3.1.2 IDENTIFICATION OF DATA ELEMENTS

Based on the target species and ecosystems, NOAA identified available data layers that provide spatial coverage of attributes of interest. Table 3-2 lists the data elements scored for the Ecosystem/Species Relative Importance and Sensitivity resource categories.

TABLE 3-2. DATA ELEMENTS FOR ECOSYSTEM/SPECIES RELATIVE IMPORTANCE AND SENSITIVITY

	LAYER NAME (FROM SOURCE)	DESCRIPTION	SOURCE
SPECIES			
Fish	fishdist_UTM	Salmon distribution and structural habitat, by species	WA Department of Fish and Wildlife
	fish_UTM	Pacific herring spawning/pre-spawning	Puget Sound ESI
	fishl_UTM	Salmon and forage fish spawning, by species	Puget Sound ESI
Invertebrates	invert_Project	Locations of invertebrate species (geoduck, hard-shell clams, soft-shell clams, Pacific oyster, Dungeness crab, red rock crab, pandalid shrimp, sea urchins)	Puget Sound ESI
Marine Mammals	m_mampt_UTM	Locations of sea otter, California sea lion, and harbor seal	Puget Sound ESI
	Seal_UTM	Haul out sites for Steller sea lion, California sea lion, harbor seal, and northern elephant seal and abundance at sites	WA Department of Fish and Wildlife
Birds	murrelet_UTM	Marbled murrelet locations and life stage data	WA Department of Fish and Wildlife
	nest_UTM	Breeding sites of bald eagle, great blue heron, and seabirds	Puget Sound ESI
	birds_UTM	Locations of alcids, diving birds, and waterfowl, primarily by species, and gulls/terns and shorebirds (not by species, except Caspian tern)	Puget Sound ESI
Ecosystem			
	Habitats_UTM	Location of kelp and eelgrass	Puget Sound ESI
	Eelgrass_UTM	Eelgrass distribution along shoreline and whether continuous or patchy	WA DNR ShoreZone
	SaltMarsh_UTM	Salt marsh distribution along shoreline and whether continuous or patchy	WA DNR ShoreZone
	esi lines_UTM	ESI shoreline classifications, lines	Puget Sound ESI (Includes WA ShoreZone)
	esi polygons_UTM	ESI shoreline classifications, polygons	Puget Sound ESI (Includes WA ShoreZone)

3.2 RESOURCE SUBCATEGORY: ECOSYSTEM AND SPECIES RELATIVE IMPORTANCE SCORING

3.2.1 ECOSYSTEM RELATIVE IMPORTANCE

Relative importance for ecosystems was derived following the United Nation's (UN) Millennium Assessment guidelines (2003) on ecological services. The ecosystem services model is used to describe the services associated with particular ecosystems (identified by the structural habitat present) and assign scores for relative importance. The ecosystem services model can be used to describe ecosystems on either a global scale (Millennium Ecosystem Assessment, 2003) or a local scale (Batker et al., 2008). While this model was developed to support the economic valuation of natural resources, it provides a comprehensive methodology for identifying the roles that particular ecosystems play in the broader natural systems.[8] While the ecosystem services approach describes the benefits that humans receive from particular ecosystems, many of these services (e.g. water filtration, storm protection, primary production, nitrogen cycling) are relevant and beneficial to a wide set of users of the ecosystem. The application of this approach to individual grid cells is a simplification of the complex interactions and interdependence of ecosystems and the services they provide; however, the approach provides a consistent model for comparing and identifying areas of greatest importance.

Relative ecosystem importance was assigned based on biodiversity and on ten attributes classified into two types of ecosystem services: regulating and supporting.[9] Regulating services include all the benefits derived from the contribution of ecosystems to large scale regulation processes (i.e., shoreline stabilization). Supporting services refer to all natural processes that maintain direct and indirect goods and services derived from ecosystems (i.e., primary productivity). The definitions of the services are as follows (Millennium Ecosystem Assessment, 2003; Batker et al., 2008):

- **High biodiversity/ species richness** – Indicates a high quantity of species within an area or ecosystem. High biodiversity facilitates ecosystem resilience and the provision of other ecosystem services.
- **Shoreline stabilization/ erosion control** – Promoting physical stability of shorelines and aiding in soil retention.
- **Water flow regulation and storage** – Regulation of runoff and flooding, as well as fresh water retention and storage.
- **Storm protection** – Physical buffering from storm surges, large waves, wind,, and flood waters.

---

[8] Note that within the context of this paper, the term value refers to relative ecological value (i.e., the value of ecological functions), and it does not have the connotations associated with economic values and market prices. However, NOAA generally uses the term importance instead to minimize any potential confusion.

[9] The Millennium Assessment also includes provisioning services (food, fuel, and medicines for humans) and cultural services (spiritual, aesthetic, recreational, and scientific). To the extent applicable to this analysis, these services are covered under human use scoring and so are not included in this section.

- **Carbon sequestration** – Capture and storage of carbon.
- **Nutrient cycling** – Locational transfer of nutrients, transformation of unusable nutrient forms to useful forms, and detoxification and absorption of contaminants.
- **Primary productivity** – Carbon fixation by plants and the foundation of most food chains.
- **Secondary production** – Production of consumer organisms.
- **Spawning/nursery grounds** – Provision of relatively protected areas suitable for hatching and maturing.
- **Shelter –** Physical accommodation and protection for organisms.
- **Foraging/food resource for functional groups** – Provision of biologically-available biomass by a web of organisms within an ecosystem.

For most services, the presence of a particular service was assigned based on previously identified services for Puget Sound ecosystems in Batker et al. (2008). Additional assignments (secondary productivity, spawning/nursery grounds, and foraging/food resources for functional groups) were defined qualitatively based on best professional judgment. Assignment of associated ecosystem services was based on scientific knowledge of each ecosystem type, and on general understanding of the ecosystem's biological diversity, physical structure and ecological function. Although each of these services could be applied to any ecosystem type to some degree, points were only given to ecosystems having a significant role on the specific service relative to the other ecosystems (Table 3-3). The total number of services provided by each ecosystem type was then used to assign a relative score, as shown in Table 3-4. The relative score for each ecosystem is shown on the bottom line in Table 3-3.

While quantification of ecosystem services may occur on a larger scale than this analysis (e.g. consideration of all of Puget Sound as one system), these scorings provide a useful relative analysis tool for comparing ecosystem types within the Puget Sound coastal and inland water systems. These scorings do not represent the absolute value (either economic or ecological) of a given parcel of land; rather they provide a tool for evaluating trade-offs, vulnerabilities, and uncertainties in Puget Sound as a whole. This tool is focused on the nearshore environment; therefore, inland ecosystems receive a reduced importance.

TABLE 3-3. ECOSYSTEM IMPORTANCE BASED ON NUMBER OF ASSOCIATED QUALITATIVE ECOSYSTEM SERVICES ATTRIBUTES[1]

QUALITATIVE SERVICE\ECOSYSTEM ATTRIBUTES	EELGRASS	KELP	SALT MARSH	FRESH MARSH	BEACHES	TIDAL FLAT	ROCKY INTERTIDAL	SWAMP
High biodiversity/ species richness	X		X	X		X	X	X
Regulating Services								
Shoreline stabilization/ erosion control	X		X		X	X	X	X
Water flow regulation and storage			X	X				X
Storm Protection	X	X	X	X	X		X	X
Carbon Sequestration	X		X	X		X		X
Supporting services								
Nutrient cycling	X	X	X	X		X		X
Primary productivity	X	X	X	X		X		X
Secondary production	X	X	X	X		X		
Spawning/nursery grounds	X	X	X	X	X			
Shelter	X	X	X	X			X	X
Foraging/food resource for functional groups	X	X	X	X		X	X	X
Number of Services	10	7	11	10	3	7	5	9
Ecosystem Score	4	3	4	4	2	3	2	4

[1] Modified from Batker et al. (2008) and Millennium Ecosystem Assessment (2003).

TABLE 3-4. ECOSYSTEM IMPORTANCE MATRIX

Endpoint	Importance Level				
	Minimal Importance	Low Importance	Medium Importance	High Importance	Very High Importance
Ecosystem importance[1,2]		<3 qualitative service attributes	3-5 qualitative service attributes	6-8 qualitative service attributes	>8 qualitative service attributes

[1] Base information derived from ESI and ShoreZone. See Table 3-2 for details.
[2] Ecosystem importance derived following Millennium Ecosystem Assessment (2003) guidelines and Batker et al. (2008).

3.2.2 SPECIES RELATIVE IMPORTANCE

The ecological and biological importance of the resources was derived from current Federal Endangered Species Act listings and Washington State's Priority Habitats and Species (PHS) List. Endangered species serve as "sentinel" species to indicate larger ecological problems that could affect the functioning of the ecosystem and, likely, humans as well.

Criteria developed for the WDFW PHS list apply to "Priority species" defined as "fish and wildlife species requiring protective measures and/or management actions to ensure their survival" (WDFW, 2008). Priority species (WDFW, 2008) fit one or more of the following criteria:

- **Criterion 1.** State-Listed and Candidate Species - State-listed species are native fish and wildlife species legally designated as Endangered (WAC 232-12-014), Threatened (WAC 232-12-011), or Sensitive (WAC 232-12-011). State Candidate species are fish and wildlife species that will be reviewed by the department (POL-M-6001) for possible listing as Endangered, Threatened, or Sensitive according to the process and criteria defined in WAC-232-12-297.[10]
- **Criterion 2.** Vulnerable Aggregations - Vulnerable aggregations include species or groups of animals susceptible to significant population declines, within a specific area or statewide, by virtue of their inclination to aggregate. Examples include heron rookeries, seabird concentrations, marine mammal haul outs, shellfish beds, and fish spawning and rearing areas.
- **Criterion 3.** Species of Recreational, Commercial, and/or Tribal Importance - Native and non-native fish and wildlife species of recreational or commercial importance, and recognized species used for tribal ceremonial and subsistence purposes, whose biological or ecological characteristics make them vulnerable to decline in Washington or that are dependent on habitats that are highly vulnerable or are in limited availability.

Species listed as threatened or endangered (T/E) under the Endangered Species Act (ESA) were given the highest score (Very High). Species not listed as T/E but determined to be Species of Concern by NOAA are given the next highest score (High). The remaining species were assigned scores based on criteria 1 and 2 from the WDFW Priority Habitats and Species (PHS) List. For the Puget Sound pilot, criterion 1 was ranked above criterion 2 to reflect a focus on species that are currently at risk within the study zone. Criterion 3 was omitted from the scoring process because it is more relevant to the human use factors. The criteria met by the species according to WDFW determined the relative importance of each species as shown in Table 3-5. When a species met multiple criteria, its score was based on the higher WDFW criteria for that species. For instance, a species classified as both #1 and #2 under the PHS list was scored based on the higher scoring characteristic (#1), which would correspond to "High Importance" in

[10] Any sensitive data (e.g., nesting sites) will be appropriately protected in the Environmental Response Management Application (ERMA).

Table 3-5. Species that were noted as being of interest (*i.e.*, listed in Table 3-1), but are not ranked under any of the criteria, are assigned a low value. The scoring results by species are shown in Table 3-6.

In each grid cell, a varied number of species of interest may be present. Due to the screening nature of this assessment, the maximum score for each grid cell provides the species relative importance score.

TABLE 3-5. SPECIES RELATIVE IMPORTANCE SCORING MATRIX.

Endpoint	Importance Level				
	Minimal Importance	Low Importance	Medium Importance	High Importance	Very High Importance
Species importance[1,2]		Other species of interest (Table 3-1)	PHS Criteria #2	Species of Concern, PHS Criteria #1	Federally listed threatened or endangered species

[1] Base information derived from ESIs and other relevant data layers. See Table 3-2 for details.
[2] Criteria as defined under WDFW PHS list, (http://www.wdfw.wa.gov/hab/phs/2008/introductory_sections/phs_definitions.pdf)

TABLE 3-6. SPECIES ECOLOGICAL IMPORTANCE BASED ON CURRENT FEDERAL (T/E/SOC) AND STATE SPECIES CRITERIA (#1, #2)[1]

RESOURCE	SPECIES	SCORING CRITERIA	SCORE
Fish	Coho	SoC	3
	Chinook	T/E	4
	Pink salmon	#2	2
	Steelhead	T/E	4
	Chum	#1, #2	3
	Sockeye salmon	#1, #2	3
	Native char (bull trout)	T/E	4
	Pacific herring	#1, #2	3
	Rock sole	other	1
	Surf smelt	#2	2
	Pacific sandlance	#2	2
Birds	Alcids (including murrelet)	#2	2
	Diving birds	#1, #2	3
	Waterfowl	#2	2
	Gulls and terns	#2	2
	Shorebirds	#2	2
	Raptor- bald eagle	#1	3
	Wading birds	#2	2
Marine Mammals	Steller sea lion	T/E	4
	California sea lion	#2	2
	Harbor seal	#2	2
Invertebrates	Dungeness crab	#2	2
	Red rock crab (intertidal)	other	1
	Pandalid shrimp	#2	2
	Geoduck (intertidal)	#2	2
	Hard-shell Clams	#2	2
	Pacific Oyster	Other	1
	Soft-Shell Clams	Other	1
	Sea urchins	Other	1

[1] Criteria as defined under WDFW PHS list: (http://www.wdfw.wa.gov/hab/phs/2008/introductory_sections/phs_definitions.pdf)

3.3 RESOURCE SUBCATEGORY: ECOSYSTEM CONTAMINANT SENSITIVITY SCORING

3.3.1 ECOSYSTEM SENSITIVITY TO OIL SPILLS

Ecosystem sensitivity to oil spills was based on the Environmental Sensitivity Index (ESI) classification (NOAA, 2002). Under the ESI classifications, shoreline ecosystems are scored according to a scale relating to sensitivity to oil (1 is the least sensitive to oiling, 10 is the most sensitive),, natural persistence of oil, and ease of cleanup which translate to the overall extent of likely injury, both acute and chronic.[11] The ESI classifies saltwater marshes, freshwater marshes, and swamps as the most likely to be damaged by oiling (ESI of 10). Oil in these structural habitats can remain for a long period of time, penetrate deeply into the substrate, and impact a variety of associated plants and animals. As a result of the ESI classification, saltwater marshes, freshwater marshes, and swamps were given the highest score for oil spill sensitivity. Sheltered tidal flats are also highly sensitive based on the physical and biological character of the structural habitat and have an ESI of 9. Sheltered rocky shores have an ESI of 8 because of the long-term persistence of oil. Exposed tidal flats (ESI of 7) are exposed to wave and tidal energy that reduces the risk of long-term persistence. Beaches have an ESI between 3 and 6 depending on the grain size. The least sensitive habitats to oiling as characterized in ESIs are exposed rocky shores (ESI of 1 or 2), where oil is removed quickly by waves and tides. Eelgrass and kelp exist mostly as subtidal habitats and thus are not given an ESI class. However, both ecosystems are highly sensitive to oiling and provide important structural habitat for many sensitive animals (NOAA, 2002). They are also included in the ESI as sensitive habitats. Table 3-7 shows the scoring matrix for oil spill sensitivity for the coastal ecosystems in the study area, and Table 3-8 shows the sensitivity scores.

In some cases, an ecosystem that is characterized as less sensitive to contamination may contain aggregations of a sensitive species (e.g., oyster reef in a rocky intertidal area). In these cases, the sensitivity is characterized by the more sensitive species located there, since the maximum sensitivity score for a given grid cell is carried through the analysis.

TABLE 3-7. SCORING MATRIX FOR ECOSYSTEM OIL SENSITIVITY

Endpoint	Sensitivity Level				
	Minimal Sensitivity	Low Sensitivity	Medium Sensitivity	High Sensitivity	Very High Sensitivity
Oil Sensitivity[1]		ESI 1-2, unvegetated subtidal	ESI 3-6	ESI 7-8 Kelp and eelgrass	ESI >8

[1] Base information derived from ESIs and other relevant data layers. See Table 3-2 for details.

[11] Ease of cleanup is included along with direct injury factors to represent the ability of particular ecosystems to be readily cleaned, reducing the overall extent of injury.

TABLE 3-8. ECOSYSTEM SENSITIVITY TO OIL SPILLS[1]

SENSITIVITY / ECOSYSTEM	EELGRASS	KELP	SALT MARSH	FRESH MARSH	BEACHES	EXPOSED TIDAL FLAT	EXPOSED ROCKY INTERTIDAL	SHELTERED TIDAL FLAT	SHELTERED ROCKY INTERTIDAL	SUBTIDAL	SWAMP
Sensitivity	3	3	4	4	2	3	1	4	3	1	4

[1] Final sensitivity to oil spills based on the ESI score associated with specific habitat structures within Puget Sound.

3.3.2 ECOSYSTEM SENSITIVITY TO SEDIMENT CONTAMINATION

Structural habitats were assigned a sensitivity score for sediment contamination due to waste site releases based on intrinsic sediment dynamics (potential for accumulation of fine-grained sediments that would be released from contaminated sites). Low sensitivity to sediment contamination was assigned to exposed intertidal habitats with limited sediment accumulation (rocky shores, ESI of 1 or 2), or where the sediments are composed of relatively coarse sediments that are regularly worked by wave action (beaches, ESI of 3 to 6), which winnows out the fine-grained sediments to which contaminants are more likely to bind. Medium sensitivity to sediment contamination was assigned to more protected habitats less influenced by wave action, but lacking either vegetative structures or substrates that would more effectively trap sediments (kelp, exposed tidal flats, sheltered rocky shores, ESI of 7,8). High sensitivity to sediment contamination was assigned to protected habitats characterized by either the presence of vegetation that may effectively trap sediments or high organic carbon contents that increase contaminant content (sheltered tidal flats, marshes, eelgrass). Table 3-9 shows the ecosystem sensitivity matrix, and Table 3-10 shows the assigned sensitivity scores for sediment contamination.

TABLE 3-9. ECOSYSTEM SENSITIVITY SCORING MATRIX FOR SEDIMENT CONTAMINATION

Endpoint	Sensitivity Level				
	Minimal Sensitivity	Low Sensitivity	Medium Sensitivity	High Sensitivity	Very High Sensitivity
Sensitivity to sediment contamination[1]		ESI 1-6	ESI 7, 8 Kelp	ESI 9,10 Unvegetated subtidal, eelgrass	

[1] Base information derived from ESIs and other relevant data layers. See Table 3-2 for details.

TABLE 3-10. GENERAL ECOSYSTEM SENSITIVITY TO SEDIMENT CONTAMINATION

SENSITIVITY/ ECOSYSTEM	EELGRASS	KELP	SALT MARSH	FRESH MARSH	BEACHES	EXPOSED TIDAL FLAT	EXPOSED ROCKY INTERTIDAL	SHELTERED TIDAL FLAT	SHELTERED ROCKY INTERTIDAL	SUBTIDAL	SWAMP
Sensitivity	3	2	3	3	1	2	1	3	2	3	3

[1] http://www.pugetsoundnearshore.org/technical_papers/geomorphic_classification.pdf

3.4 RESOURCE SUBCATEGORY: SPECIES CONTAMINANT SENSITIVITY SCORING

3.4.1 SPECIES SENSITIVITY TO OIL SPILLS

Species sensitivity to oil spills was based on habitat requirements, life history parameters, and vast professional experience from past oil spill events. Table 3-11 shows the matrix that defines the criteria used to assign each sensitivity score. Table 3-12 shows the sensitivity scores assigned to each species, with a short explanation of the basis for the score.

