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Oil Spill Risk Assessment – Relative Impact Indices by Oil Type and Location

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Abstract

An oil spill risk assessment model was developed for the US state of Washington, where risk was calculated as the product of spill probability and impact (consequence) indices. Spill probability was analyzed by source type, oil type, spill volume, season, and geographic zone based on historical data. Probability distributions were developed for actual spill volumes and probabilistic-based potential spill volumes for both current and future risk assessments. The development of the methodologies to evaluate probability and total risk are described in detail in a companion paper in these proceedings. This paper describes the development of the impact indices incorporated in the total risk scores.

The potential impacts of spills of different volumes, oil types, timing (seasonality) and locations in geographic zones of Washington were assessed based on the Washington Compensation Schedule (WCS) qualitative rating system, with some modifications based on expert opinion. Potential impacts per volume spilled were rated on a numerical scale from low to high, considering oil toxicity, persistence, and the vulnerability of the state's marine and aquatic resources at particular locations and times of year. For the estuarine and marine waters of the state, the WCS ratings were calculated by geographical sub-regions of varying sensitivity and for each oil type, habitat type, resource type and season. To obtain a sub-region-level score, WCS ratings were calculated in each cell of a gridded habitat map of state waters and averaged over each of the 12 geographic zones covering those waters. For inland waters, a rating system was developed using recent land use data, hydrologic maps, locations and heights of fish barriers, fish run health ratings, and stream water quality data. The inland ratings were calculated for each oil type and by each of 62 watersheds in the state, and averaged by five geographic zones.

The impact risk was highest for the heavy fuels, followed by crude oil; lower for light oils and gasoline, which are similar for a given zone; and lowest for jet fuel and non-petroleum oils. This trend is related to the higher persistence and mechanical injury scores (measuring propensity to coat and foul organisms) of the heavier oils, which therefore have more impact on birds, mammals, habitats, and recreation then the non-persistent oils. The seasonal variation of the impact risk scores was relatively small, because seasonal highs for some resources are balanced by different seasonal patterns for other resources; however, the scores are higher in spring and summer than in fall or winter. This trend is in agreement with spill impact observations and modeling, in general.

1 Introduction

French McCay et al. (2008) performed a review and analysis for the Joint Legislative Audit and Review Committee (JLARC) identifying the qualitative and relative risk of oil spills to the navigable waters and inland areas of Washington State. The purpose of the study was to inform policy regarding resource allocation for oil spill prevention, preparedness, and response activities. Oil spill risk is defined as the likelihood (i.e., probability) of spills of various types occurring multiplied by the consequences (impacts) of those incidents. In other words,

Spill risk = probability of spill x impacts of spill (1)

Etkin et al. (2009) evaluated expected spill frequencies by volume range, location, oil type, source and cause, as well as the overall risk to the waters of Washington State. This paper describes impact-related (consequence) factors contributing to risk.

To form the perspective of the study, we reviewed previous reports, oil spill evaluations (NRC 1985, 2002; Kittle et al., 1987; Levine, 1987; Lindstedt-Siva et al., 1987; Mancini et al., 1989), impact modeling studies in Washington (King and Sanger, 1979; Speich et al., 1991; Ford et al., 1991; French McCay et al., 2005a,b, 2006) and elsewhere (French McCay 2003, 2004; French McCay et al., 2003, 2004, 2005c,d), and available data that are relevant to Washington waters (Briggs et al., 1989; French et al., 1996; Thompson, 1999; Nysewander et al., 2001). Based on this review and analysis, the major risk consequence factors that emerged as important for the categorization of relative risk across sectors of the Washington maritime and related economies were spill volume, location, timing, toxicity, persistence, and expected frequency of spills by sector. Studies and modeling of the impacts of oil spills have shown the following, which are reflected in the impact risk model developed herein:

- More persistent and viscous oils (i.e. heavy fuels) cause more impact to birds, mammals and shorelines than do lighter oils.
- Spills of light oils (e.g., diesel) and crude oil cause higher impacts in the water column (on fish, shellfish and plankton) than equal volume spills of heavy fuels or gasoline, because heavy fuels are not easily entrained into the water column (requiring high turbulence to do so), and gasoline is much more volatile and so results in lower water column toxicity than the light fuels and crude oils.
- Impacts vary considerably and primarily by the sensitivity of the environment oiled and the density of vulnerable organisms in those locations oiled.
- Impacts vary by season of the year because the densities of vulnerable organisms vary by season. Seasonal patterns of organisms vary considerably, such that overall impact risk varies less as a composite for all resources combined than for individual organism groups.