TABLE 3-11. SPECIES SENSITIVITY SCORING MATRIX FOR OIL CONTAMINATION

Endpoint	Sensitivity Level				
	Minimal Sensitivity	Low Sensitivity	Medium Sensitivity	High Sensitivity	Very High Sensitivity
Sensitivity to oil contamination[1]			Oil avoidance; subtidal species	Indirect pathway of exposure; nearshore species	Direct pathway of exposure; water-surface species

[1] Base information derived from ESIs and other relevant data layers. See Table 3-2 for details.

3.4.2 SPECIES SENSITIVITY TO SEDIMENT CONTAMINATION

Species sensitivity to sediment contamination from facilities was based on sediment-uptake pathways and trophic interactions, based on exposure potential. A simplified exposure pathway analysis is shown in Figure 3-1. Briefly, species sensitivity to contaminated sediments was assumed to be a function of the degree of dependency on sediments and the trophic distance between sediments and the species of interest. Table 3-13 defines the characteristics of each sensitivity score. Table 3-14 shows the sensitivity scores assigned to each species, with a short explanation of the basis for the score.

TABLE 3-12. SPECIES SENSITIVITY TO OIL SPILLS[1]

RESOURCE	SPECIES	SENSITIVITY SCORE	JUSTIFICATION
Fish	Coho	2	Salmonids inhabit subtidal areas and have limited impact from oil floating on the water surface. Impacts may occur if oil mixes within the water column or accumulates in sediments; younger life stages may be at risk in shallow areas where there is less dilution and where they are less likely to avoid exposure.
	Chinook	2	
	Pink salmon	2	
	Steelhead	2	
	Chum	2	
	Sockeye salmon	2	
	Native char (bull trout)	2	
	Pacific herring	3	These nearshore fish forage and spawn in the intertidal/shallow subtidal zone of sand beaches. They may be impacted by direct oil contamination of spawning substrate and exposure to oil that becomes mixed into the water in the surf zone.
	Rock sole	3	
	Surf smelt	3	
	Pacific sandlance	3	
Birds	Alcids	4	Alcids, diving birds, and waterfowl are highly sensitive because they spend the majority of their time on the water surface allowing a direct pathway of exposure of oiling from surface slicks. Oiling of birds reduces the buoyancy, water repellency, and insulation provided by feathers and may have lethal impacts.
	Diving birds	4	
	Waterfowl	4	
	Gulls and terns	2	Although present in and around nearshore waters, these species do not spend as much time on the water surface so are less likely to be directly impacted by floating slicks. They can be exposed to oil through the capture of prey at the water surface and on shorelines.
	Shorebirds	2	
	Raptors- bald eagle	3	Both wading birds and bald eagles forage for fish and can become contaminated when feeding in areas with floating oil. Wading birds may be exposed to oil from oiled vegetation. Oiled adults can bring back oil to nests.
	Wading birds	3	
Marine Mammals	Steller sea lion	2	Marine mammals have a moderate sensitivity to oil spill impacts because they are highly mobile and can avoid contaminated areas. However, they may be exposed to oil on the water surface or stranded on intertidal haul out sites.
	California sea lion	2	
	Harbor seal	2	
Invertebrates	Dungeness crab	2	Invertebrates receive a medium score because they are subtidal. Some impacts may occur if oil mixes within the water column; younger life stages may be at risk in shallow areas where there is less dilution and where they are less likely to avoid exposure.
	Red rock crab (intertidal)	2	
	Pandalid shrimp	2	
	Geoduck (intertidal)	2	
	Hard-shell Clams	2	
	Pacific Oyster	2	
	Soft-Shell Clams	2	
	Sea urchins	2	

[1] Species sensitivity based on habitat requirements, life history parameters, and extensive literature and experience from past oil spills.

FIGURE 3-1. EXPOSURE TO CONTAMINATED SEDIMENTS VIA SEDIMENT AND FOOD-WEB PATHWAYS

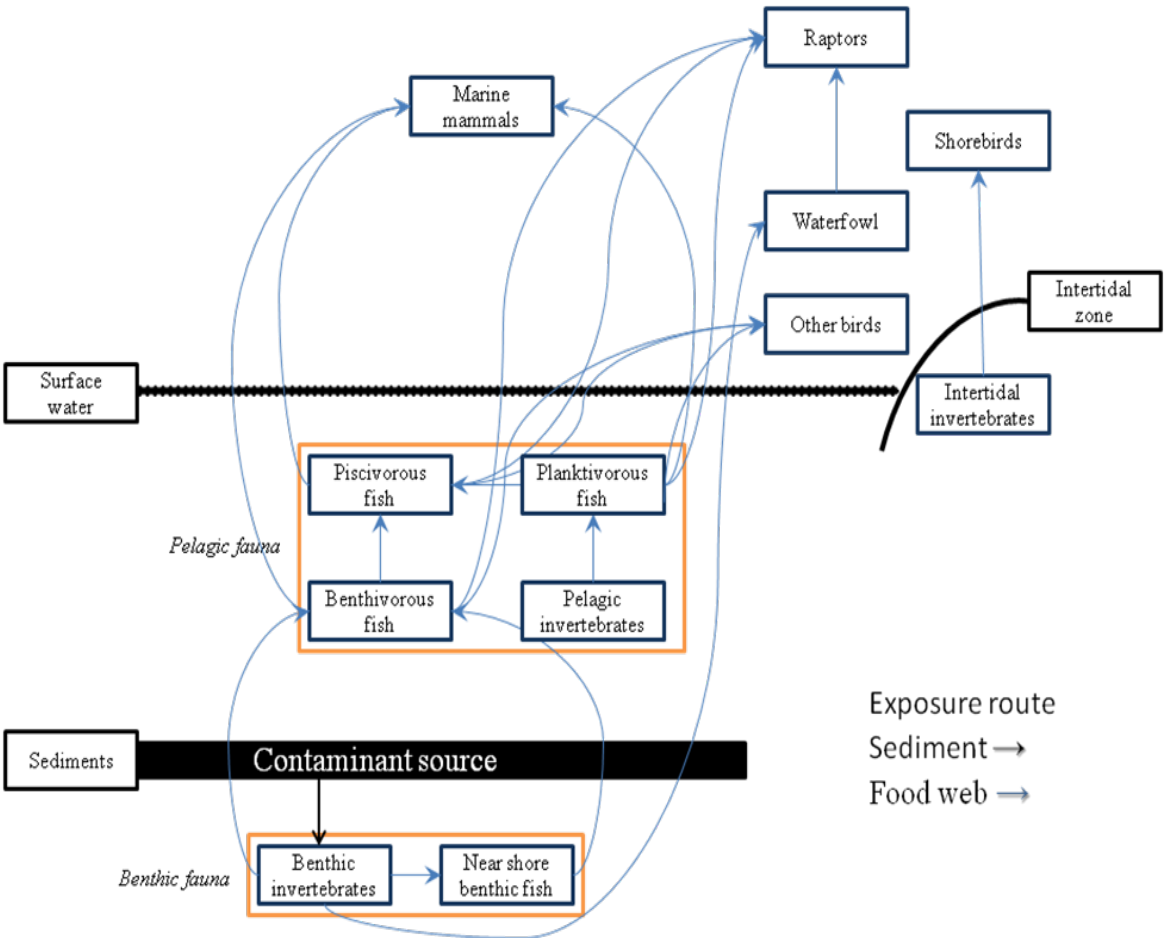


TABLE 3-13. SPECIES SENSITIVITY SCORING MATRIX TO SEDIMENT CONTAMINATION

Endpoint	Sensitivity Level				
	Minimal Sensitivity	Low Sensitivity	Medium Sensitivity	High Sensitivity	Very High Sensitivity
Sensitivity to sediment contamination[1]		Intertidal diet; broad diet	Fish-based diet; pelagic diet	Benthic-based diet	Nearshore benthic residents and sediment dwellers

[1] Base information derived from ESIs and other relevant data layers. See Table 3-2 for details.

TABLE 3-14. SPECIES SENSITIVITY TO CONTAMINATED SEDIMENTS

RESOURCE	SPECIES	SENSITIVITY SCORE	JUSTIFICATION
Fish	Coho	2	Juvenile salmon show preferences for shallow benthic/epibenthic invertebrates (copepods, amphipods), pelagic invertebrates (polychaeta, crab larvae, amphipods), and terrestrial insects in estuaries within the Puget Sound estuaries.[1]
	Chinook	2	
	Pink salmon	2	
	Steelhead	2	
	Chum	2	
	Sockeye salmon	2	
	Native char (bull trout)	2	
	Pacific herring	4	Nearshore species associated with sediments, particularly during spawning may have the greatest risk of exposure to contaminants. Spawn may be particularly sensitive to direct effects from contact with contaminated sediment. Feed on epibenthic fauna.[2]
	Rock sole	4	
	Surf smelt	4	
	Pacific sandlance	4	
Birds	Alcids	2	Diet largely dependent on fish.[3]
	Diving birds	2	
	Waterfowl	3	A significant fraction of their diet is based on shellfish strictly associated with potentially contaminated sediments.
	Gulls and terns	2	Diet largely dependent on fish.
	Shorebirds	1	Feed primarily on intertidal fauna and therefore may be at a lower risk of exposure to contaminated sediments.
	Raptors- bald eagle	2	Salmon, gulls, and waterfowl are the major component of their diet.[4]
	Wading birds	2	Diet largely dependent on fish.[5]
Marine Mammals	Steller sea lion	1	Marine mammals have a diverse diet. They are opportunistic animals that feed on locally and seasonally abundant species.[6]
	California sea lion	1	
	Harbor seal	1	
Invertebrates	Dungeness crab	3	Benthic fauna with a substantial diet based on benthic invertebrates (shrimp and clams).[7]
	Red rock crab (intertidal)	1	Intertidal organisms less likely to be exposed to nearshore contaminated sediments.
	Pandalid shrimp	4	Sediment dwelling organisms likely exposed to sediment bound- contaminants.
	Geoduck (intertidal)	4	
	Hard-shell Clams	4	
	Soft-Shell Clams	4	
	Pacific Oyster	3	Low-intertidal organisms attached to hard substrate organisms likely exposed to sediment-bound contaminants suspended in the water column.
	Sea urchins	3	Benthic fauna with a substantial benthic diet.

[1] http://www.nwfsc.noaa.gov/publications/techmemos/tm8/tm8.html; and http://your.kingcounty.gov/dnrp/library/2004/KCR1841/NEARSHORE_PART_1.pdf
[2] http://your.kingcounty.gov/dnrp/library/2001/kcr2051/Appendix-A.pdf
[3] Lance and Thompson, 2005
[4] http://wdfw.wa.gov/hab/phs/vol4/baldeagle.pdf
[5] http://www.pugetsoundnearshore.org/technical_papers/herons.pdf
[6] Cullon et al., 2005
[7] http://wdfw.wa.gov/hab/phs/dungeness_crab/2008_dungeness_crab_phs_recs.pdf

4. HUMAN USES RELATIVE IMPORTANCE AND SENSITIVITY

4.1. THREAT CATEGORY DEFINITION

Human uses are an important category of natural resource services that can be threatened by climate change and contamination events. In damage assessment from oil spills and hazardous waste releases, impacts to human uses are evaluated alongside impacts to ecological functions and services. As described in the previous section, the Millennium Ecosystem Assessment (2003) includes the categories of provisioning and cultural ecosystem services, which are closely related to human interactions with the natural environment. Provisioning services include benefits such as food production (e.g., commercial fishing) and fuel production. Cultural services include a range of benefits provided by ecosystems, such as spiritual and heritage value of resources as well as recreational benefits of functioning ecosystems. As a screening approach, this tool only includes a subset of the total potential benefits to humans provided by the Puget Sound habitats.

The relative importance of selected human uses can be determined by a variety of methods, including computing dollar values for activities, assigning values based on quantitative data, such as numbers of trips or pounds of catch, or applying decision rules (e.g., a public boat ramp receives a value of 4 while a military boat ramp receives a value of 0). Data limitations will restrict the approach that can be used to assign relative importance or values: for example, economists do not have reliable dollar values for every benefit to humans and where dollar values are available, they are typically developed for a specific site and set of circumstances. As described in Section 4.4 below, this version of the CAPRI tool uses quantitative data or decision rules to assign relative importance values, depending on the type of data available.

4.2. SELECTION OF HUMAN USE ISSUES OF IMPORTANCE

While there are multiple provisioning and ecosystem services provided by the ecosystems in the Puget Sound, this human use section of the analysis focuses primarily on recreational ecosystem services and commercial food production services. For this version of the CAPRI tool, NOAA delineated four broad areas of human use as listed below:

- Recreational Fishing – includes recreational finfish and shellfish activities in coastal and estuarine areas;
- Other Recreational Uses – includes other recreational uses by the public in coastal areas, such as beach attendance, park attendance, or other shoreline uses as well as potential tribal uses of the habitat;

- Commercial Fishing – includes commercial finfish and shellfish activities;
- Other Commercial Uses – includes other commercial uses of coastal areas, such as ports/ferry terminals.

Despite the focus and titles of these categories, datasets used within a given category may also capture a broader set of values than simple recreational or commercial use; for example, “Other Recreational Uses” includes a “Tribal Lands” dataset, whose values would be expected to be associated with benefits outside of pure recreational use. Presence of state parks, another dataset in the “Other Recreational Uses” category, may also provide benefits to those who never engage in recreational use of the parks. The economic literature provides evidence that the public can place significant “existence” value on the knowledge that a given resource exists in a certain state, whether or not they ever plan to use that resource directly.

Grouping the data into four categories provides a clearer understanding of the type of data in the category as opposed to one recreational category that grouped recreational fishing activities and beachgoing/shoreline use activities into one category. Dividing human use data types into the four categories described above also accommodates the potentially varied priorities of CAPRI users. For example, in the damage assessment context, users may desire to focus on the recreational rather than commercial data categories to evaluate how those categories influence the results.

The datasets used in the analysis are listed in Table 4-1 below.

Clearly the datasets above do not reflect the entirety of human uses in Puget Sound. Additional datasets that would be of interest in the future include spatially referenced park attendance data, beach attendance data, commercial fishing catch other than aquaculture, and information on the degree of use of port and ferry terminals in Puget Sound (e.g., vessel traffic). These datasets could allow for a more refined comparison of the threat to human uses by providing additional quantitative information on the present degree of human use in different locations. Combined with data on the monetary value of certain activities (e.g., a day of park visitation), quantitative data on the number of park visits/park attendance could provide an economic estimate of the loss should a given site be impacted by a climate change or contamination factor.

TABLE 4-1. DATASETS USED IN CAPRI HUMAN USE IMPORTANCE AND SENSITIVITY SCORING

HUMAN USE CATEGORY	DATASET	DATA	SOURCE
Recreational fishing	Recreational Fishing	Total Fish Pounds Landed by Zone in Puget Sound	Washington Department of Fish and Wildlife
	Recreational Shellfish Beaches	Status of Shellfish Beaches (Approved, Closed, Conditional, Unclassified)	Washington State Department of Health
	Recreational Shellfish Harvest	Total Shellfish Pounds Landed by Zone in Puget Sound	Washington Department of Fish and Wildlife
Other Recreational Uses	Shoreline Public Access	Type and Degree of Public Access Along Shoreline	Washington State Department of Ecology
	Public Lands: Federal Lands	Type of Federal Land	National Atlas of the United States
	Public Lands: Washington State Parks	Washington State Parks	Washington Department of Natural Resources
	Public Lands: Indian Lands	Indian Lands	Washington State Department of Transportation
Commercial Fishing	Aquaculture	Total Pounds Produced by Aquaculture Area in Puget Sound	Washington Department of Fish and Wildlife
	Commercial Shellfish Growing	Classification of Shellfish Growing Areas (approved, conditional, prohibited, restricted, unclassified)	Washington State Department of Health
Other Commercial Uses	Overwater Structures	Presence of Certain Overwater Structure Types	Washington State Department of Natural Resources
	Ports and Ferry Terminals	Presence of Ports	United States Army Corp of Engineers
	Shoreline Modification (boat ramps)	Presence of Boat Ramps Relative to Other Types of Shoreline Modification	Washington State Department of Natural Resources

4.3 HUMAN USE RELATIVE IMPORTANCE SCORING

Two methods were used to score the importance of grid cells for human uses. Quantitative data (e.g., fish catch) were binned in quintiles and assigned scores. For non-numeric data (e.g., the type of land use present in a certain grid cell), NOAA used a decision rule based on best professional judgment. Table 4-2 lists the approach used for each of the datasets in the human use analysis.

TABLE 4-2. DATASETS AND IMPORTANCE SCORING PROCEDURES USED IN HUMAN USE INDEX

DATASET	IMPORTANCE SCORING PROCEDURE
Recreational Fishing Catch Quantities	Normalization Quintiles
Recreational Shellfish Beach Status	Decision Rule
Recreational Shellfish Harvest Quantities	Normalization Quintiles
Shoreline Public Access	Decision Rule
Public Lands: Federal Lands	Decision Rule
Public Lands: Washington State Parks	Decision Rule
Public Lands: Indian Lands	Decision Rule
Aquaculture Production Quantities	Normalization Quintiles
Commercial Shellfish Growing Status	Decision Rule
Presence of Overwater Structures	Decision Rule
Presence of Ports and Ferry Terminals	Decision Rule
Shoreline Modifications	Decision Rule

4.3.1 APPROACH FOR ASSIGNING IMPORTANCE VALUES FOR GRID CELLS FROM QUANTITATIVE DATA

For the datasets containing continuous quantitative data, a binning approach was employed to assign the relative importance values to grid cells where those human uses occur. As shown in Table 4-2, the recreational fishing, recreational shellfish harvest, and aquaculture datasets were analyzed using this approach. The raw indicator values (e.g., pounds of fish catch in a given area) were converted into normalized values that account for the differences in geographic area covered by each data indicator. The normalized continuous, quantitative data are then summed by category and grid cell (e.g., recreational fishing and recreational shellfish harvest are summed to one continuous, quantitative value for “Recreational Uses”). The data are then divided into 4 bins and assigned values from 0 through 4. The end result is that grid cells with a score of 4 would have high relative levels of the indicator variable (e.g., fish catch) and areas with a score of 1 would have lower relative levels of the indicator variable.

The above procedure resulted in a single relative importance value for each grid cell for the continuous data from the “Recreational Fishing” category along with a single relative importance value for the “Commercial Fishing” category. Normalization was not used for either the “Other Recreational Uses” or “Other Commercial Uses” categories. Rather, NOAA applied a decision rule (as outlined below) in these cases.

4.3.2 DECISION RULE APPROACH FOR ASSIGNING IMPORTANCE VALUES FOR GRID CELLS FROM NON-NUMERIC DATA

This approach uses the professional opinion of those working on human use and natural resource issues to determine the relative importance assigned to a particular data attribute within a dataset. The tables below provide the values assigned for each of these data attributes for each of the four human use categories, with a brief description of the rationale for these relative valuations. Further discussion and review can lead to refinement of the suggested relative importance values.

Recreational Fishing

Only three datasets, or components, were available for analysis in the "Recreational Fishing" category. Two components of the recreational fishing category were discussed in the normalization section above. The remaining component of the recreational fishing category was recreational shellfish beaches, a binary data item. Values of 0 through 4 were not used in this case as the beach status essentially falls into two categories, available or not available for public use. As shown in Table 4-3, a value of 1 was assigned for beaches that are approved or conditional for shellfish collection, under the assumption that these beaches are more valuable than closed or unclassified shellfish beaches. This also does not mean that the closed beaches have no value (or do not have values unrelated to shellfish collection), but rather that in their current state, the approved and conditional beaches are providing more value to users of the resource. Using the binary scheme for this type of data provides for an assignment of potential for human use (e.g., if it is approved for shellfishing) that can then be combined with quantitative information on the degree of use if such data are available.