While we considered utilizing similar risk assessment modeling studies to those performed previously in Washington (French McCay et al., 2005a,b, 2006), we decided that such modeling would need to be prohibitively detailed in nature in order to cover spills over the range of volumes and oil types in all marine, estuarine and inland waters of the state. In addition, what was needed was an index of relative consequences, and quantification of impacts was not necessary for the risk analysis. Thus, we evaluated and used the Washington Compensation Schedule (WAC 173-183, "Pre-assessment Screening and Oil Spill Compensation Schedule Regulations" hereafter cited as WCS) sensitivity rankings as a measure of impact that were developed by the WA Department of Ecology (ECY). The WCS develops a per-unit-volume relative impact score, considering sensitivity of the locations oiled, relative density and seasonal distributions of sensitive biota, and factors related to oil type (toxicity, persistence). We modified the WCS in order to develop a relative impact model and rating system for use in the risk assessment.

Each spill incident was assigned a per-gallon (the unit of volume used in the WCS) impact score based on its geographic location (and so sensitivity of the resources oiled), oil type, and season (such that seasonal variations in resource densities were incorporated). The impact score was then multiplied by the spill volume (in US gallons) to derive a spill risk score. While the impact score is therefore proportional to spill volume, and so does not reflect the potential lessening of incremental impacts incurred with additional volume spilled at higher spill sizes, it does incorporate the most important factors controlling impact, i.e., the sensitivity and density of the resources in the locations oiled and the oil type, which determines the nature and degree of injury.

The spill risk scores were normalized to a 100-point scale. Spill risk scores were developed for each spill source type within each of the geographic zones, each of several aggregated geographic zones, and for all waters of the state. An additional analysis of seasonal risk was also conducted, although risk was not sensitive to this factor, since the resources that are most impacted vary by season such that the seasonal changes of the various resource impacts balance out to some degree. The development of the absolute and relative spill risk scores, as well as the results, are described in Etkin et al. (2009).

The potential impacts of spills of different volumes, oil types, timing (seasonality) and locations in the different geographic zones were assessed based on the WCS qualitative rating system, with some modifications based on expert opinion. Potential impacts were rated on a numerical scale from low to high, considering oil toxicity, persistence, and the vulnerability of the state's marine and aquatic resources at particular locations and times of year. Each of the impact categories (e.g., shorelines, biota, socioeconomic, etc.) were assigned a relative impact rating based on the modified WCS model. For the estuarine and marine waters of the state, the WCS ratings were developed for each oil type and season; averaged by geographical sub-regions of varying sensitivity, as defined in WAC 173-183; and then averaged over each of the 12 geographic zones covering those waters. For inland freshwaters, a rating system was developed based on the approach in WAC 173-183, using recent land use data, hydrologic maps, locations and heights of fish barriers, fish run health ratings, and stream water quality data. The inland ratings were developed for each oil type and by each of 62 watersheds in the state, and averaged by geographic zone.

2. Model Development

2.1 Definitions

The following definitions clarify terms to be used.

- **Acute Toxicity:** the degree to which oil is capable of causing adverse effects on fish, invertebrates and wildlife after short-term exposure (hours to days).

- **Location type:** spill location with regard to general location category – marine waters, estuarine waters, inland freshwater bodies and waterways (lakes, rivers, streams), and land (for spills in which oil also enters water).
- **Mechanical Injury:** injury caused by coating, fowling or clogging of organisms and their appendages and apertures, such that movements and behaviors are mechanically inhibited.
- **Oil type:** general chemical category of oils, including crude oil, heavy oil (including heavy fuel oil, intermediate fuel oil, No. 6 fuel oil, No. 5 fuel oil, asphalt, wax), light oils (e.g., diesel, mineral oil, motor oil, low-sulfur marine gas oil, lubricating oil, hydraulic oil, No. 2 fuel, home heating oil, bilge slops, waste oils, “chlorinated oil”), gasoline, jet fuel, and non-petroleum oils (organic oils, biodiesel, animal fat, vegetable oil, volatile organic distillate).
- **Seasons:** "Season" or "seasons" means winter, spring, summer, and/or fall, where winter occurs during the months December through February, spring occurs during the months March through May, summer occurs during the months June through August, and fall occurs during the months September through November.
- **Zone:** one of the geographical locations of the state developed during this study. Marine zones are divided into sub-regions (smaller geographic areas than the zones based on distribution of environmental resources and water body separations) according to the WCS and the inland zones are divided into the 62 watersheds known as Water Resource Inventory Areas (WRIAs) of the State.

2.2 Geographical Zones

The geographic zones used for analysis in this study were based on geography, circulation of currents, climate (inland waters) and the Washington Compensation Schedule (WCS) sub-regions (smaller geographic areas than the zones, which are based on distribution of environmental resources and water body separations) in estuarine and marine areas. The results in estuarine and marine waters are organized by the geographical zones as shown in Table 1 and Figure 1.

Table 1. Geographic zones in estuarine and marine waters.

Code	Estuarine and Marine Zone
1	Washington Outer Coast (Pacific Ocean, not including bays)
2	Grays Harbor
3	Willapa Bay
4	Strait of Juan de Fuca
5	Inner Straits
6	Rosario Strait and vicinity
7	Whidbey Basin
8	Northern Puget Sound
9	Central Puget Sound
10	South Puget Sound
11	Hood Canal
12	Western Columbia River (downstream of Bonneville Dam)

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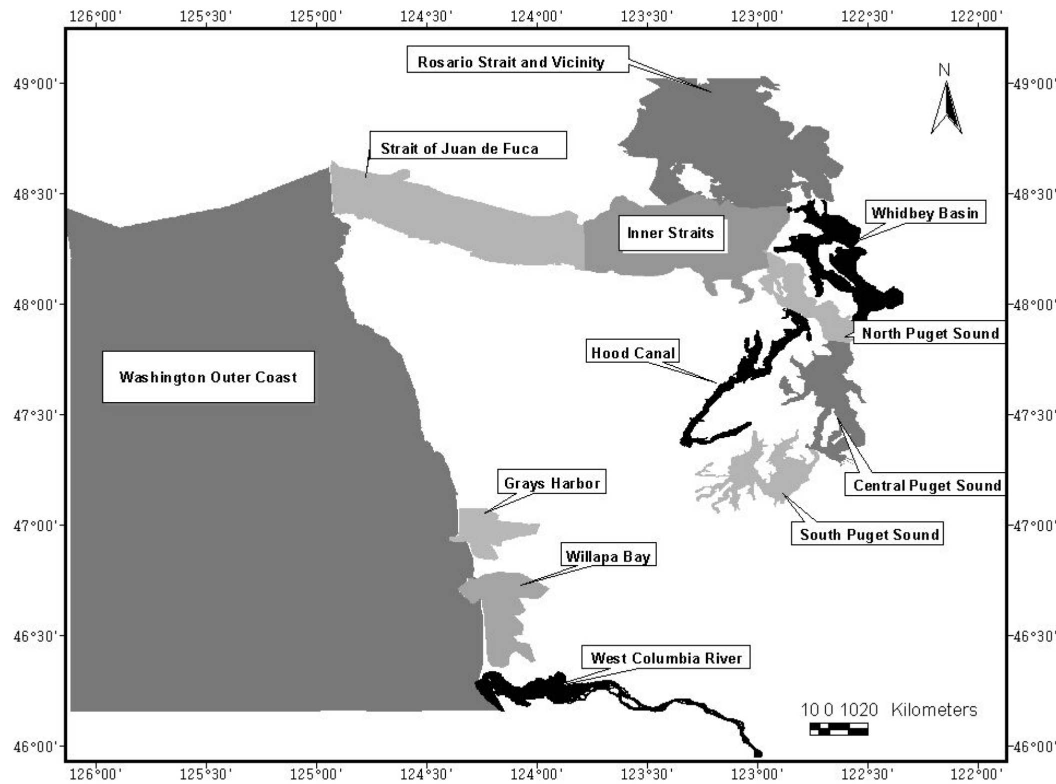

Figure 1. Estuarine and marine geographic zones.