TABLE 4-3. IMPORTANCE VALUES ASSIGNED TO RECREATIONAL SHELLFISH BEACHES

CLASSIFICATION	ASSIGNED IMPORTANCE VALUE
Approved	1
Closed	0
Conditional	1
Unclassified	0

Other Recreational Uses

All of the elements of the "Other Recreational Uses" category were scored using decision rules. Table 4-4 shows the values assigned based on different types of shoreline access. Higher values were assigned to those areas assumed to provide greater benefit to the general population for recreational use, hence the highest values for public boat ramps, docks, ferries and marinas and the lowest values for military shoreline areas and private areas. Bridges were assigned a value of "0" to avoid double counting with the "Overwater structures" dataset described later in this document.

TABLE 4-4. IMPORTANCE VALUES ASSIGNED TO SHORELINE PUBLIC ACCESS

TYPE OF ACCESS	ASSIGNED IMPORTANCE VALUE
Bridge on a public road/highway	0
Private camp	0
Military land with known access restricted to military personnel	0
Government owned park accessible only by personal watercraft	2
Government owned land accessible only by personal watercraft	2
Government owned tidelands accessible only by personal watercraft	2
Private land with public access only by personal watercraft	1
Private land with known public access (formal organization)	1
Privately owned community beach	0
Private marina open to the public	1
Private yacht club	0
Government park	3
Government owned land with known public access	3
Government owned tidelands with known public access from land	3
Government owned land with no known public access	0
Public boat launch	4
Public dock	4
Public ferry terminal	4
Public marina	4
Public pier	4
Tidelands with railroad and are adjacent to public beach	2
Tribal land with known public access	4
Tribal land accessible to the public with permission	4
Island owned by a tribe with public access	4

Public lands are also expected to provide value to those using the natural resources of Puget Sound for recreational activities. Table 4-5 indicates the value ascribed to each type of Federal land listed in the "Public Lands: Federal Lands" dataset. Given security restrictions, Department of Defense-associated Federal lands were given a recreational value of "0" (except for Army Corps of Engineers lands), while National Park Service and Forest Service areas were given relatively higher importance scores. Further information concerning the range of activities occurring on these lands could provide additional information for relative valuation, but the present assignment is useful as a screening approach.

TABLE 4-5. IMPORTANCE VALUES ASSIGNED TO PUBLIC LANDS: FEDERAL LANDS

TYPE OF FEDERAL LAND	ASSIGNED IMPORTANCE VALUE
Air Force DOD	0
Army Corps of Engineers DOD	4
Army DOD	0
Bureau of Reclamation BOR	4
Department of Energy DOE	1
National Fish Hatchery FWS	0
National Forest FS	2
National Historic Park NPS	4
National Monument FS	4
National Park NPS	4
National Recreation Area FS	4
National Recreation Area NPS	4
National Reserve NPS	4
National Scenic Area FS	3
National Wildlife Refuge FWS	3
Navy DOD	0
Public Domain Land BLM	1
U.S. Coast Guard DOT	0
Wilderness BLM	3
Wilderness FS	3
Wilderness NPS	3

The datasets analyzed also included "Public Lands: Washington State Parks" and "Public Lands: Indian Lands." All state parks included as "Public Lands: Washington State Parks" were assigned a value of 3 in the tool and all Indian lands areas in the "Public Lands: Indian Lands" dataset were assigned a value of 4. The high value for Indian lands is related to the unique cultural and spiritual connections that may be associated with these lands.

Commercial Fishing

Aquaculture values were assigned based on the normalization procedure described previously. The other dataset currently included in the "Commercial Fishing" category, commercial shellfish areas, was scored as shown in Table 4-6. Values of 0 through 4 were not used in this case as the beach status essentially falls into two categories, available or not available for commercial use. Higher value was given to beaches with a harvest permitted (approved, conditional, restricted) than to those classified as prohibited or unclassified. As stated previously for the recreational shellfish harvest beaches, a value of 0 should not be interpreted as an indicator that there is no potential value to beaches where commercial shellfish harvest is prohibited.

TABLE 4-6. IMPORTANCE VALUES ASSIGNED TO COMMERCIAL SHELLFISH HARVEST BEACHES

DESIGNATION	ASSIGNED VALUE TO BEACHES
Approved	1
Conditional	1
Prohibited	0
Restricted	1
Unclassified	0

Other Commercial Uses

All elements in the "Other Commercial Uses" category were scored using decision rules. The "Overwater Structures" dataset contained information on the presence of multiple types of overwater structures (bridge, building, buoy/float, dock/pier, fill, other). All elements in this dataset were given a relative importance score of 2. "Ports and Ferry Terminals" contained data on the presence of ports; all ports were given a relative importance score of 4 to indicate their high importance to commercial activity.

The "Shoreline Modification" dataset contained information on the presence of boat ramps in a certain segment of shoreline and whether the ramp was the primary, secondary, or tertiary type of modification. Moving from primary to tertiary indicates a decrease in the relative contribution of the boat ramp to the shoreline modification in a given segment compared to other types of shoreline modification (e.g., rip-rap, bulkheads). For example, if a boat ramp is the only type of shoreline modification present in a given segment, it would be the primary type of modification. Given this, these grid cell attributes were assigned a value of 4, 3, and, 2 depending on whether they were primary, secondary, or tertiary modifications, respectively. The sites where boat ramps were the primary type of shoreline modification were assumed to have the highest value for commercial users. There was no overlap between the "Overwater Structures" and boat ramp component of the "Shoreline Modification" datasets. Although this dataset is currently included within the "Other Commercial Uses" category, since the data were collected using helicopter overflight images that might not indicate usage, there is some uncertainty about whether the boat ramps are for strictly commercial purposes. On-the-ground evaluation could address this question if the dataset shows up as an important contributor to the eventual human use importance score.

4.3.3 COMBINING HUMAN USE CATEGORIES INTO A SINGLE IMPORTANCE SCORE

Each grid cell may have multiple importance scores, including decision rule-based relative importance scores across all four categories, a quintile-based "Recreational Fishing" relative importance value, and/or a quintile-based "Commercial Fishing" relative importance value. The final step in the process is to assign a single human use importance score to each grid cell, which will then be carried forward into the climate and hazard analyses. The current version of CAPRI accomplishes this by assigning each grid

cell the maximum value obtained from the quintile-based and decision rule-based approaches.[12] A limitation of using the maximum is that the user cannot immediately identify the dataset (or even the category) generating the maximum value. The structure of the tool, however, will allow the user to move backward through the process and see the values contributing to the final "Human Use Importance" score for each cell.

Future versions of the tool could allow for averaging of the values across the categories or weighting of each category (or weighting of data elements within each category).

4.3.4 FUTURE STEPS FOR DATA ANALYSIS

As additional datasets become available for analysis, a more refined approach to assigning values to each grid cell may be employed. Different possibilities could be explored for transforming the continuous datasets into 0-4 scores, and for combining the continuous, quantitative data with the qualitative data.

HUMAN USE CONTAMINANT SENSITIVITY

The current version of the CAPRI tool does not incorporate the sensitivity of the individual human use category elements to oil spill and sediment contamination events, but only of the broader human use categories. In a future version of the tool, NOAA could explore interactions of the individual elements of the categories with a contaminant sensitivity factor to arrive at an overall human use value/sensitivity index or develop sensitivity factors for each of the data elements present within each of the four categories. Table 4-7 below provides an initial evaluation of potential interactions of the human use categories with oil spills and contamination events. The first three categories have a high potential degree of interaction while the fourth has a medium potential degree of interaction.

TABLE 4-7. SENSITIVITY OF HUMAN USES TO CONTAMINANTS

	RECREATIONAL FISHING USES	OTHER RECREATIONAL USES	COMMERCIAL FISHING	OTHER COMMERCIAL USES
Oil Spills	Changes in visitation or access due to oil spills.	Changes in visitation or access due to oil spills.	Changes in commercial fishing trips or access due to oil spills.	Contamination of developed areas, overwater structures, and shoreline infrastructure.
Sediment Contamination	Changes in visitation or access due to contamination of sediments.	Changes in visitation or access due to contamination of sediments.	Changes in commercial fishing trips or access due to contamination of sediments.	Dredging restrictions that affect port access, other secondary impacts of contamination

[12] Due to a difference in approach on human use factors versus ecological factors, the combination of activity scores (e.g. recreational fishing and recreational shellfishing) prior to determining the maximum value for a grid cell may discount the impact of these factors. In future versions this will be approached uniformly across categories.

5. CLIMATE CHANGE FACTORS

5.1 OVERVIEW

The potential climate change factors are numerous: structural habitat change and inundation from sea level rise; changes in air and water temperatures; increased streamflow, flooding and storm severity/frequency; changes in timing and quantity of precipitation; and ocean acidification. The Puget Sound pilot considers a small subset of potential factors. Some factors were omitted because they have fairly homogenous change within the area (*e.g.*, surface water temperature) or because the predicted absolute changes are very small relative to regional average values (*e.g.*, precipitation).For other factors, data were not available or spatial coverage was limited. Thus, the pilot included only structural habitat change and inundation from sea level rise and changes in air temperature. If these analyses are extended to broader geographic areas, additional data sets may be included.

The SLAMM analysis performed previously by the National Wildlife Federation (NWF) forms the basis for the structure of the climate change analysis. NWF ran SLAMM for 10 sites in Puget Sound, using five climate scenarios and four future dates: 2025, 2050, 2075, and 2100 (Glick et al., 2007).[13] These same four years are used to select forecasts from the other models, for consistency. The SLAMM analysis also uses a 30 meter by 30 meter grid cell; all of the datasets in the analysis are scaled to this same grid size (climate, facility, and resource data).

Climate change factors are scored on a scale of zero to four, representing minimal change to a significant degree of change. The climate factor scores represent the magnitude of change and are based on literature predictions as well as professional judgment. Climate factors are scored for each grid cell for each of the four analysis dates and two scenarios (A1Bmax, A1Bmax scaled to 1.5m sea-level rise). In general, greater degrees of change cause greater impacts. The degree of impact that a climate factor has on a threat or resource (e.g. the effect of habitat change or of increased temperature on the ecosystem/species category) differs between threat/resource categories and is specified by the interaction matrix. Some threats or resources are not affected by particular aspects of climate change and thus have an interaction value of zero.

[13] SLAMM5, the version run by NWF, employs sea level rise estimates (including A1Bmax) derived from IPCC 3 (2001). Under A1Bmax, sea level rise is predicted to reach 0.69 meters by 2100. The 1.5-meter scenario uses the A1Bmax trajectory, scaled up to reach 1.5 meters by 2100. Further details on the scenario are in the technical documentation for SLAMM (http://warrenpinnacle.com/prof/SLAMM/SLAMM5.0.2_Tech_Doc.pdf).

5.2 CLIMATE FACTOR 1: WETLAND HABITAT CHANGE / LOSS

For changes to structural habitat, NOAA created a scoring matrix based on the change in habitat type predicted by SLAMM (Sea Level Affecting Marshes Model) for each grid cell. SLAMM is a spatial model that calculates rates of inundation, erosion, and saturation based on site-specific parameters and predicts habitat area by wetland class on a decadal scale. SLAMM offsets the impacts of sea level rise by simulating sedimentation and accretion based on user-identified accretion rates. Modeled saturation of upland soils allows migration of coastal wetlands. The model also estimates potential second order effects of erosion and exposure to wave action from storms.

The characterization of baseline structural habitat in SLAMM derives from National Wetlands Inventory (NWI) data. Based on the Cowardin wetlands and deepwater habitat classifications, grid cells are divided into 23 categories.[14] For this analysis, those categories are further grouped into general structural habitats. Table 5-1 shows the correspondence between the original SLAMM categories, the groupings for the change analysis, and the broader ecosystem groupings discussed in Section 4. Due to the different data sources for the SLAMM analysis and the ecosystem resource category, these two groupings do not perfectly match, a function of both differences in evaluation year for the data and of classification methods.

To implement this method, relevant SLAMM outputs are projected in Universal Transverse Mercator 10 (UTM 10, the format used throughout this analysis) and extracted to the grid developed for the vulnerability index.[15] The structural habitat type for each grid cell (30m x 30m), for each scenario and year, is held in an MS Access table. For each grid cell, change values for the four dates are calculated by comparing the initial habitat type to that present in the evaluated year. Based on the change matrix (Table 5-2), NOAA queried the data to produce an additional field for each record indicating the habitat climate change score of 0-4. The maximum change value corresponds to the conversion of dry land to wetland or the conversion of any dry or wetland habitat to open water. Other habitat changes (e.g., swamp to marsh or beach to tidal flat) receive scores between 1 and 3. Figure 5-1 demonstrates this process for one subsite.

[14] Additional categories have been added for the most recent version of SLAMM. The version used in this analysis, SLAMM5, has 21 wetland/open water categories as well as developed and undeveloped dry land, which are derived from additional user inputs.

[15] The SLAMM maps were generated using Lambert Conical Conformal projection, so the rasters are slightly askew relative to the grid created in UTM 10. The value for each grid cell is determined from the centroid value. If updated SLAMM scenarios are run in the future, they can be generated using UTM 10 rather than Lambert, to avoid the skewing.

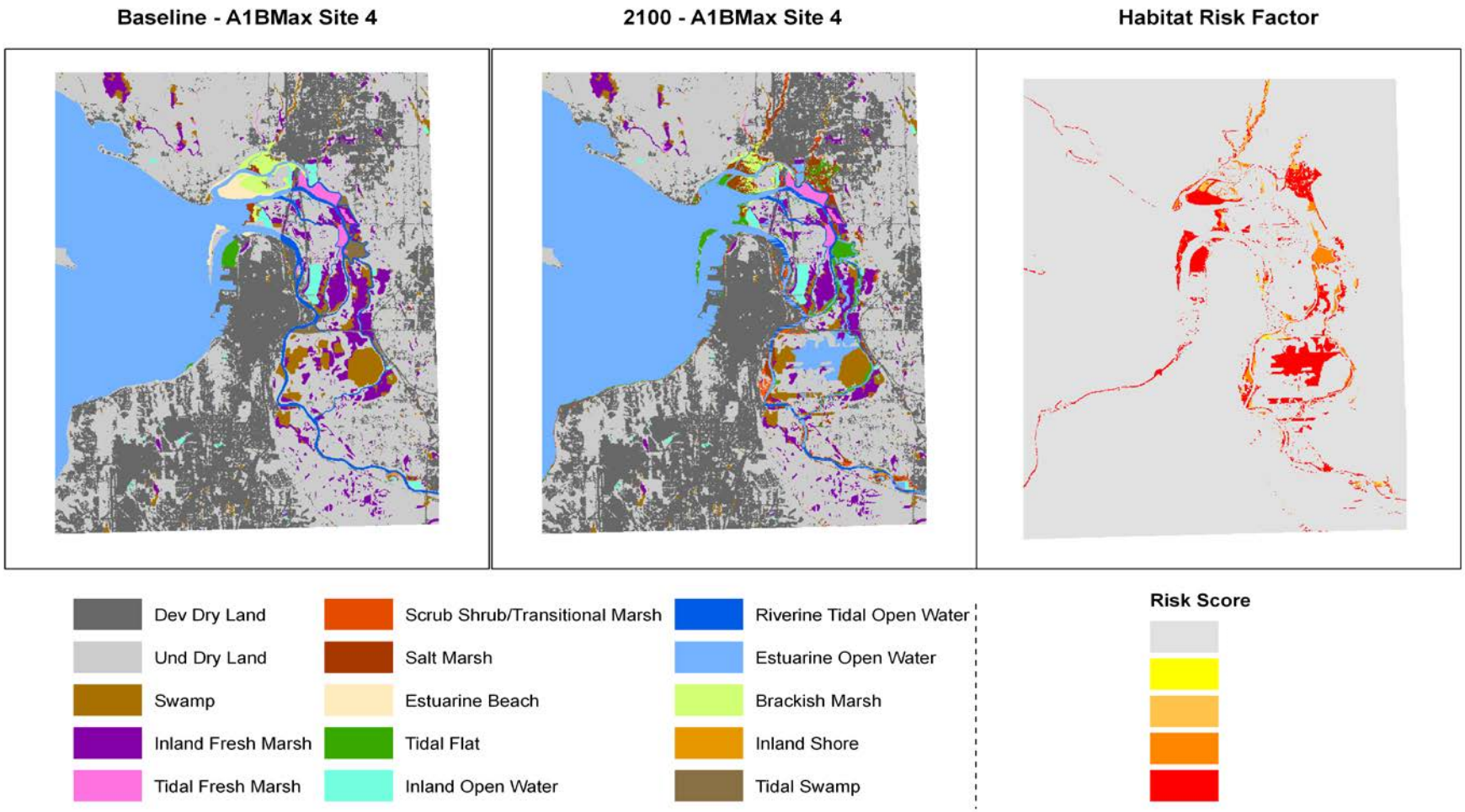
TABLE 5-1. CORRESPONDENCE OF SLAMM STRUCTURAL HABITAT CATEGORIES; HABITAT CHANGE CATEGORIES; AND ECOSYSTEM CATEGORIES

SLAMM HABITAT CATEGORIES	HABITAT CHANGE CATEGORIES	ECOSYSTEM CATEGORIES
Devdryland	Dry Land	Dry Land
Unddryland	Dry Land	Undeveloped Dry Land
Swamp	Swamp	Swamp
Cypressswamp	Swamp	Swamp
Inlandfreshmarsh	Freshwater Marsh	Fresh Marsh
Tidalfreshmarsh	Freshwater Marsh	Fresh Marsh
Scrub Shrub / Transitional Marsh	Scrub Shrub Marsh	Salt Marsh
Salt Marsh	Salt Or Brackish Marsh	Salt Marsh
Mangrove	Scrub Shrub Marsh	n.a.
Estuarine Beach	Beach	Beach
Tidalflat	Tidal Flat	Tidal Flat
Ocean Beach	Beach	Beach
Oceanflat	Tidal Flat	Tidal Flat
Rockyintertidal	Beach	Rocky Intertidal
Inlandopenwater	Open Water	n.a.
Riverinetidalopenwater	Open Water	n.a.
Estuarineopenwater	Open Water	n.a.
Tidalcreek	Open Water	n.a.
Openocean	Open Water	n.a.
Brackishmarsh	Salt Or Brackish Marsh	Salt Marsh
Tallspartina	Salt Or Brackish Marsh	Salt Marsh
Inlandshore	Beach	Beach
Tidalswamp	Swamp	Swamp

TABLE 5-2. MATRIX FOR HABITAT CHANGE SCORES (BASED ON SLAMM OUTPUT)

	FINAL CONDITION	DRY LAND (D)	SWAMP (W1)	FRESH-WATER MARSH (W2)	SCRUB/ SHRUB MARSH (W3)	SALT OR BRACKISH MARSH (W4)	BEACH (B)	TIDAL FLAT (F)	OPEN WATER (O)
Initial Condition	**D**	0	4	4	4	4	4	4	4
	W1	--	0	2	1	3	3	3	4
	W2	--	--	0	2	2	3	3	4
	W3	--	--	--	0	2	3	3	4
	W4	--	--	--	--	0	3	3	4
	B	--	--	--	--	--	0	2	4
	F	--	--	--	--	--	--	0	4
	O	--	--	--	--	--	--	--	0

FIGURE 5-1. ILLUSTRATIVE HABITAT CHANGE SCORES FOR SNOHOMISH SUB-SITE (5100, A1BMAX)



5.3 CLIMATE FACTOR 2: DRY LAND INUNDATION

Three areas are not well addressed by the SLAMM modeling used in the Puget Sound pilot: inundation of developed land, increased flooding frequencies for dry land, and differentiation within the subtidal structural habitats. Therefore, to complement the scores for changes in wetland habitat derived from SLAMM, NOAA also used an inundation climate factor which describes the potential inundation of developed land and the increase in flooding potential on dry land. Increases in flood risk particularly relate to hazards posed by facilities.