The maritime (estuarine and marine) zones cover the Pacific Ocean coast of Washington State, and connecting estuaries from to the border with Oregon to the border with Canada. The Washington Outer Coast consists of the shorelines along the Pacific Ocean, and this zone connects to four estuaries: Western Columbia River (estuarine portion of the Columbia River); Willapa Bay; Grays Harbor; and the Strait of Juan de Fuca. The Columbia River changes from estuarine to inland freshwater river (discussed below) at the Bonneville Dam, so these areas further inland are not considered maritime. The Strait of Juan de Fuca continues into Inner Straits with the border along a line from Discovery Island light south to New Dungeness light (~123.60^{o}W). The Inner Straits zone then continues north to the border in Rosario Strait and Vicinity, and southeast into Puget Sound, all areas. Puget Sound is a semi-enclosed glacial fjord that we have divided into five sub-regions: North Puget Sound; Whidbey Basin; Central Puget Sound; South Puget Sound, and Hood Canal. Freshwater from Puget Sound and the Georgia Strait empties into the Pacific Ocean though the Strait of Juan de Fuca at the surface. Salt water entering through the Strait of Juan de Fuca flows underneath the freshwater into the San Juan Islands and into Puget Sound (through the North Puget Sound sub-region at Admiralty Inlet). The main deeper basin in Puget Sound is divided into Northern and Central Puget Sound based on two sub-basins. A shallow sill at the Tacoma Narrows separates Southern Puget Sound from the Main Basin. Hood Canal is a narrow arm of Puget Sound also separated from the main basin by a few shallow sills. Though most of the water enters Puget Sound through Admiralty Inlet, a significant portion tries to exit through Whidbey Basin, leading to the strong tidal currents at Deception Pass. These sills and basins, circulation patterns and the WCS sensitive area designations (which also recognize these oceanographic divisions) were used to develop the zones in Puget Sound.

Table 2 and Figure 2 delineate the inland zones used for the development of risk scores. The spill risk scores were first compiled by watershed, as defined by WA DOE Water Resource Inventory Areas (WRIA) maps delineating 62 WRIAs (smaller outlined areas within the zones of Figure 2), and then averaged to derive the inland zone scores. Increasing amounts of data for the State is organized and analyzed by WRIA. The freshwater portions of Columbia River and Snake River fall within or border a number of WRIAs. Spills included in the Columbia and Snake Rivers zone (14) are those occurring in the river, on the banks, or in areas emptying directly into the main river stem. Tributaries of the WRIAs are included in the corresponding inland zone. Details of the mapping of WRIAs into zones are available in French et al. (2008).

Table 2. Geographic zones in inland (freshwater) bodies of Washington State.

Code	Inland Zone
13	Lake Union and Lake Washington (including the Ship Canal)
14	Eastern Columbia and Snake Rivers (upstream of Bonneville Dam)
15	Olympic Peninsula
16	West of Cascades (west of topographic divide)
17	East of Cascades (east of topographic divide)

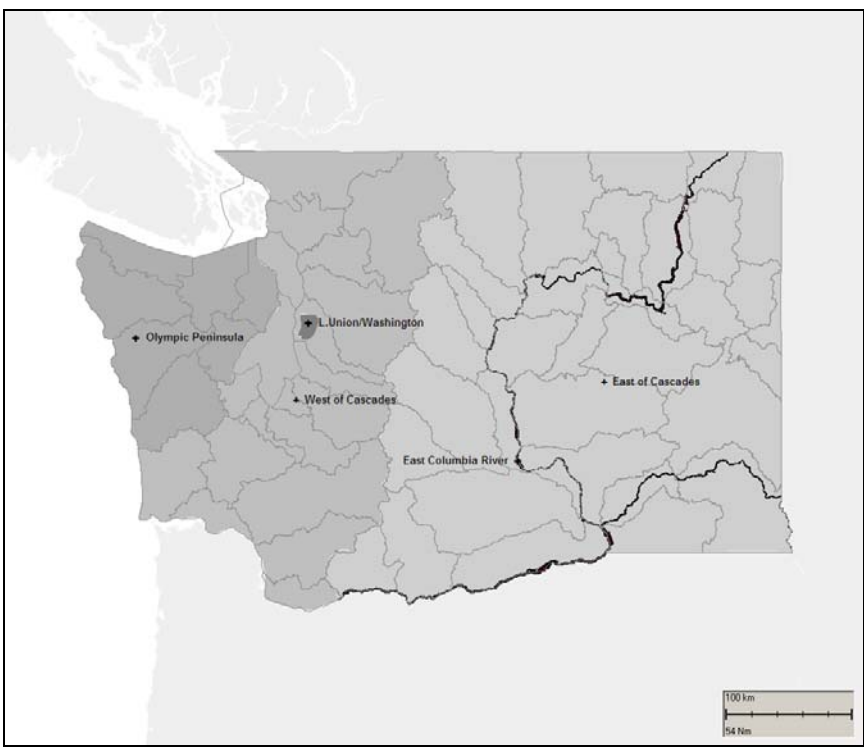

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Figure 2. Inland zones of Washington State with indication of the individual Water Resource Inventory Areas (WRIAs) included in each of the zones.

2.3 Oil Types and Seasons

Oil types that have or may be spilled into Washington waters were categorized into 6 categories, based on physical-chemical properties affecting impact risk (Table 3). The risks were also computed by season, as defined in Section 2.1, because the impact of spills varies by the seasonality of affected resources.

Table 3. Oil categories and types for which risk scores were developed.

Oil Category	Oil Types Included
Crude oils	crude oil, crude condensate
Heavy oils	heavy fuel oil, intermediate fuel oil, Bunker C, No. 6 fuel oil, No. 5 fuel oil, asphalt, wax
Light oils	diesel, mineral oil, motor oil, low-sulfur marine gas oil, lubricating oil, hydraulic oil, No. 2 fuel, home heating oil, bilge slops, waste oils, naphthas, “chlorinated oil”, “other oil*, “unknown”*
Gasoline	various grades of gasoline
Jet fuel	kerosene
Non-petroleum oils	biodiesel, animal fat, vegetable oil, volatile organic distillate

* “Other oil” and “unknown” are most likely light fuels. In cases in which the oil spilled is either not known or not accurately recorded in data, it is most likely to be a light oil since this is otherwise the largest and most common category.

2.4 Overview of Relative Impact Model

French-McCay et al. (2005b, 2006) previously applied the WCS procedures for marine and estuarine waters in modeling analysis for Washington Department of Ecology of oil spill impacts and environmental (natural resource damage) costs for oil spills in Washington waters. We reviewed these results, as well as other modeling results and expert opinion, to develop a scheme for relative impact ratings. We also reviewed sensitivity maps and related information of marine, aquatic, and coastal resources of importance to the state as part of this consideration.

The WCS was selected as the basis for determining risk, as encompassing a quantitative method for determining public resource damages based on spill volume, oil effects and vulnerability rankings. The WCS covers various types of oil spills in all waters of the State (estuarine, marine and inland freshwater), providing a useful approach for an overall evaluation of impact risk. In general WCS includes the factors below which can be used in estimating overall impact risk to the State:

- Relative ranking for each class of oil based on factors that affect severity (i.e., toxicity) and persistence of spill on environment;
- Relative vulnerability ranking of the environment, which characterizes the sensitivity of estuarine, marine, aquatic, and coastal resources of importance to the state (i.e.., location and associated resource use); and
- A quantitative method for determining public resource damages based on oil effects and vulnerability rankings or resources designed to compensate people of the state; i.e., the damages range from $1 to $100 ($50 in the original

statute) per gallon spilled, scaled by the vulnerability score which is based on the above considerations.