While dry land has been the primary focus of the inundation discussions, and wetlands the focus of structural habitat change through SLAMM, NOAA also anticipates potential impacts in the nearshore environment. In particular, increased water depth may eliminate some aquatic vegetation areas. While the current CAPRI framework will not address changes in the nearshore subtidal environment, the inundation model could be applied to this in the future, depending on available bathymetric data sets and depth data for structural habitat types (e.g., submerged aquatic vegetation, subtidal oyster reefs). These impacts are less concrete and defined, and likely to be smaller in extent than some of the other factors.[16] This analysis could be developed as part of the future efforts.

The first step in the implementation of the inundation modeling is to assign elevations to the study area grid based on available elevation data.[17] NOAA used average elevation, as opposed to minimum elevation. Since the selected grid is of relatively fine resolution (30m x 30m), the average should adequately characterize the distribution of elevations within the cell area. If the resolution were coarser, use of minimum elevation would be more appropriate, and would create a conservative estimate of inundation risk, as an increased area would likely be subject to flooding.

To estimate the inundation level for each future time period, the following equation sums three key factors that affect the extent to which an area incurs inundation risk from sea level rise:

$$\textit{Inundation level} = SLR + TC - LS$$

Where:

SLR = Projected sea level rise

TC = Tidal datum correction (NAVD88 to MHHW)

LS = Local subsidence

[16] The impact may be particularly limited for kelp beds, which are frequently found in depths up to 20 meters, with some types found up to 30 meters.

[17] The elevation data are from the 2005 Puget Sound digital elevation model from the University of Washington School of Oceanography, with the exception of the southern portion of the Nisqually subsite, which used data from the USGS National Elevation Dataset.

Definition of terms:

- Projected sea level rise. For each of the selected climate change scenarios, NOAA estimated sea level rise based on the two separate scenarios: A1B from IPCC 4 and a fixed rate of 1.5 meters by 2100 (which is representative of potentially higher ice melt scenarios as proposed by other researchers).
- Tidal datum correction. In coastal areas, flooding is more likely to occur during high tides. To account for tides, NOAA "corrected" the elevations (which are typically relative to the orthometric datum NAVD88) to be relative to the mean higher high water (MHHW) tidal datum. That is, elevation values are converted to reflect elevations relative to sea level during the sea's highest point in an average tidal day (i.e., the higher of the two tide cycles in a ~25 hour lunar day). Using MHHW reflects that these areas are typically under water at least once, if not twice per day. NOAA's VDATUM tool can produce a single correction factor for each study site.[18]
- Local subsidence. The inclusion of subsidence and upwelling projections for the study site accounts for changes in local land levels over time. Mote et al. (2008) developed subsidence projections for Puget Sound based on available data. They developed projections for 2050 and 2100 for three climate change scenarios: very low, medium, and very high. Assuming that the two climate change scenarios used in the framework roughly equate to the medium and very high estimates (A1B and 1.5 meters, respectively), the framework uses Mote et al. (2008)'s subsidence projections. For time steps in which Mote et al. (2008) does not provide projections, NOAA conducts a simple linear interpolation. Table 5-3 presents the subsidence values developed from Mote et al. (2008) for each 25-year time step. Note that the authors project no subsidence for Puget Sound under the medium climate change scenario.

[18] NOAA's VDATUM tool vertically transforms geospatial data among a variety of tidal, orthometric and ellipsoidal vertical datums. To develop the NAVD88 to MHHW correction for a study site, the elevation dataset is run through the VDATUM tool, with averaging of differences between NAVD88 and MHHW across the entire study site. However, VDATUM coverage may be limited for some study sites. For study areas in which VDATUM does not provide coverage, NOAA's team interpolates tide gage information published by NOAA's National Ocean Service. The difference between NAVD88 and MHHW is calculated for each tide gage. These values are then interpolated across the study site to create a surface of correction values. Finally, the framework uses the average of the correction values across the surface of the study site. NOAA's team chose the spline interpolation method, as it preserves values of the input tide gage information. For more information on NOAA's VDATUM tool, see http://vdatum.noaa.gov/welcome.html.

TABLE 5-3. PROJECTED SUBSIDENCE IN PUGET SOUND 2000 TO 2100

YEAR	PROJECTED SUBSIDENCE (MEDIUM SLR SCENARIO)	PROJECTED SUBSIDENCE (VERY HIGH SLR SCENARIO)
2000	0 cm	0 cm
2025*	0 cm	5 cm
2050	0 cm	10 cm
2075*	0 cm	15 cm
2100	0 cm	20 cm

* Subsidence interpolated from nearest values
Source: Mote et al. 2008. Sea Level Rise in the Coastal Waters of Washington State. State of Washington, Department of Ecology, Climate Impacts Group.

Table 5-4 below shows the inundation climate scores by level. For each time step and scenario, those grid cells with elevations below the inundation level are assigned the highest climate score (4), as they are most likely to be flooded at that time step. However, elevations close to, but still above, the inundation level also incur some measure of elevated flooding risk from storm events. The base flood elevation (BFE) across the study area is the unit of elevation for determining proximity to the inundation level. That is, the definition of "substantial flood risk" is grid cells with elevations within one BFE above the inundation level. Therefore, they are assigned a score of 3, which reflects the high flood risk. Given the simplicity of this approach, the framework keeps the scoring process simple by not parsing the inundation risk scores any further than the three categories shown in Table 5-4.[19]

The current BFE serves as the proxy for the vertical dimension of the future flood risks as it is a measurable indicator of potential flooding conditions. In the database, this unit could be altered by NOAA to reflect a different measure, such as a static elevation unit (*e.g.*, within 1 meter, *etc.*). To identify appropriate BFE values for each of the four pilot areas, the framework uses FEMA Flood Insurance Studies for Snohomish, King, and Pierce Counties. These studies present BFE values at numerous locations near or in the study areas. For Snohomish River Estuary pilot area, seven BFE values located within the area result in an averaged BFE of 8.7 feet.[20] The Lower Duwamish River pilot area did not contain BFE values; however, the average of the nearest 4 values yields 16.5 feet.[21] Both Commencement Bay and Nisqually Estuary pilot areas have a single BFE value located within the study areas, yielding 12.4 and 13.3 feet, respectively.

[19] The framework does not estimate changes in vulnerability for areas that are already underwater in the base year (e.g., open ocean).

[20] The seven BFE values within Snohomish were 8.4, 8.4, 8.5, 8.5, 8.5, 8.8, and 10.

[21] The four values correspond to areas about 2.5 to 4 miles south of the pilot area, with values of 12.6, 13.6, 19.8, and 19.8.

TABLE 5-4. CLIMATE FACTOR SCORES FOR PROJECTED INUNDATION IMPACTS

Impact Level	Climate Factor Score		
	0 No Impact	3 High Impact	4 Very High Impact
Location relative to inundation level	Above 1 base flood elevation unit	Within 1 base flood elevation unit above inundation level	Below Inundation level

5.4 CLIMATE FACTOR 3: AIR TEMPERATURE

For air temperature, NOAA focused on the ecological impacts of changes in air temperature. At the anticipated values for Puget Sound (increases of <5.5°C), impacts to non-ecological factors (e.g. volatility, solubility) are expected to be minimal. Many of the threat/resource categories, particularly the facility toxicity and exposure threat categories, are expected to have zero to minimal interaction with air temperature (*i.e.*, an interaction factor of zero).

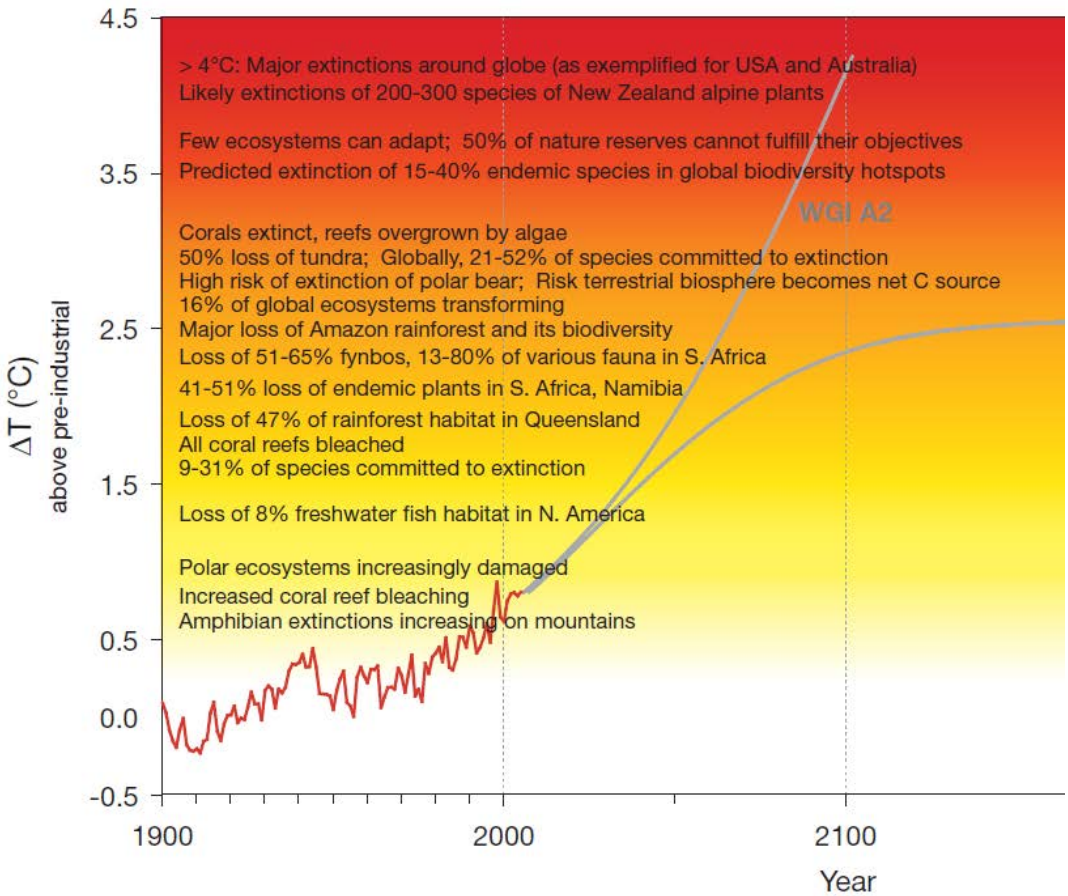
The climate factor scores for air temperature are a synthesis of impacts from IPCC's 2007 report, *Climate Change 2007: Impacts, Adaptation and Vulnerability* (Fischlin et al., 2007). That report describes the expected types of ecological impacts of each degree of increase in temperature, relative to pre-industrial levels (Figure 5-2). For the Puget Sound pilot study, NOAA uses temperature predictions for the twenty-first century from the University of Washington Climate Impacts Group (UW-CIG). UW-CIG provided climate forecasts under the IPCC A1B scenario for the twenty-first century, derived from downscaling the outputs of five climate models. Available data from UW-CIG are 25-year averages of minimum, maximum, average, and standard deviation for air temperature on an annual basis, as well as seasonally (winter and summer). The data are divided into 4412m x 4412 m grid cells. The data from the larger grid cells are divided into the study grid cells (30m x 30m) and scores are assigned to each grid cell based on projected 25-year averages around the target dates (2025, 2050, 2075, 2100). To score the grid cells, the change in degrees Celsius between the target date and the baseline (average of 1979-1999, used by UW-CIG) is calculated.

The resulting climate factor scores (which primarily affect ecological-type factors) are presented in Table 5-5, with the original IPCC synthesis presented in Figure 5-2. The effects of temperature increase are based largely on the suitability of the ecosystem for its current inhabitants. Extensive extinctions and extirpations are anticipated as a result of even fairly small changes in temperature. While other species may migrate into these areas over time, it still indicates extreme vulnerability to stressors. Change is evaluated between the baseline and each of the future time periods.

TABLE 5-5. CLIMATE FACTOR SCORES FOR PROJECTED TEMPERATURE INCREASES

Impact Level	Climate Factor Score				
	0 No Impact	1 Low Impact	2 Medium Impact	3 High Impact	4 Very High Impact
Projected Temperature Increase	0-0.5 °C	0.5-1.5 °C	1.5-2.5 °C	2.5-3.5 °C	>3.5 °C

FIGURE 5-2. ECOSYSTEM IMPACTS AS A FUNCTION OF CHANGE IN TEMPERATURE



Source: Compendium of projected risks due to critical climate change impacts on ecosystems for different levels of global mean annual temperature rise, relative to pre-industrial climate. Figure 4.4 and data from Table 4.1 from the IPCC report, Climate Change 2007: Impacts, Adaptation and Vulnerability (Fischlin et al., 2007).

5.5 DEGREE OF INTERACTION BETWEEN CATEGORY SCORES AND CLIMATE CHANGE FACTORS

5.5.1 FACILITY LIKELIHOOD OF RELEASE INTERACTION WITH CLIMATE FACTORS

The likelihood of release threat category is expected to be very sensitive to changes in structural habitat and to inundation (Table 5-6). Both of these climate change factors could substantially change the likelihood of re-suspension or release of contaminants from soil or sediment, and could put facility structures at risk. Increased temperature is unlikely to have a significant effect on the likelihood of release at the predicted levels of change. Toxicity is essentially unchanged by climate factors. Potential minor differences in volatility may occur that are likely within the range already seen in seasonal and interannual variation.

TABLE 5-6. CLIMATE INTERACTION MATRIX FOR FACILITIES

	HABITAT CHANGE	INUNDATION	TEMPERATURE INCREASE
Likelihood of Release	Very High	Very High	Low

5.5.2 ECOSYSTEM/SPECIES IMPORTANCE INTERACTION WITH CLIMATE FACTORS

Ecosystems and species are very sensitive to changes in habitat, given that the structural habitat defines the ecosystem and the species it can support. Direct effects of climate change include structural habitat change and loss, and subsequent impacts on species utilization and distribution. Indirect impacts include ecosystem impairment from newly released or available contaminants and oil and sediment remobilization from nearby facilities identified as potential sources of contaminants. These predicted impacts can also affect completed and planned restoration projects and influence the viability of future projects. The ecosystem/species importance category represents the value placed on a species; accordingly, NOAA is more concerned about impacts of climate change on the resources that are most important. The highest priority for the vulnerability index is areas with important resource and a high likelihood of climate impact.

Sensitivity of dry land to inundation is high, but less significant, since the majority of the targeted ecosystems and species are in open water/intertidal/wetland areas (Table 5-7). Increases in air temperature are expected to have very high interactions with both vegetation and fauna, as noted in IPCC's 2007 report (Fischlin et al., 2007). Within CAPRI, the appropriate relationship table is used to calculate the output for each climate factor.

TABLE 5-7. CLIMATE INTERACTION MATRIX FOR ECOSYSTEM/SPECIES IMPORTANCE

	HABITAT CHANGE	INUNDATION	TEMPERATURE INCREASE
Ecosystem/Species importance	Very High	High	Very High

5.5.3 HUMAN USE IMPORTANCE INTERACTION WITH CLIMATE FACTORS

Human uses would be expected to be impacted by climate change factors to varying degrees. . The three climate factors are each assigned an interaction with the "Human Use Importance" score as indicated in Table 5-8 below.

TABLE 5-8. INTERACTION OF HUMAN USE IMPORTANCE SCORES WITH CLIMATE CHANGE FACTORS

	HABITAT CHANGE	INUNDATION	TEMPERATURE INCREASE
Human Use importance	High	High	Low

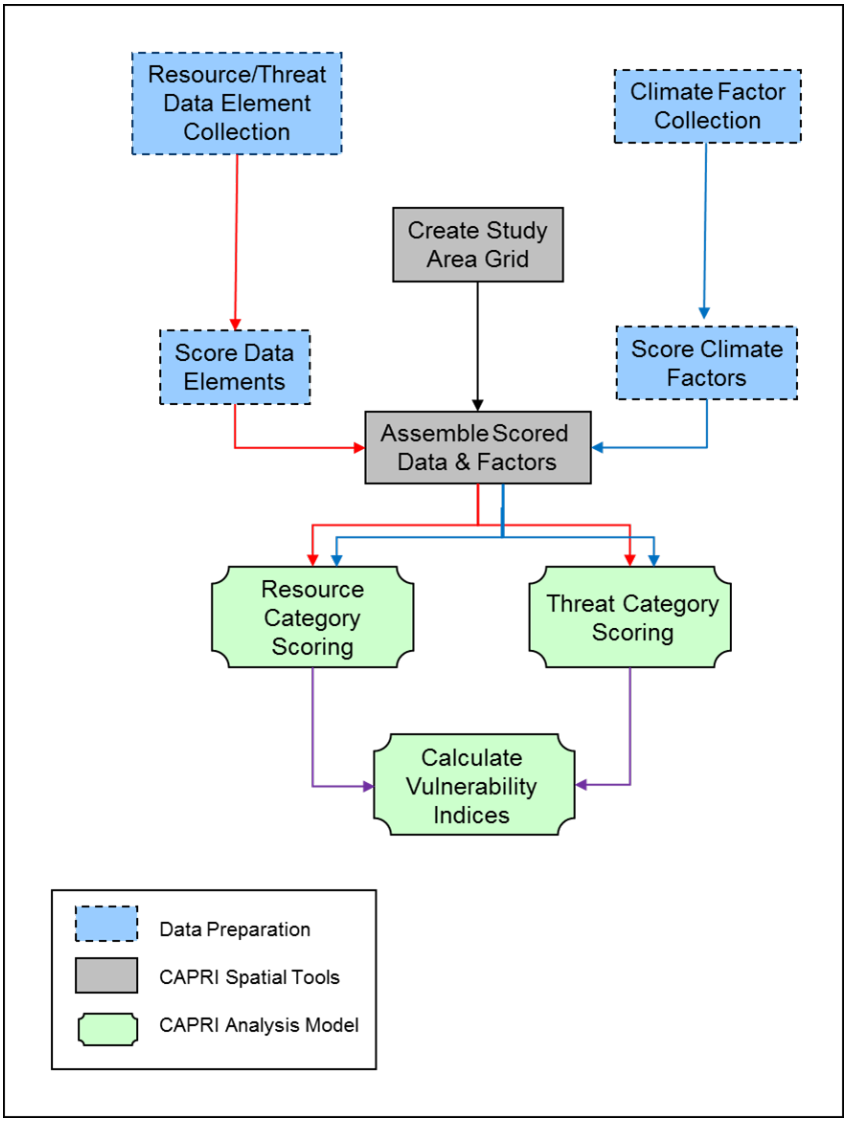
Habitat change may significantly impact human uses if it leads to changes in the distribution and/or quantity of species targeted by recreational and commercial fishers. Inundation is expected to have a significant impact on human uses included in the dataset (in the absence of adaptation measures) given the possibility for flooding of recreational and commercial fishing locations (e.g., piers and boat ramps) as well as recreational and commercial access locations. On the other hand, temperature increases are proposed to have a less significant impact on human use activities. While there is expected to be some impact on recreational uses and commercial fishing uses based on potential changes in the distribution of species, other commercial uses, such as ports and ferry terminals and boat ramps, would be expected to have low to no interaction with climate factors.

6. TECHNICAL APPROACH OF THE CAPRI TOOL

6.1 INTRODUCTION

This section describes the technical approach to preparing the data and conducting the analysis. The CAPRI analysis is divided into multiple steps to assemble and prepare the data, perform the calculations, and then view results. Figure 6-1 illustrates the elements of the CAPRI process.

FIGURE 6-1. PROCESS FLOW OF CAPRI ANALYSIS



Below is additional detail on each aspect of the CAPRI tool.

6.2 DATA PREPARATION: COMPILATION AND SCORING

6.2.1 COMPILING DATA FOR RESOURCE/THREAT CATEGORIES

As described in each of the resource and threat category sections, NOAA compiles various data elements to document specific aspects of the resources and threats to each study area. In order to prepare the data elements, NOAA's team re-projects all spatial datasets to UTM Zone 10N. To the extent that multiple datasets with similar geometries (e.g., line, points) are relevant to a specific region, the framework takes the union of the data. For example, a single data file compiled from both federal and state sources documents the location of facilities of interest. This process is repeated for each of the threat categories. Information on the data sources and methods are summarized in metadata as well as method summaries, which are incorporated directly into ERMA (the online mapping application displaying the CAPRI data and results).

6.2.2 SCORING THE DATA ELEMENTS

Next, the analysis tool scores each individual data element (*e.g.*, species present). The scores of each data element are from one or more of the key attributes contained in the data (*e.g.*, score assigned to each threatened and endangered species present). This process can vary between the resource/threat categories as well as from area to area (as a result of potential differences in the attribute fields and data values).

For the Ecosystem/Species data elements, the scoring process is conducted directly within GIS due to the straightforward translation of species presence data to a score. NOAA's team manually creates a new field within the GIS datasets to store the score and then, through selection and attribute updates, populates the data with the appropriate scores.

For the Facility and Human Use categories, scoring requires more extensive analysis involving multiple data attributes (e.g., counting the number of contaminants at a site) or more complex analysis (e.g., normalizing catch data to determine relative importance). As a result, to score these elements, NOAA's team creates separate Access databases that implement the multi-step processes.[22] In each database, the team creates queries and Visual Basic for Applications (VBA) code for processing the attributes and determining the score. The resulting values are stored in a separate table that is then joined back to the original GIS datasets.

For a given grid cell, the CAPRI analysis uses the maximum score for a given category. In cases where multiple data sets represent a single element, the team scores each. The analysis tool (described below) summarizes the data to determine the maximum score for each data element in order to determine the overall resource/threat category score.

[22] Although the MS Access databases document the methods employed and expedite the scoring process, new study areas and/or source data will likely necessitate modifying the scoring queries and/or manual scoring certain data elements.

6.2.3 COMPILING DATA FOR CLIMATE FACTORS

Similar to the process of compiling the resource/threat category data, NOAA also collects data specific to climate impacts. Section 5 provides detailed characterization of climate factors. Unlike the resource/threat category data elements, however, the climate impacts receive scores directly within the CAPRI Analysis tool.

6.3 CAPRI SPATIAL TOOLS: CREATING THE STUDY AREA DATABASE

6.3.1 GENERATING THE STUDY AREA GRID

For each new study area, the framework implementer (generally NOAA) must process the data via a series of tools (in ArcToolbox). These tools assist in the following steps:

- First, NOAA generates a new geodatabase for storing the data specific to a particular study area (e.g., Snohomish, Duwamish). This step is necessary to ensure that the database structure is consistent for application in the later steps.
- Next, the user generates a vector-based grid covering the selected study area. For fine-scale analyses, NOAA would likely use 30-meter grid cells (e.g., sub-county level geographic area). For larger study areas (e.g., the full Puget Sound), cell sizes of 100 meters or more will likely be necessary to process the data in a reasonable time frame.
- To focus and improve the processing speed of the analysis, NOAA might also limit the study area to the regions of expected impact. For example, for the Puget Sound pilot effort, the study area is limited to cells less than 100 feet in elevation and/or within 100 feet of streams.

Figure 6-2 shows the toolset used for creating the study area grid.

6.3.2 ASSEMBLING DATA ON THE GRID

Next, the user organizes all of the underlying data elements from the resource/threat categories and climate factors onto the newly created common grid. Multiple tools are available to the users to integrate the data. Figure 6-3 shows the data integration tool.

FIGURE 6-2. CAPRI SPATIAL ANALYSIS TOOL BOX

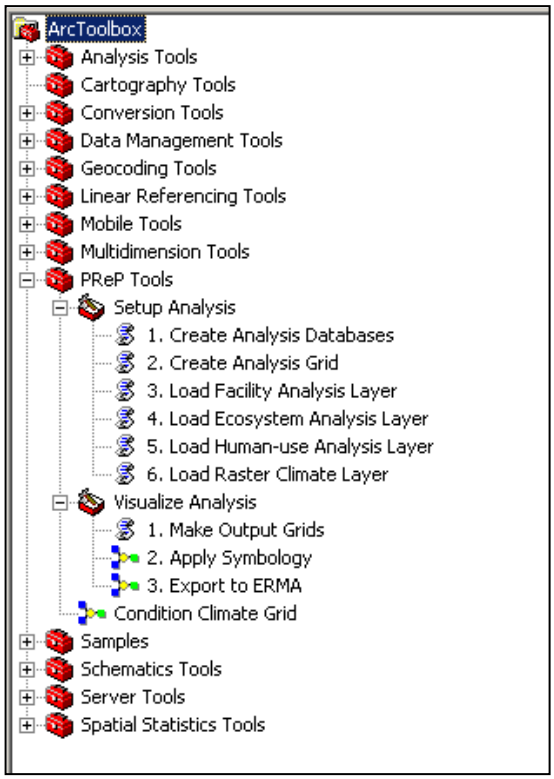
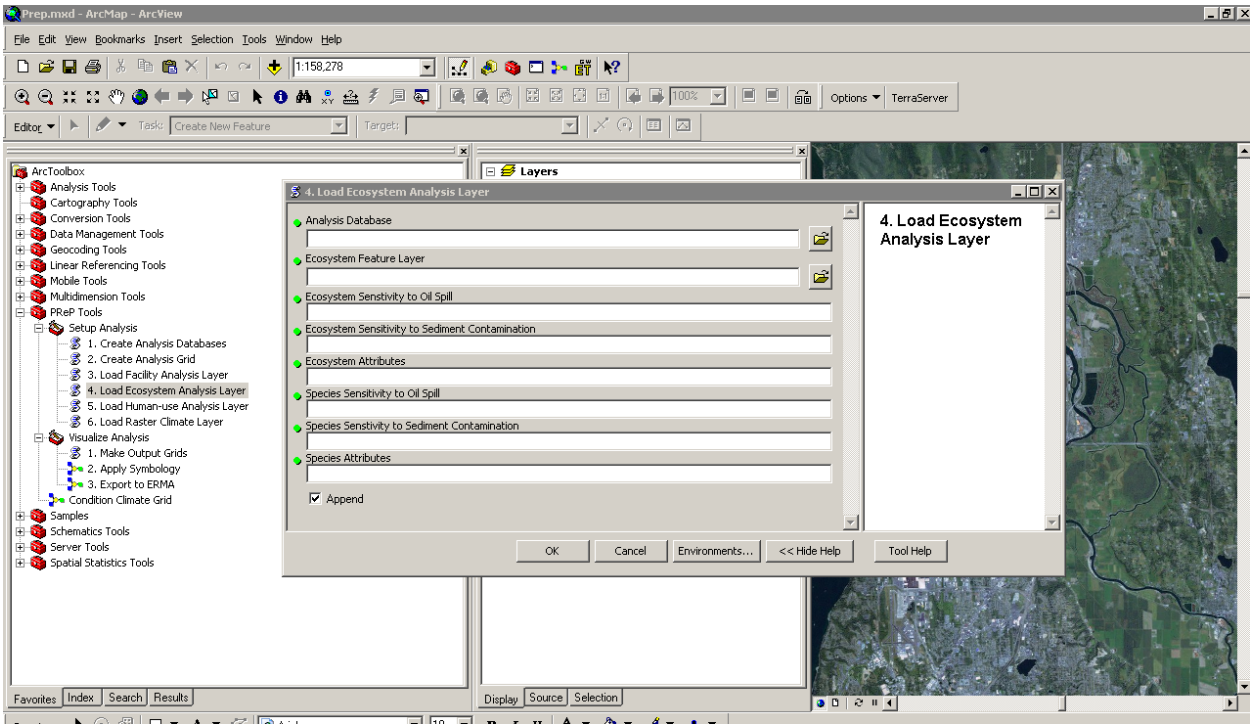


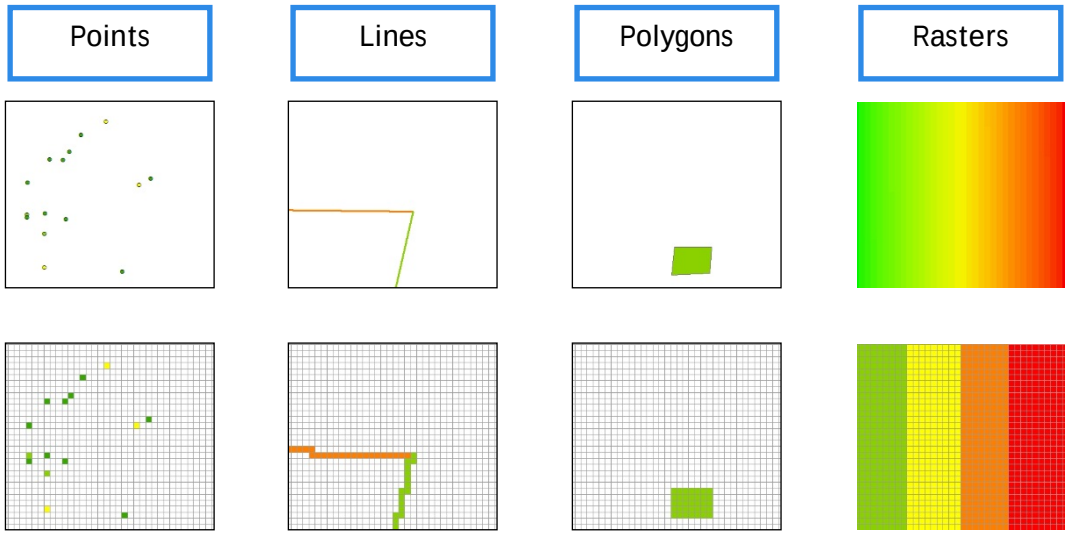
FIGURE 6-3. ILLUSTRATION OF CAPRI SPATIAL DATA LOADING TOOL



Through these tools users can integrate all data types (raster as well as point, line, and polygon-based vector data sets) onto the common grid. Figure 6-4 illustrates this process for combining the data. Within the geodatabase, separate tables store the data element scores specific to each of the categories (e.g., Ecosystem/Species: Contaminant Sensitivity). Each table maintains information on the unique grid cell identifiers along with the score(s) of applicable data elements.

In the case of the facility-related threat categories (i.e., degree of toxicity and likelihood of exposure), there is also a buffering analysis to extend the risk associated with a particular facility to an area proximate to the impact of a potential release. To accomplish this, each grid cell in the study area is re-assigned the maximum facility-related score contained in any cell within a half-mile.

FIGURE 6-4. ILLUSTRATION OF TRANSLATING VECTOR AND RASTER DATA TO THE COMMON GRID



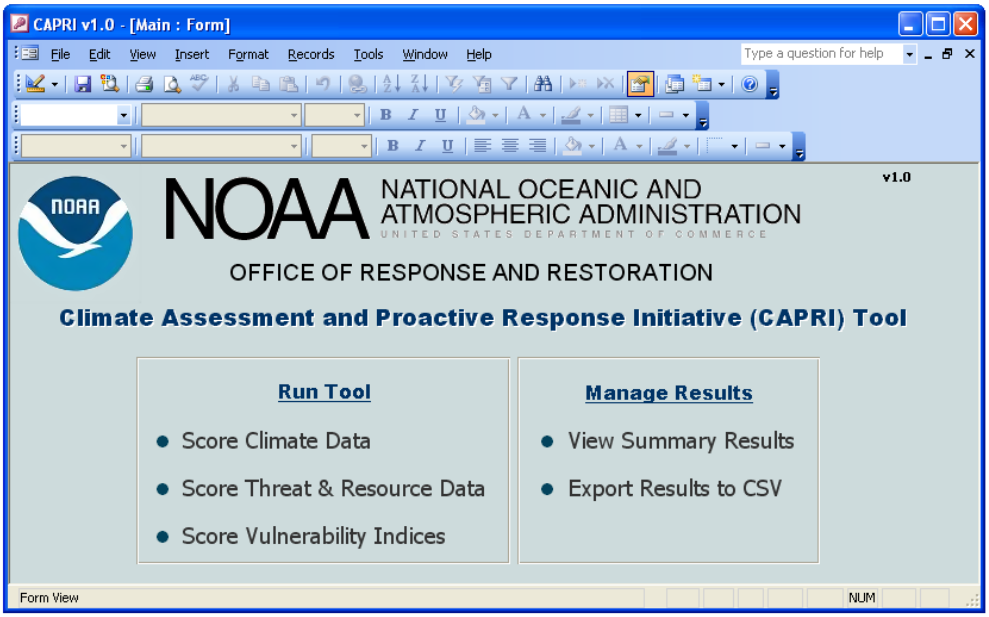
6.4 CAPRI ANALYSIS TOOL: SCORING RESOURCE/THREAT CATEGORIES AND CALCULATING VULNERABILITY INDICES

After compiling the data in the study area geodatabase, the data is then ready for analysis. The CAPRI Analysis Tool is an MS Access database that stores the scored data elements, contains simple user-interface controls to implement the analysis, and uses VBA programming to conduct the analysis. Figure 6-5 illustrates the main menu from the Puget Sound pilot. Using the links on the left-hand column, users can calculate the category scores, category vulnerability indices, and combined vulnerability index for each grid cell within the study area.[23] Depending upon the size of the study area and complexity of the

[23] The current design of CAPRI requires a separate copy of the tool for each study area. The user must manually link the tool to the study area-specific tables contained within the geodatabase. Future versions, however, may include an option that automatically links to the appropriate geodatabase.

calculation method used, it may take several minutes to complete the calculations for each grid cell.

FIGURE 6-5. CAPRI MAIN PAGE



6.5 SCORING THE CLIMATE FACTORS

For each climate factor (e.g., habitat change), the score depends upon the climate scenario being analyzed (e.g., IPCC A1B Scenario) and the year of analysis (e.g., 2025, 2050, 2075, and 2100). CAPRI iterates through each of the factors, scenarios, and years and applies the logic described in Section 2 to generate a table of the corresponding scores. For the Puget Sound pilot, this process resulted in 24 separate sets of climate factor scores (3 climate factors * 2 scenarios * 4 analysis years). Additional climate scenarios or climate factors can be added to the model. The new scenario details would be added directly within the table infrastructure in Access, with the CAPRI GIS tools used to make the predictions for each factor. The user/developer would then re-run the Climate Score tool.

6.6 SCORING RESOURCE/THREAT CATEGORIES

The next step in the analysis is to determine the category scores. For each grid cell in the study area, the analysis identifies the corresponding data element scores within a particular resource/threat category (e.g., Degree of Toxicity Score) and determines the maximum score that exists. The logic applied to conduct the scoring of facilities, ecosystem/species, and human uses is described in Sections 2 through 4. The metadata available through ERMA provides additional details on the methods used to create each of the resource/threat scores.

6.7 CALCULATING VULNERABILITY INDICES

The next step is to apply the category scores, climate factors, and relationship tables to obtain the category indices. Through VBA programming code, the CAPRI tool processes each grid cell within the study area to identify individual category scores and create the vulnerability index. Section 1 of the report describes the logic used in combining the data to determine the corresponding scores and indices.

Based on the respective category indices, the tool uses relationship tables to determine the corresponding resource/threat indices. To combine the climate factor scores with the ecosystem/species and human use importance as well as the facility likelihood of release scores, the analysis uses relationship tables specific to the relative level of interaction anticipated between a climate factor and the resource or threat.

The corresponding relationship tables for the levels of interaction are included below. Information on the level of interaction anticipated for each resource and threat category is provided in Section 5. The different levels of interaction allow for variations in output with the same underlying scores. For example, a facility likelihood of contaminant release score of 3 and a climate factor score of 2 would result in a 3 with a high or very high interaction (e.g., for a climate factor like inundation of the facility), but in a 1 if there is only a low or minimal interaction between likelihood of release and that factor (e.g. for a factor like air temperature).

After determining the category indices, CAPRI uses the same relationship from the very high interaction table (above) to integrate data from the indices to create the resource-threat indices as well as the final combined vulnerability index.

6.8 VISUALIZING AND EXPORTING RESULTS

The right-hand links on the CAPRI main menu (Figure 6-5) allow users to view key statistics for the study area. Figure 6-7 shows the results summary page. Users can opt to view summary results for the combined vulnerability index as well as the resource/threat category scores and vulnerability indices. The CAPRI summary results page reports the average and standard deviation of scores (excluding zero and null results within the site) as well as the distribution of values. By changing the climate scenario and analysis year, the user can explore differences in the potential impacts under different climate regimes.

As shown in Figure 6-8, the CAPRI tool provides a utility for exporting the analysis results into csv files. The csv files identify the grid cell identifiers and corresponding scores/index values for the user's selection. The resulting file can be used to import the data into other software such as ArcGIS.

FIGURE 6-6. RELATIONSHIP TABLES OF OUTPUT SCORES FOR POSSIBLE COMBINATIONS OF CLIMATE CHANGE FACTOR SCORES AND THREAT/RESOURCE SCORES

VERY HIGH INTERACTION

		Climate Change Factor Score				
		0	1	2	3	4
Threat/ Resource Score	0	0	0	0	0	0
	1	0	1	1	2	2
	2	0	1	2	3	3
	3	0	2	3	4	4
	4	0	2	3	4	4

HIGH INTERACTION

		Climate Change Factor Score				
		0	1	2	3	4
Threat/ Resource Score	0	0	0	0	0	0
	1	0	1	1	2	2
	2	0	1	2	3	3
	3	0	2	3	3	3
	4	0	2	3	3	3

LOW INTERACTION

		Climate Change Factor Score				
		0	1	2	3	4
Threat/ Resource Score	0	0	0	0	0	0
	1	0	1	1	1	1
	2	0	1	1	1	1
	3	0	1	1	1	1
	4	0	1	1	1	1

Given the extent of geographic variations within the site, users will likely benefit from visualizing the results within GIS. The resulting data can be viewed directly within a GIS infrastructure (such as ArcGIS) by linking the resulting tabular data to the original study grid. To foster a more detailed understanding of the reason behind the results, the resulting data will be made available in ERMA, an online mapping tool. ERMA allows users to view specific areas and then drill-down through the individual category vulnerability indices and category scores to identify the detailed drivers of the overall combined vulnerability index.