The potential impacts of spills of different volumes, oil types, timing and locations in different geographic zones of Washington were assessed based modifications to the WCS and expert opinion. In the WCS, impacts were rated on a numerical and/or descriptive scale from low to high, considering oil toxicity, persistence, and the vulnerability of the State's marine and aquatic resources at particular locations and times of year. Each of the impact categories (e.g., shorelines, biota, socioeconomic, etc.) was assigned a relative impact rating. Qualitative ratings of oil toxicity and the vulnerability of the state's marine and aquatic resources at particular locations and times of year are described in WAC 173-183. The WCS scale is broad enough to accommodate the differences between the actual spills, which are relatively small, and the worst-case discharge scenarios orders of magnitude higher in terms of impacts and costs.

The compensation schedule includes factors accounting for:

- Oil type:
  - Relative rankings for each class of oil are based on factors that affect severity and persistence of spill on environment:
    - Acute Toxicity Score, proportional to content of soluble 1- to 3-ring aromatics;
    - Mechanical Injury Score, related to density where heavier oils receive proportionately higher scores; and
    - Persistence Score: Relative ranking scores determined by empirical data describing the length of time the spilled oil is known to (or likely to) persist in a variety of habitat types.
  - Oil types include the first 5 below; a sixth type was added using the WCS methodology:
    - Crude oil,
    - Heavy fuel oil (Bunker C),
    - Light fuels (No. 2 fuel oil and diesel),
    - Gasoline,
    - Jet fuel (kerosene), and
    - Non-petroleum oils.
- Spill vulnerability score (SVS): Relative vulnerability ranking of environment, which is mapped by WCS marine/estuarine sub-region, specific location (Columbia River), or type and condition of the freshwater water body and involves.
  - location of spill (within defined compensation schedule zones, which are averaged over the sub-region and zone to define risk);
  - habitat and public resource sensitivity to oil;
  - seasonal distribution of public resource;
  - areas of recreational use and aesthetic importance;
  - proximity of the spill to important habitats for birds, mammals, fish and endangered species; and
  - other areas of special ecological or recreational importance.

- Cleanup: A method is included in the WCS to adjust damages to account for actions taken by responsible party. (Credit is allowed for the spill volume cleaned up within 24 hours of release if contained, recovered and measured; and also if no shoreline impacts occurred). However, as for most spills, little oil is actually cleaned up under these criteria. Thus, we assumed no cleanup credit in developing the impact risk scores.

Each of the impact categories (e.g., shorelines, biota, socioeconomic, etc.) were assigned a relative impact rating based on the WCS system. For the estuarine and marine waters of the state, the WCS ratings were developed for each oil type and season; averaged by geographical sub-regions of varying sensitivity, as defined in WAC 173-183; and then averaged (weighted by area) over each of the 12 geographic zones covering those waters. The impact score is a function of zone, oil type and season resulting in an impact risk score per volume of oil spilled.

The WCS was applied to spills into inland waters using vulnerability scores related to water type (classification based on water quality and usage) and habitat type (index indicating habitat quality and degree of human-induced alteration). The WCS for inland waters is complex and requires data for assigning the spill vulnerability scores that are not included in the WCS or readily available. Thus, we developed a model for calculating the spill vulnerability scores for the inland freshwater zones defined in Figure 2 and Table 2 by adapting the WCS system to determine percentages of water body areas in each risk category, such that an impact score could be applied to each category, and an area-weighted score developed by zone and oil type.

For inland waters, the rating system was developed using recent land use data, hydrologic maps, locations and heights of fish barriers, fish run health ratings, and stream water quality data. The risk scores for inland waters were first calculated by watershed, using the Washington State Water Resource Inventory Areas (WRIAs, Figure 2). Then the impact scores for the WRIAs were averaged (area weighted) in each geographic zone, to yield an impact risk score per volume of oil spilled. The Columbia and Snake River data were treated separately, as described below (in Section 2.7).