FIGURE 6-7. CAPRI SUMMARY RESULTS PAGE

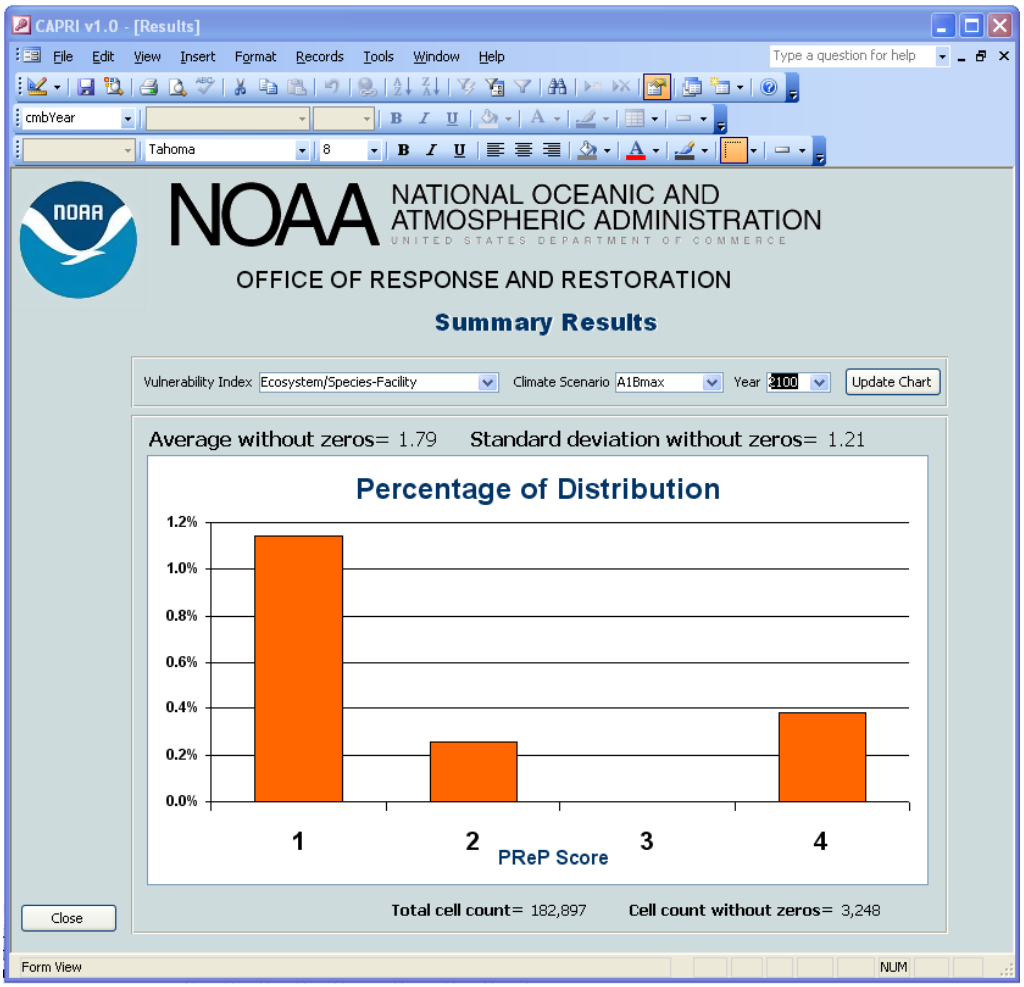
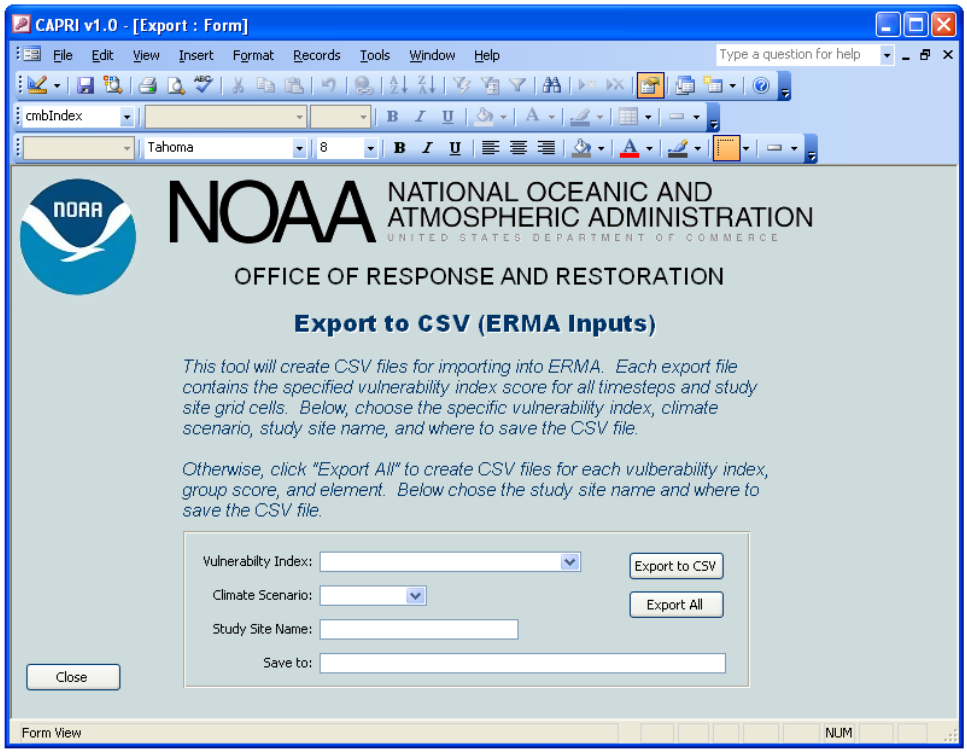


FIGURE 6-8. CAPRI DATA EXPORT PAGE



7. RESULTS

7.1 INTRODUCTION

This section summarizes the initial results obtained through the Puget Sound pilot. Tabular and map-based results illustrate the combined vulnerability index (CVI) values for each of the four study areas – Commencement Bay, Duwamish, Nisqually, and Snohomish. Next, the resource and threat category indices for a single study area demonstrate how users can drill down from the CVI to the individual data elements in order to determine the drivers of climate vulnerability. After examining the CAPRI results, the paper discusses application of the data and the potential for applying CAPRI results in the context of restoration site planning.

7.2 OVERVIEW OF COMBINED VULNERABILITY INDEX RESULTS

7.2.1 SUMMARY STATISTICS

Table 7-1 provides an overview of the results for the four study areas and for different climate scenarios and years of analysis. Using the 1.5 meter sea level rise climate scenario, one can compare the changes in CVI scores for the four sites over the different analysis years. As expected, the percent of area within a study site that is most vulnerable to the potential release of hazardous waste or oil due to climate change increases as the extent of the climate impacts (e.g., additional land inundation) increases. For example, within the Snohomish study area, the amount of land with higher vulnerability scores is limited to 0.3% in 2025 but increases to 0.5% in 2100, which corresponds to an increase from approximately 110 acres to 203 acres of land. For all study areas, the increase over time in the highest sensitivity scores results from movement of cells from lower vulnerability (scores of 1 or 2) to higher vulnerability, rather than from areas scored as zero initially. Note that the Commencement Bay study site has the largest percentage area scored as vulnerable to the potential release of hazardous waste or oil due to climate change impacts (approximately 7.2 square miles of land under the 1.5 meter / 2100 scenario). The other study sites have a significantly smaller percentage of land scored as vulnerable. Review of data layers within ERMA can demonstrate the drivers: the Commencement Bay results are driven by the large number of industrial facilities found there, in combination with low-lying land and extensive human use resources.

TABLE 7-1. COMBINED VULNERABILITY INDEX RESULTS FOR THE 1.5 METER SCENARIO

STUDY SITE(AREA ANALYZED)*	CVI SCORE	ANALYSIS YEAR			
		2025	2050	2075	2100
Commencement Bay (21.1 miles^2)	Lower (1 & 2)	32.9%	32.5%	32.2%	31.7%
	Higher (3 & 4)	1.4%	1.8%	2.1%	2.6%
Duwamish (21.8 miles^2)	Lower (1 & 2)	8.2%	8.1%	8.0%	7.9%
	Higher (3 & 4)	0.8%	1.0%	1.1%	1.1%
Nisqually (79.4 miles^2)	Lower (1 & 2)	1.5%	1.4%	1.3%	1.3%
	Higher (3 & 4)	0.5%	0.6%	0.7%	0.7%
Snohomish (63.6 miles^2)	Lower (1 & 2)	2.1%	2.0%	1.9%	1.9%
	Higher (3 & 4)	0.3%	0.4%	0.5%	0.5%

Notes:
* Area analyzed for each study area is limited to areas under 100 feet in elevation or within 100 feet of streams.

Table 7-2 provides a comparison between the IPCC A1B scenario and the 1.5 meter sea-level rise scenario, using 2100 as an example analysis year. As expected, the quantity of land considered highly vulnerable is greater under the 1.5 meter scenario, which is the scenario with higher sea-level rise projections. For the Commencement Bay study area, only 1.9% of the land has higher vulnerability under the IPCC A1B scenario versus 2.6% under the 1.5 meter sea-level rise.

TABLE 7-2. COMBINED VULNERABILITY INDEX RESULTS FOR 2100

STUDY SITE (AREA ANALYZED)*	CVI SCORE	SEA LEVEL RISE SCENARIO	
		1.5 METER	A1B
Commencement Bay (21.1 miles^2)	Lower (1 & 2)	31.7%	32.4%
	Higher (3 & 4)	2.6%	1.9%
Duwamish (21.8 miles^2)	Lower (1 & 2)	7.9%	8.1%
	Higher (3 & 4)	1.1%	1.0%
Nisqually (79.4 miles^2)	Lower (1 & 2)	1.3%	1.4%
	Higher (3 & 4)	0.7%	0.6%
Snohomish (63.6 miles^2)	Lower (1 & 2)	1.9%	2.0%
	Higher (3 & 4)	0.5%	0.4%

Notes:
* The area analyzed for each study area is limited to areas under 100 feet in elevation or within 100 feet of streams.

For each study area, the quantity of land that receives a score of zero remains constant throughout each of the climate scenarios and years of analysis. All of these cells scored as zero are the results of having a zero or null value for either threats or resources. Because the climate factor score for temperature is greater than zero across all grid cells and analysis years, cells containing non-zero threat and resource scores will always have a non-zero CVI value.

Given that the resource and facility threat categories are independent of the analysis year (i.e., the framework does not model changes in resource uses over time), the differences (or lack of differences) in vulnerable areas between analysis years are directly attributable to changes in climate threats.

7.2.2 COMPARATIVE MAPS

Figures 7-1 through 7-4 illustrate the CVI results using the 1.5 meter sea-level rise scenario forecasts in 2100 for the four study sites. This represents the scenario and year with the largest proportion of land scored as highly vulnerable (score of 3 or 4). Since the methodology used to develop the CVI is based on vulnerability to facility contamination, maps of CVI scores only show vulnerability (scores of 1, 2, 3, or 4) in areas with regulated facilities. This can be seen across all four study sites, but is most easily recognized at the Nisqually study site (Figure 6-3), which shows CVI scores located around several facilities.

As previously presented in Tables 7-1 and 7-2, the Commencement Bay study area (Figure 7-1) shows considerable vulnerability over a large proportion of the analyzed area resulting from a group of centrally located contaminated facilities, which overlap with areas containing high levels of human use resources. In the Duwamish study site (Figure 7-2), a different pattern emerges, where areas of vulnerability can generally be found following the Duwamish River, which is highly industrialized. The areas further upstream, less affected by historical contamination, currently have more ecological resources and, subsequently, more vulnerability. In addition, several areas of high vulnerability are located along Lake Washington in the northeast corner of the map. The Snohomish study site (Figure 7-4) demonstrates patterns similar to the other study sites, with small areas of vulnerability centered on the lower Snohomish River delta and several contaminated facilities north of the river.

FIGURE 7-1. COMBINED VULNERABILITY INDEX – COMMENCEMENT BAY STUDY AREA (1.5 METER SEA LEVEL RISE SCENARIO / 2100)

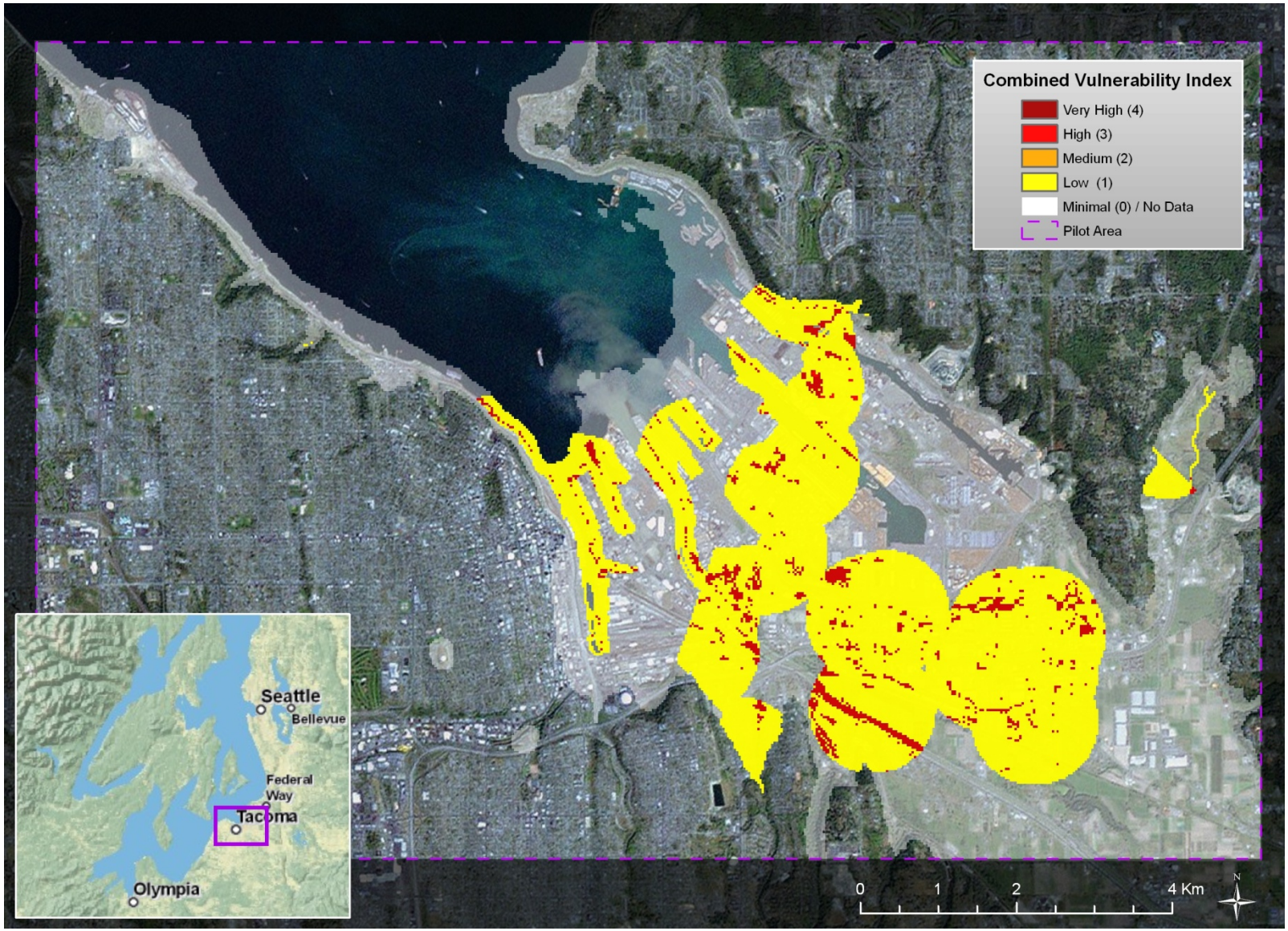


FIGURE 7-2. COMBINED VULNERABILITY INDEX – DUWAMISH STUDY AREA (1.5 METER SEA LEVEL RISE SCENARIO / 2100)

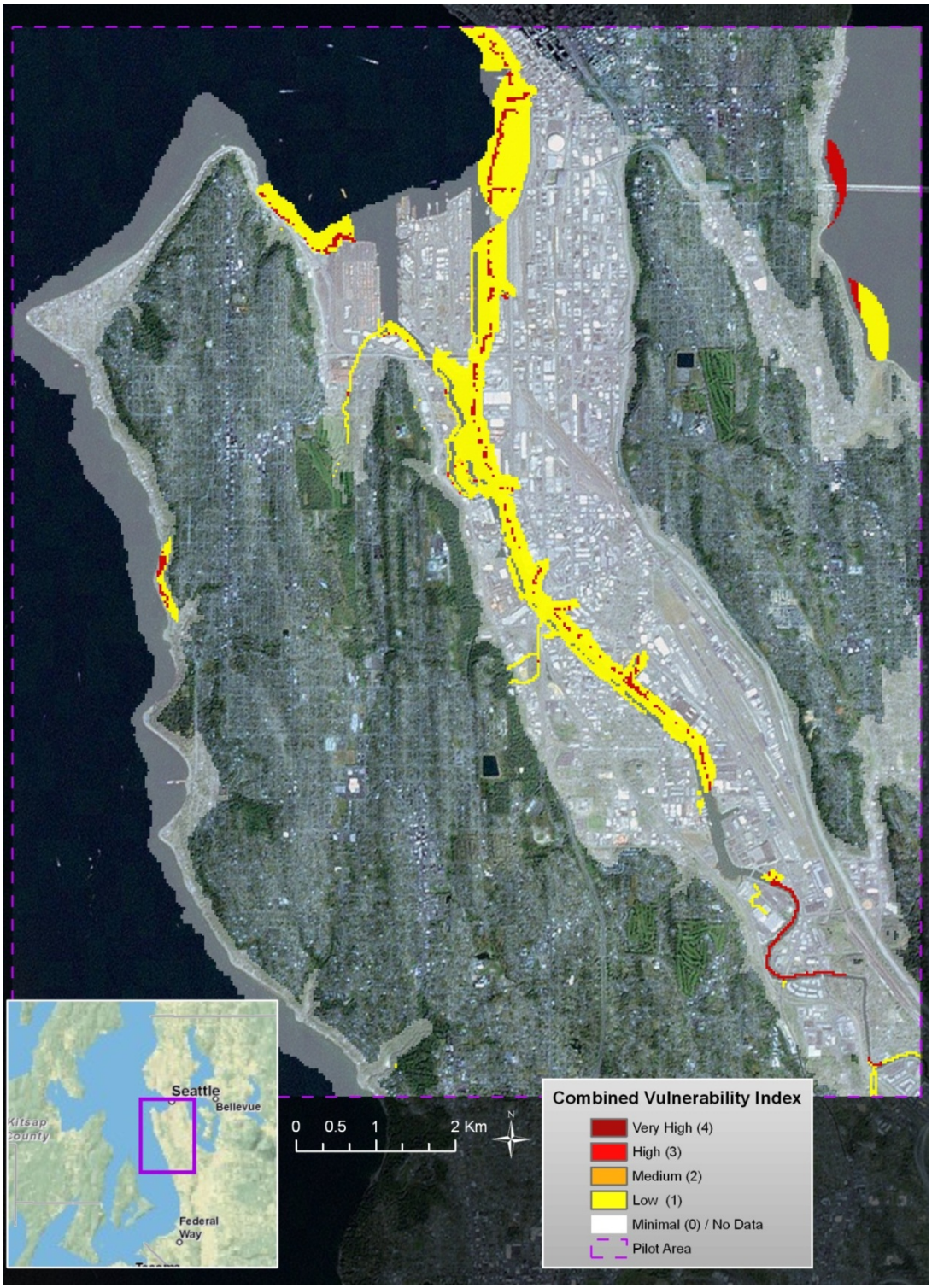


FIGURE 7-3. COMBINED VULNERABILITY INDEX – NISQUALLY STUDY AREA (1.5 METER SEA LEVEL RISE SCENARIO / 2100)

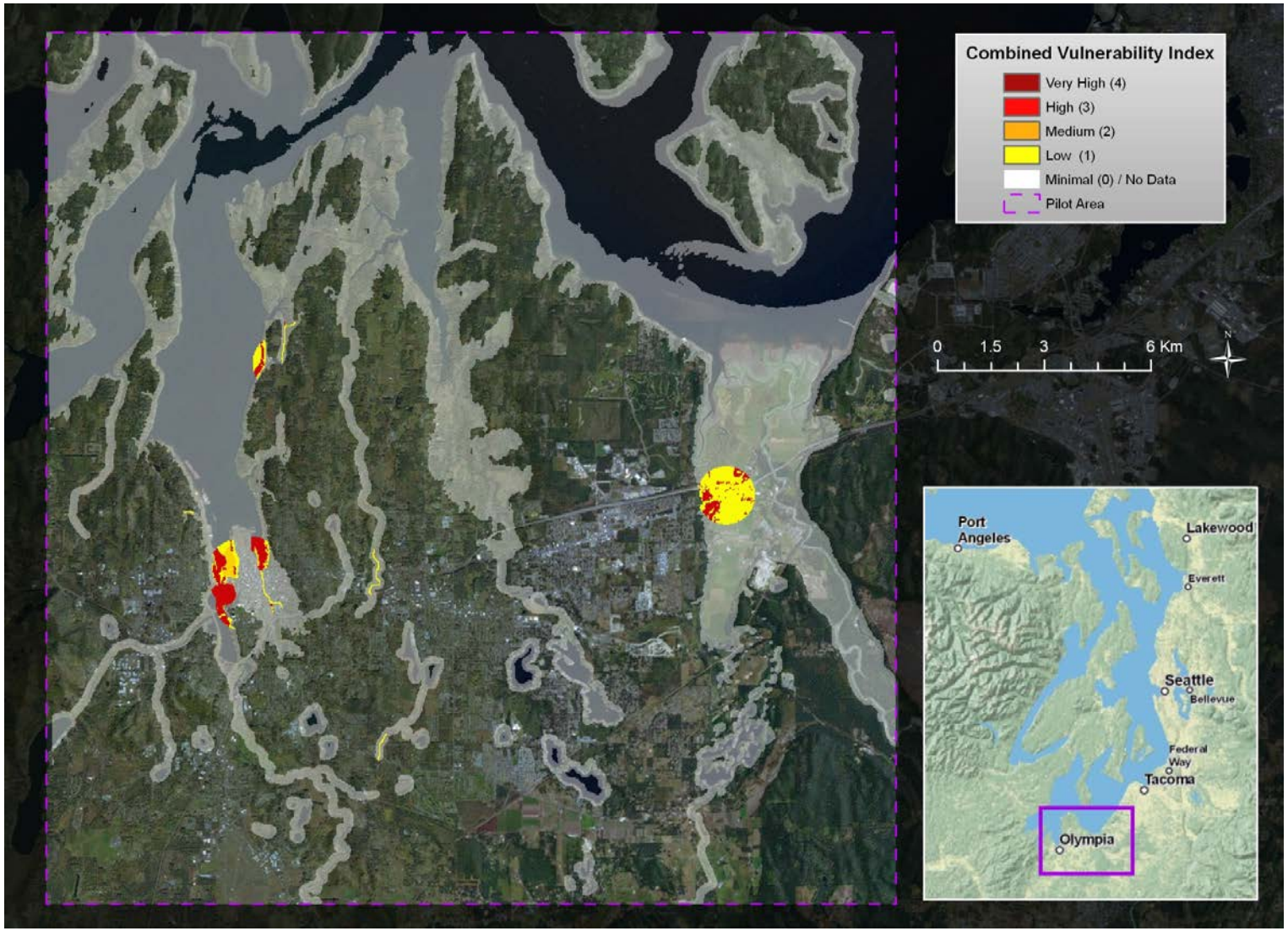
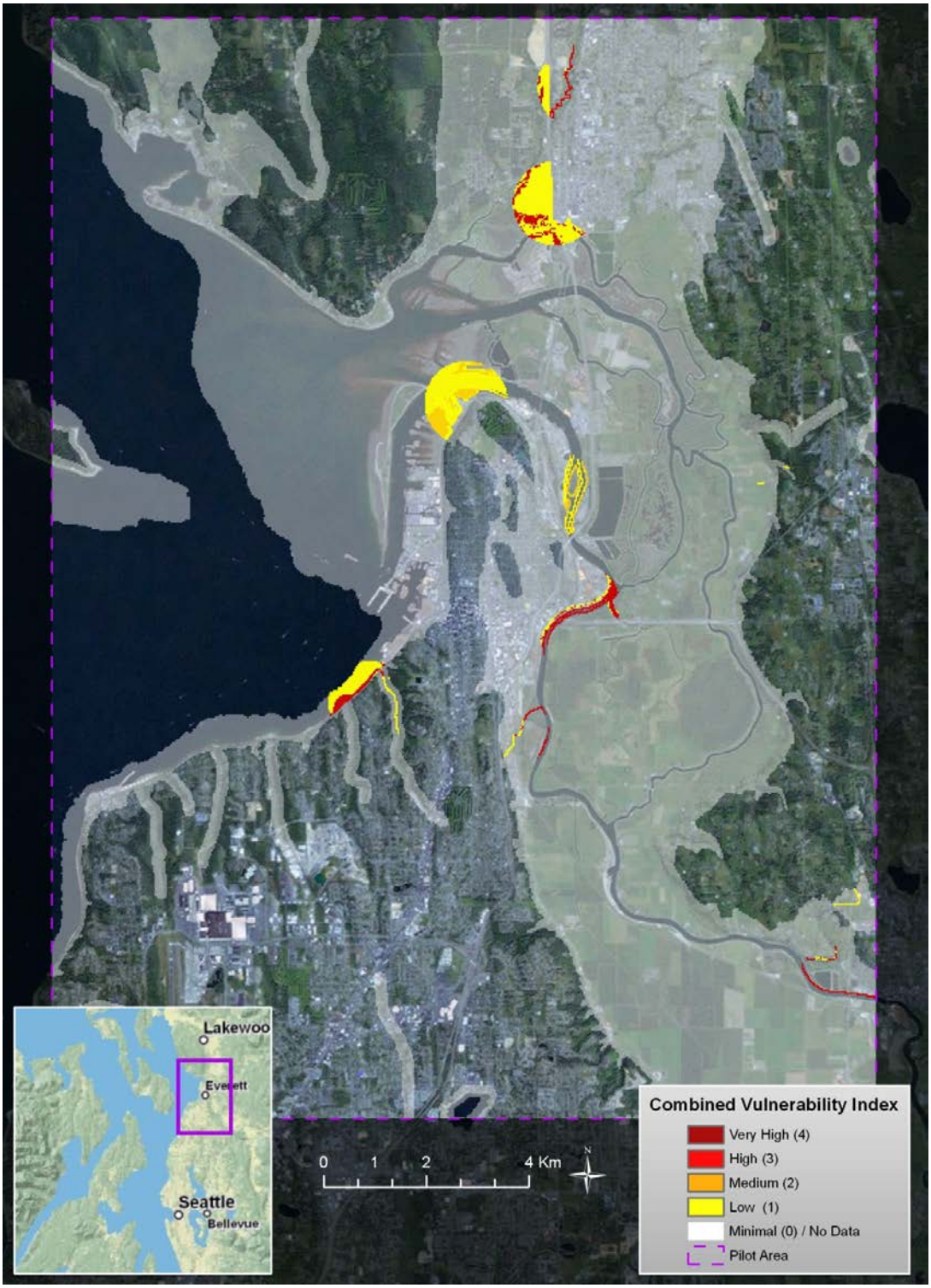


FIGURE 7-4. COMBINED VULNERABILITY INDEX – SNOHOMISH STUDY AREA (1.5 METER SEA LEVEL RISE SCENARIO / 2100)



7.3 EXPLORING THE DETAILED RESULTS

The CAPRI framework is intended to allow users to not only view the combined vulnerability index values, but to also then work back through the analysis structure to identify the drivers of vulnerability for specific areas. This section illustrates the drill-down process through the exploration of the results for the Snohomish study area.

7.3.1 TABULAR RESULTS

Using the analysis of the Snohomish study area as an example, Figure 7-5 provides the distribution of index values for each of the indices. As shown, due to the combination of index values through the CAPRI framework, higher vulnerabilities are reflected in the category indices than in the combined resource/threat indices, which represent the co-occurrence of both important resources and facility threats in the same locations. For example, approximately 36% of the analyzed area has an Ecosystem/Species Index value greater than zero. Only 13% of the analyzed area has a Facility Index value greater than zero. The resources and threats characterized by these index values overlap (and therefore have Ecosystem/Species-Facility Index values) for only 1.8% of the analyzed area. Similarly, the overlap between the Human Use Index and Facility Index values greater than zero are minimal (also generating a total of 1.8% of land with a non-zero Human Use-Facility Index). There is a small degree of overlap in the areas that are sensitive as determined by the Ecosystem/Species-Facility Index and those from the Human Use-Facility Index. As a result, collectively 2.4% of the analyzed area has a Combined Vulnerability Index greater than zero.

7.3.2 COMPARING RESULTS INDICES

Figure 7-6 highlights a small portion of the Snohomish study area to demonstrate the relationships between the six CAPRI results indices; all maps were developed using the 1.5 meter scenario in 2100. This depiction matches the index calculation portions of the CAPRI methods flow diagram found in the introduction (Figure 1-2).

Working from left to right through the data, Figure 7-6 demonstrates how the resource and threat factors contribute to the indices. Specifically, the Resource/Threat Indices reflect the spatial overlap of resources and climate (Ecosystem Species Index and Human Use Index) and facility and climate (Facility Index) vulnerability. For example, the Ecosystem/Species-Facility Index reflects the areas of overlap between the Ecosystem Species Index and the Facility Index, illustrated by the high vulnerability area found at “A.” Similarly, the Human Use-Facility Index reflects the overlap of the Human Use Index and the Facility Index, resulting in the areas of vulnerability found at “B.” This illustration highlights the importance of the Facility Index as a key driver in the development of the latter vulnerability indices.

FIGURE 7-5. VULNERABILITY INDEX DISTRIBUTIONS FOR SNOHOMISH STUDY AREA (1.5 METER SEA LEVEL RISE SCENARIO / 2100)

Category Indices

	No Score	One	Two	Three	Four
Ecosystem/Species VI	64.4%	5.0%	24.0%	0.8%	5.9%
Facility Threat VI	87.2%	11.2%	0.3%	0.3%	1.1%
Human Use VI	65.9%	30.5%	0.0%	3.5%	0.0%

Resource-Threat Indices

	No Score	One	Two	Three	Four
Ecosystem/Species-Facility VI	98.2%	1.1%	0.3%	0.0%	0.4%
Human Use-Facility VI	98.2%	1.6%	0.0%	0.0%	0.2%

Combined Vulnerability Index

No Score	One	Two	Three	Four
97.6%	1.6%	0.3%	0.0%	0.5%

Figure 7-6 further illustrates that the CVI is the combination of the two Resource/Threat Indices. As shown, the areas of vulnerability in the Ecosystem/Species-Facility Index (see "A" in the graphic) appear in the CVI, along with those originating from the Human Use-Facility Index (see "B" in the graphic). In this case, the CVI areas of higher vulnerability found at "A" result from the Ecosystem Species Facility Index, and the areas of lower vulnerability at "B" results from the Human Use Facility Index.

When the CAPRI results are viewed from within the ERMA tool, users can explore the data layers leading to the CVI results. For specific areas with non-zero index values, users will then be able to work backwards to the Resource/Facility Threat Indices (i.e., the Ecosystem/Species-Facility Index and the Human Use-Facility Index) to better understand the driving factors behind the vulnerability. Users will also be able to view the separate Resource (i.e., Ecosystem/Species and Human Use) and Facility Indices and to identify the climate and resource/threat data elements that drive climate vulnerability.

CAPRI's multi-layered approach also provides the flexibility to investigate the aspects of climate vulnerability that are most important to a user. Through the ERMA interface, users will also be able to jump directly to the specific index that matches their area of interest. For example, biologists may opt to explore the Ecosystem/Species Index to view the climate vulnerabilities independent of facilities.

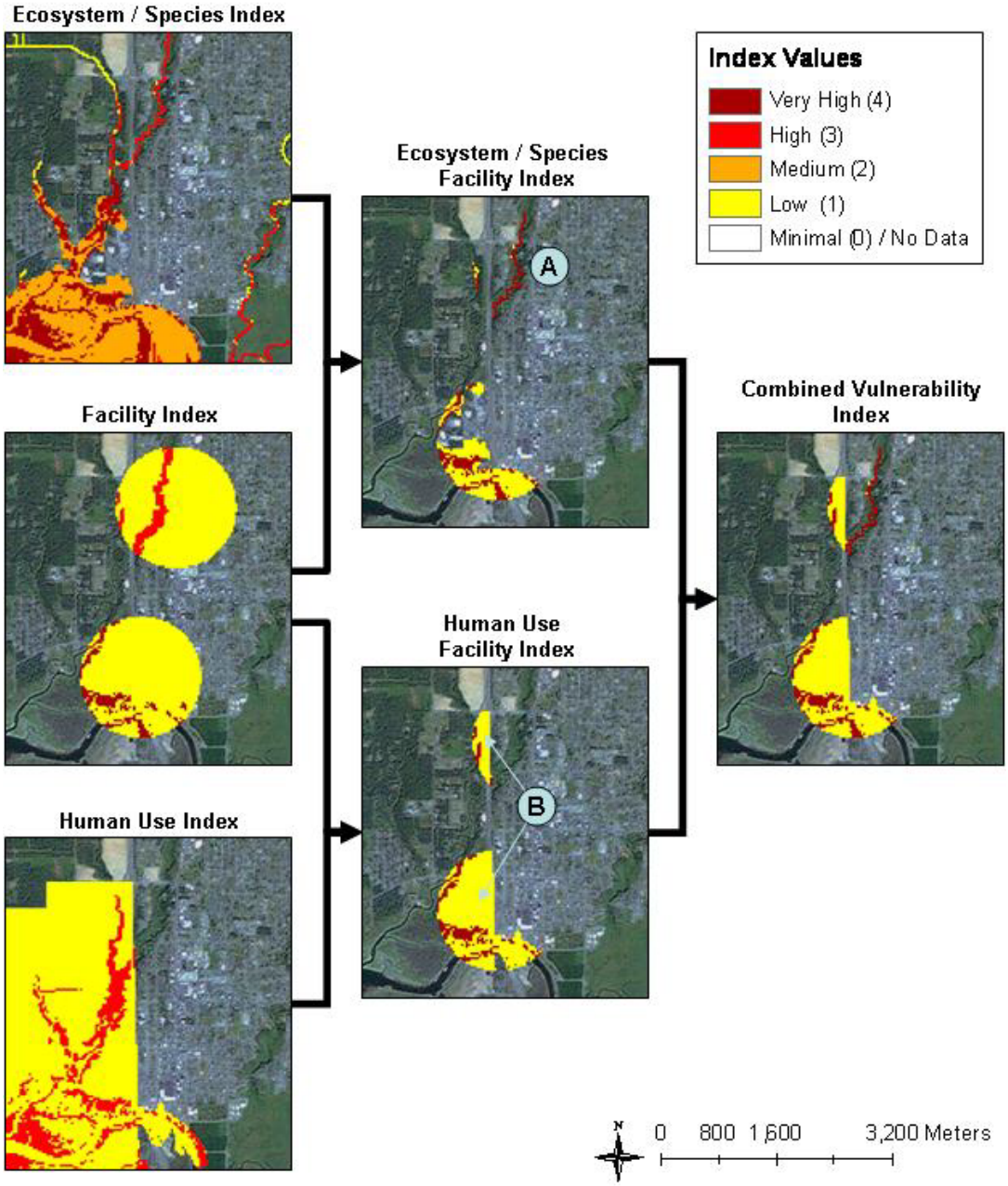
7.4 APPLYING RESULTS FROM CAPRI

The CAPRI framework is intended to provide NOAA and its partners with information needed to plan for and adapt to the potential impacts of climate change. At a first pass, the results illustrate areas most vulnerable to impacts from identified facilities as a result of climate change (Figures 7-1 to 7-4) and provide valuable information on response priorities. Through the drill-down options available in ERMA, NOAA or other users can identify the resources and threats that are driving the vulnerability index for that location. Appropriate adaptation or response options could then be identified and implemented to address or minimize the vulnerabilities.

Moving forward, NOAA can review potential vulnerabilities and then identify solutions for preventing and responding to identified vulnerabilities. These include both direct actions (e.g., the marsh improvement project noted above) and indirect actions that provide general improvement and resilience to the system. Broadly speaking, available actions fall into three categories:

- **Prevention**: Efforts to reduce the likelihood of exposure events (e.g. reducing risks from existing or future facilities);
- **Adaptation**: Ecosystem and/or human use improvement projects which protect current resources, increase resilience, or replace lost resources; and
- **Management**: Prioritization of actions to reflect local priorities, financial constraints, and regulatory process.

FIGURE 7-6. CAPRI RESULTS INDICES FOR THE SNOHOMISH STUDY SITE (1.5 METER SEA LEVEL RISE SCENARIO / 2100)

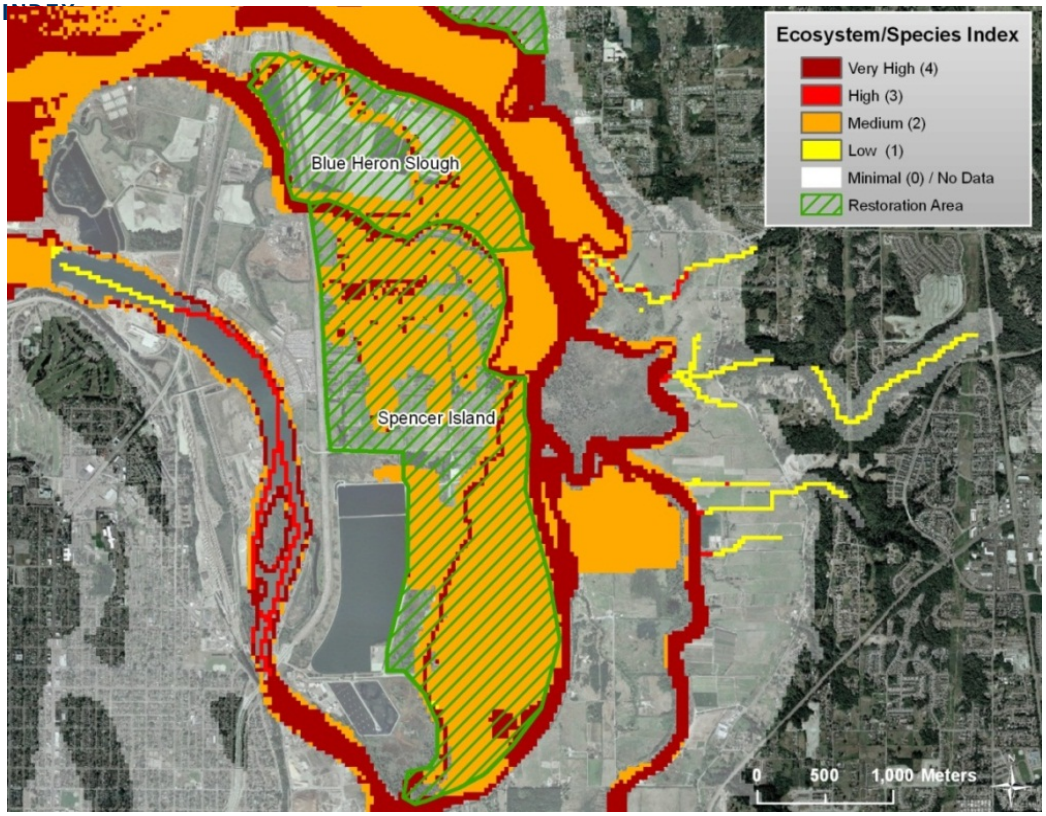


NOAA is already developing and compiling resources for adaptation (*e.g.*, the Coastal Climate Adaptation resources for state, local, and regional officials).[24]

7.4.1 EXAMPLE APPLICATION: CAPRI AND RESTORATION PLANNING

Within the Snohomish study area, NOAA uses ERMA to overlay the footprint of a NOAA restoration site on the CAPRI vulnerability map. In this instance, NOAA looks at the Blue Heron Slough and Spencer Island sites in Snohomish (Figure 7-7). Instead of looking at facility-related vulnerability, the ecosystem/species index can be used to identify areas within the restoration sites that are vulnerable to climate change factors and sensitive to potential contaminant impacts.

FIGURE 7-7. IDENTIFICATION OF RESTORATION SITES AND THE CAPRI ECOSYSTEM/SPECIES INDEX



These restoration sites contain large areas with a medium to high level of predicted climate change impacts. The primary driver, which can be observed by viewing the scored climate change layers for the areas, is change in structural habitat type as a result of sea level rise. Like many coastal restoration projects, the sites of interest are wetland areas and are within the predicted impact area from the SLAMM or inundation model. To prevent these impacts, restoration planners might choose to improve marsh health to

[24] The Coastal Climate Adaptation project is available electronically from the NOAA Coastal Services Center at http://community.csc.noaa.gov/climateadaptation/.

increase accretion, strategically increase elevations to prevent edgeward loss, and implement improvements to shores if erosion is a local problem (e.g. living shorelines approaches). These considerations can also be used in planning future restoration projects, using CAPRI's predictions of ecosystem/species vulnerability to climate change to identify vulnerable sites, either to avoid those locations or to inform decisions on target elevation, desired vegetation, and related characteristics.

7.4.2 OVERVIEW OF OPTIONS

Many groups and agencies are researching climate adaptation and response options. Much of the current adaptation literature is focused on current or planned development and on impacts to infrastructure.[25] In contrast are adaptation programs related to specific species, such as the World Wildlife Federation's adaptation planning for marine turtles, which includes replanting or preserving coastal vegetation, prohibiting or restricting construction within a set distance from the high water mark, and controlling land-based activities to reduce pollution and sedimentation.[26]

Several projects detail adaptation options and vulnerability assessment tools. Relevant to the Puget Sound pilot sites in particular are the State of California Climate Adaptation Strategy[27] and the Washington Climate Change Impacts Assessment[28], both published in 2009. The Washington report in particular includes detailed adaptation options for the Pacific Northwest (see Chapter 11, Table 2 of the Impacts Assessment).

7.4.3 PREVENTION OPTIONS

Prevention options aim to reduce the risks from facilities and related infrastructure. The CAPRI framework currently highlights facilities that are priority sites based on contamination or remediation status, storage or disposal of hazardous waste, landfill status, or transport and handling of oil. To reduce threats from these facilities, one can either reduce potential exposure to these materials or reduce the toxicity of material that might be released.

Prevention options that NOAA or its partners might use at priority facilities identified by CAPRI include the following:

1. **General facilities**

   - Changes to containment systems for on-site disposals – minimization of storage below current and predicted base flood elevations;

---

[25] For example, multiple projects from the United Nations Development Programme (http://www.undp.org/climatechange/adapt/) and the U.S. Agency for International Development (http://www.usaid.gov/our_work/environment/climate/), in particular their publication "Adapting to Coastal Climate Change: A Guidebook for Development Planners".

[26] See the Toolbox for the project: http://www.panda.org/lac/marineturtles/act/.

[27] The California report is available from http://www.climatechange.ca.gov/adaptation/.

[28] The Washington report is available from http://cses.washington.edu/cig/res/ia/waccia.shtml/.

- Reduction in on-site storage of hazardous materials and bulk chemicals – options to synthesize hazardous materials on-site or to develop on-demand delivery systems, substitution of less-hazardous materials;
- Increased awareness of current and predicted base flood elevations – outreach and guidance to protect operations that are within flood zones, particularly for smaller facilities.

2. **Superfund/remediation sites**

- Sediment cleanup, particularly targeting areas that are predicted to have increased storm impacts or flooding (in coordination with U.S. EPA, state officials, etc.)

3. **Underground Infrastructure**[29]

- Pipe/pipeline support, including increased use of response drills and quality assurance/quality control programs to ensure proper maintenance and prompt response to releases;
- Support and awareness of leak/failure issues with underground storage tanks, particularly in areas subject to increased flooding vulnerability (in coordination with U.S. EPA, state officials, etc.);
- Support for local/state programs to identify and repair sewage and water pipe issues to minimize releases of hazardous materials due to flooding; and
- Awareness and investigation of additional transport options for hazardous materials.

[29] Infrastructure delineations are limited in the datasets used in the CAPRI prototype for Puget Sound. This type of dataset will be important for future analysis.

8. NEXT STEPS

8.1 INTRODUCTION

The Puget Sound pilot study reflects the initial development of the CAPRI framework for evaluating contaminant impacts in the coastal zone related to climate change. This framework provides a flexible structure for conducting screening level vulnerability analyses that can be applied to coastal areas across the nation.

While the current CAPRI framework provides valuable information on climate vulnerability, the results are limited by the available data for the location. Through the process of developing the pilot, NOAA has also identified components of the framework that could be refined in future iterations. Below, the discussion of next steps consists of three categories:

1. **Improved Data:** Categories where new data and/or improved data would be particularly beneficial;
2. **Modifications to the Tool:** Potential changes to the CAPRI framework to enhance CAPRI; and
3. **Further Application of CAPRI:** Potential further applications of the CAPRI framework.

8.2 IMPROVED DATA

The underlying data within CAPRI are crucial to the validity and relevancy of the outputs. NOAA anticipates that the spatial resolution and detail of the data will improve over time, and has thus developed the CAPRI framework in a manner that facilitates incorporation of new data and sub-categories for each of the resource, threat and climate change categories. This section contains, for each of the primary data categories, several areas where additional or improved data could be integrated.

8.2.1 ECOSYSTEM/SPECIES DATA NEEDS

- **Upland Areas:** CAPRI currently uses ecosystem data from the nearshore environment. Incorporation and scoring of additional datasets that focus on upland ecosystems, particularly streams and forest systems, would increase the coverage of potentially vulnerable ecosystems. These additions would be particularly valuable in concert with additional climate factors (e.g., streamflow) that are of greater potential impact to some of the further inland areas.

- **Subtidal Areas:** The current data are also minimal in differentiation of subtidal areas, with the exception of areas of kelp and eelgrass. Additional data on subtidal areas would further improve the predictive ability of CAPRI.
- **Sensitivity:** Currently, the framework analyzes sensitivity to oil spills and to sediment contamination. Additional sensitivities (e.g. to groundwater contamination or to surface water contamination) could be evaluated and scored by ecosystem/species type.
- **Land Use:** In concert with the addition of upland ecosystems into the CAPRI framework, the land use categories for upland may also provide valuable information on relative ecological services. In particular, this may distinguish between no/minimal values (e.g., highly developed) and low to moderate values (e.g., agricultural lands, park lands).

8.2.2 HUMAN USE NEEDS

- Contaminant Sensitivity: Unlike the ecosystem/species resource category, the Puget Sound pilot did not incorporate information on the sensitivity of human uses to contamination. If appropriate data are identified in the future, information on the spatial distribution of human use sensitivity would fit directly within the CAPRI framework.

8.2.3 FACILITY DATA NEEDS

- Non-Waste Sites: Many hazardous materials are stored at facilities but not classified as waste. Further investigation into methods for incorporating data collected under programs such as the Toxics Release Inventory could provide additional robustness to the suite of identified facilities.
- Up-to-Date Contaminant Data: For the Puget Sound pilot, NOAA's team was unable to identify a centralized source of regularly updated contaminant data from sites, even those listed under Superfund. Evaluating sites for potential contaminant releases is difficult since much of the available data are from preliminary listings, and may not reflect remediation or restoration activities that have taken place. If available in the future, such data would be important to incorporate to more fully characterize the contamination threats.
- Remediation status: Similarly, data on remediation site status are not readily available, even for Superfund sites, and are frequently only obtainable by reviewing individual site reports. Collating these data would improve the predictive capacity of CAPRI.

8.2.4 CLIMATE FACTOR DATA NEEDS

- Additional Climate Factors: Due to limitations in data availability, the current CAPRI framework only includes three climate factors, one of which is very homogenous throughout the study region (air temperature). Incorporation of additional climate factors (stream flow, water temperature) would broaden the suite of impacts addressed. These additional climate factors may also prove to be

key drivers of vulnerability in areas where inundation (either of wetland or upland) is less of a threat.

- Refined Climate Change Predictions: For Puget Sound, CAPRI uses habitat change projections developed by NWF using SLAMM. These projections could be changed to address specific scenarios, to cover a greater portion of the study area, or to reflect improvements in more recent versions of the model (e.g., enhanced salinity change modeling). Similarly, improved elevation modeling using LiDAR data as well as more complex hydrodynamic models would further improve the projections of land at risk of inundation and future storms.

8.3 MODIFICATIONS TO THE TOOL

Based upon the initial pilot results, NOAA has identified several components of the CAPRI framework that could be modified to further enhance the usability and applicability of the tool. These improvements would serve to give the users greater control over the analysis methods and exploration of the results in order to fully explore specific areas of concern. Such enhancements could then be applied to further study of the Puget Sound or in the analysis of other locations.

8.3.1 INTERACTIONS BETWEEN DATA ELEMENTS

A potential refinement to the CAPRI structure would be to more closely link specific categories of threats and resource sensitivities to obtain scores and index values specific to a type of contamination. For example, data specific to a resource's sensitivity to oil contamination are grouped with sensitivity to sediment contamination in order to develop an overall sensitivity score. Similarly, data on the likelihood of sediment contamination and oil contamination from facilities are combined into an overall threat score. These grouped scores are then combined to assess the overlap between threats and sensitivities.

Future versions of CAPRI could parse the sources of various sensitivities and threats to allow for a more detailed combination of the data. The corresponding tool could then be used to generate separate score and index values specific to either sediment contamination or oil contamination, in addition to the combined sensitivity.

8.3.2 INTERACTIONS WITHIN BUFFER ZONES

When facilities or resources overlap in a buffer zone, the maximum values are used. However, this could be allowed to calculate increased values (either threat or resources) if an interaction is expected to occur that would be higher than the maximum value of each individual item. For example, if there are two overlapping facilities, each with three contaminant groups, they both get a score of 2, but a grid cell that is within the buffer of both of those might potentially have six different contaminant groups and therefore should get a score of 3 rather than 2.

8.3.3 ENHANCED USER CONTROLS

The framework could be modified to allow greater user control in the process of determining vulnerabilities. As a screening tool, the framework uses the maximum value of vulnerability at each step. As additional datasets are added to the framework and

individuals seek to explore the data in different ways, modifications might include the following options:

- Allowing users to limit the CAPRI analysis (i.e., generation of the indices) to a subset of the elements. For example, a user interested specifically in impacts on commercial uses might opt to limit the human use scoring and index development to use only those data elements specific to the commercial uses.
- Allowing users to further adjust the relationship table used to control the process in which resources and threats are integrated into a single indicator (i.e., index) of vulnerability.

These modifications would require a change in the structure of the model, primarily related to database structure and the timing of calculations (i.e., what is done "on the fly" with user interaction versus prior to the user interface).

8.3.4 ZERO VERSUS NULL VALUES

Currently, the framework treats a grid cell with a score of zero the same as a grid cell with no score (null values). While this has limited downward impact on vulnerability (due to the use of maximum scores when combining resource/threat factors within the framework), the lack of differentiation fails to highlight the uncertainty associated with some null values.

For some datasets (e.g. nest presence or ferry terminals), it is appropriate that unscored locations (null values) are treated as zeros, since the framework assumes that the evaluated data set is complete. However, in other cases the null value represents a lack of information, rather than the absence of a threat/resource. For example, the structural habitat projections from SLAMM cover limited areas of Puget Sound. Grid cells that are outside the projection zone are not scored for that climate factor, resulting in a zero impact for the factor.

NOAA recommends further investigation into how best to differentiate these null values resulting from lack of information from true zero values. A potential avenue would be to allow two different settings for datasets when they are added to the analysis: (1) indicate that cells with no value should be treated as zero (*e.g.*, grid cells with no nest presence); or (2) indicate that cells with no value should be treated as null (*e.g.*., grid cells outside the SLAMM projection area). Null cells could then be treated differently than zeros, and perhaps have an uncertainty associated with them, for the purpose of not dropping out of the analysis. Given that there may also be regional differences in datasets over what should be zero versus null, based on how local datasets are constructed, giving local users/developers a choice of designations would improve the flexibility of the model.

8.4 FACILITATING USE OF RESULTS FROM CAPRI

Much of the interpretation and analysis of the results from the CAPRI framework is expected to be conducted within ERMA, which allows users to drill down through results to assess specific drivers as well as overall climate vulnerabilities. Section 7 of this paper describes how the results can be applied to assist in climate impact prevention and

adaptation. Meanwhile, NOAA recognizes several additional ways in which the CAPRI results could be analyzed to further assist decision makers. Below are several areas to expand or facilitate the use of CAPRI results, both independently and within ERMA.

- **Link with supplementary adaptation resources:** NOAA recommends the inclusion within ERMA of links to NOAA climate adaptation resources currently under development (e.g., the Coastal Climate Adaptation program), as well as to programs relevant to study areas (e.g. Washington Climate Change Impacts Assessment for Puget Sound assessments). These connections could be made within ERMA or through write-ups created for each study area**.** In particular, this could be a flowchart that leads the ERMA user through potential adaptation options that correspond to vulnerability drivers they identify through ERMA.
- **Ground-truth vulnerability assessments:** The initial results from CAPRI for Puget Sound should be ground-truthed by stakeholders with expertise or familiarity with certain locations and facilities and the potential impacts of climate change. Users (NOAA or others) could initially identify several areas that have high combined vulnerability indices, as well as several areas that have either high threat or resource indices, but low vulnerability indices. The user could then identify stakeholders with expertise in these areas (*e.g.*, academic experts, federal representatives, Puget Sound organizations, county planners, facility owners, local environmental groups). These groups can review potential vulnerabilities indicated by the CAPRI analysis, discuss their own experiences and local knowledge, and indicate whether critical data or decision points have been overlooked.

8.4.1 EXPANDED ANALYSIS OF CAPRI RESULTS WITHIN ERMA

- **Tools to facilitate identification of vulnerability drivers:** While the drivers of specific vulnerabilities can be identified by drilling down in ERMA, this is a potentially cumbersome task that would need to be repeated multiple times. The creation of a reporting tool in ERMA that shows the drivers for particular areas would facilitate evaluation and potential responses to vulnerabilities. For example, a spatial tool could be developed that allows the user to characterize a particular area (i.e., grid cell) and identify the relative score of each data element and then link to information from the raw data source.
- **Creation of area-specific rankings:** To facilitate use of CAPRI's results in climate impact prevention and adaptation, ERMA could be further expanded to characterize the vulnerability of specific areas such as existing or potential restoration sites. For example, users could be allowed to select specific areas and generate a report that identifies the proportion of land characterized into each of the CAPRI index scores. When examining multiple sites, such a tool could be used to identify which sites have the higher relative vulnerability and warrant further analysis.

- **Habitat and use restoration prioritization:** As part of ongoing ecological protection and natural resource damage responses, NOAA and other federal, state, and local groups undertake habitat restoration efforts. Such efforts could be aided through more detailed summaries of the habitats and/or uses most vulnerable in particular regions and sub-regions evaluated as part of CAPRI. For example, such a report might catalog the total area by habitat type (e.g., NWI wetland category) that is classified as very high vulnerability by the CVI.

REFERENCES

Batker, D., P. Swedeen, R. Costanza, I. de la Torre, R. Boumans, K. Bagstad. 2008. *The Economic Value of Nature's Services in the Puget Sound Basin.* Earth Economics, Seattle, Washington.

Craft C., J. Clough, J. Ehman, H. Guo, S. Joye, M. Machmuller, R. Park, and S. Pennings. 2009. Effects of Accelerated Sea Level Rise on Delivery of Ecosystem Services Provided by Tidal Marshes: A Simulation of the Georgia (USA) Coast. *Frontiers in Ecology and the Environment.* 7 (2) pp. 73-78.

Cullon, D. L., S. J. Jeffries and P. S. Ross. 2005. Persistent Organic Pollutants in the Diet of Harbor Seals (*Phoca Vitulina*) Inhabiting Puget Sound, Washington (USA), and the Strait of Georgia, British Columbia (Canada): A Food Basket Approach. *Environmental Toxicology and Chemistry* 24(10): 2562-2572.

Fischlin, A., G.F. Midgley, J.T. Price, R. Leemans, B. Gopal, C. Turley, M.D.A. Rounsevell, O.P. Dube, J. Tarazona, A.A. Velichko. 2007: Ecosystems, their properties, goods, and services. *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, 211-272.

Glick, P., J. Clough, B. Nunley. 2007. Sea-level Rise and Coastal Habitats in the Pacific Northwest: An Analysis for Puget Sound, Southwestern Washington, and Northwestern Oregon. National Wildlife Federation, Reston, VA.

Global Climate Change Impacts in the United States, Thomas R. Karl, Jerry M. Melillo, and Thomas C. Peterson,(eds.). Cambridge University Press, 2009.

IPCC, 2000. *Special Report on Emissions Scenarios*. Cambridge University Press, Cambridge. United Kingdom and New York, NY.

IPCC, 2001. *Climate Change 2001: Synthesis Report. A Contribution of Working Groups I, II, and III to the Third Assessment Report of the Intergovernmental Panel on Climate Change* [Watson, R.T. and the Core Writing Team (eds.)]. Cambridge University Press, Cambridge, United Kingdom, and New York, NY, USA, 398 pp.

IPCC, 2007. *Climate Change 2007: Mitigation of Climate Change*. Fourth Assessment report, Intergovernmental Panel on Climate Change, Geneva, Switzerland.

Lance, M. M. and C. W. Thompson. 2005. Overlap in Diets and Foraging of Common Murres (*Uria Aalge*) and Rhinoceros Auklets (*Cerorhinca Monocerata)* after the Breeding Season (Chevauchement Du Régime Alimentaire Et De La Quête Alimentaire Chez Uria Aalge Et Cerorhinca Monocerata Après La Saison De Reproduction). The Auk: 887-901.

Mote, P., A. Petersen, Reeder, H. Shipman, L. Binder, 2008. *Sea Level Rise in the Coastal Waters of Washington State.* State of Washington Department of Ecology Climate Impact Group.

NOAA. 2002. Environmental Sensitivity Index Guidelines. Version 3.0. NOAA Technical Memorandum NOS OR&R 11, Seattle, Washington. 192 pp.

Park, R.A., T.V. Armentano, and C.L. Cloonan. 1986. Predicting the Effects of Sea Level Rise on Coastal Wetlands. In *Effects of Changes in Stratospheric Ozone and Global Climate, Vol. 4: Sea Level Rise*, edited by J.G. Titus, 129-152. Washington, D.C.: U.S. Environmental Protection Agency.

Rahmstorf, S. 2007. "A Semi-Empirical Approach to Projecting Future Sea-Level Rise" *Science* 315:368-370.

Rignot, E. and P. Kanagaratnam. 2006. "Changes in the Velocity Structure of the Greenland Ice Sheet."*Science* 311 (5763): 986-90.

Millennium Ecosystem Assessment. 2003. Section 2: Ecosystems and Their Service. In: Ecosystems and Human Well-being, A Framework for Assessment. Island Press, Washington, DC. (http://www.millenniumassessment.org/documents/document.300.aspx.pdf)

USEPA. 1991. Guidance for performing preliminary assessments under CERCLA. US Environmental Protection Agency, Washington, DC. Report No EPA/540/G-91/013.

USEPA. 1998. Guidelines for Ecological Risk Assessment. U.S. Environmental Protection Agency, Risk Assessment Forum, Washington, DC, EPA/630/R095/002F.

WDFW. 2008. Priority habitats and species list. Olympia, Washington. 174 pp.