2.5 Impact Risk Model Methodology for Estuarine and Marine areas of Washington (non-Columbia River)

The geographical zones (Figure 1, Table 1) were divided into sub-regions, as defined by the WCS, and then each sub-region was divided into a habitat grid with each cell representing a habitat type. The relative impact score for each cell, on a scale of 1-50 (used only as a relative scale), was calculated as:

$$0.1*[(OIL_{AT}*SVS_{AT,j}) + (OIL_{MI}*SVS_{MI,j}) + (OIL_{PER}*SVS_{PER,j}) \qquad (2)$$

using the following for SVS_{ij}

$$SVS_{ij} = HVS_i + BVS_j + MVS_j + MFVS_j + SFVS_j + SAVS_j + RVS_j \qquad (3)$$

where:

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$SVS_{i,j}$ = spill vulnerability score (from WAC 173-183-400(3), Equation 2)
OIL_{AT} = Acute Toxicity Score for oil
OIL_{MI} = Mechanical Injury Score for oil
OIL_{PER} = Persistence Score for oil
0.1 = multiplier to adjust score to the 1-50 range
i = acute toxicity (AT), mechanical injury (MI), or persistence (PER)
j = the most sensitive season affected by the spill: spring, summer, fall or winter
HVS_i = habitat vulnerability to oil's propensity to cause impact, varies by habitat type and each of acute toxicity (AT), mechanical injury (MI), or persistence (PER)
BVS_j = marine bird vulnerability score, varies by sub-region and season
MVS_j = marine mammal vulnerability score, varies by sub-region and season
$MFVS_j$ = marine fish vulnerability score, varies by sub-region and season
$SFVS_j$ = shellfish vulnerability score, varies by sub-region and season
$SAVS_j$ = salmon vulnerability score, varies by species, habitat type and season
RVS_j = recreation vulnerability score, varies by sub-region and season

Acute toxicity is the degree to which oil is capable of causing adverse effects on fish, invertebrates and wildlife after short-term exposure (hours to days). The Acute Toxicity Score for the oil (from WAC 173-183-340, Equation 3) was calculated as:

$$OIL_{AT} = [(SOL_1*PCT\text{-}WT_1)+(SOL_2*PCT\text{-}WT_2)+ (SOL_3*PCT\text{-}WT_3)]/107 \qquad (4)$$

where:
SOL_i = solubility in seawater of i-ring aromatic hydrocarbons, where i=1, 2 or 3
$PCT\text{-}WT_i$ = percent weight of i-ring aromatic hydrocarbons in the spilled oil, i = 1, 2 or 3

The Acute Toxicity Score is therefore based on the percentage of bioavailable components in the oil that could cause toxicity to fish, invertebrates and wildlife. Bioavailable components are those that are soluble or semi-soluble in water (i.e., 1- to 3-ring aromatic compounds), such that they can dissolve from the oil into water and then be taken up by the organisms directly from the water or through the gut (if oil is ingested).

The Mechanical Injury Score for the oil (from WAC 173-183-340, Equation 4) was used:

$$OIL_{MI} = (SP – 0.688)/0.062 \qquad (5)$$

where:
SP = specific gravity of the spilled oil

The Mechanical Injury Score is higher the heavier (denser) and more viscous the oil. This measures the propensity of oil to coat, fowl and/or clog organisms and their appendages and apertures, such that movements and normal behaviors are mechanically inhibited.

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Persistence relative ranking scores (from WAC 173-183-340, Equation 5) were determined by empirical data describing the length of time the spilled oil is known to (or likely to) persist in a variety of habitat types (Table 4). The Oil Acute Toxicity, Oil Mechanical Injury, and Oil Persistence scores by oil type are in Table 5. Non-petroleum oils are assumed to have the same effects scores as for jet fuel.

Table 4 Persistence scores.

Score	Anticipated persistence
5	5-10 years or more
4	2-5 years
3	1-2 years
2	1 month to 1 year
1	days to weeks

Table 5. Effects scores by oil type.

Oil Category	Acute Toxicity	Mechanical Injury	Persistence
Crude oils	0.9	3.6	5
Heavy oils	2.3	5.0	5
Light oils	2.3	3.2	2
Gasoline	5.0	1.0	1
Jet fuel	1.4	2.4	1
Non-petroleum oils	1.4	2.4	1

The *Spill Vulnerability Score* (*SVS*) of each sub-region was calculated as follows:

1. The *SVS* was calculated for each sub-region and season potentially impacted by a spill, and for each of the six oil type categories used in the study.
    - The *SVS* rates the vulnerability of public resources to spilled oil based on
        - the propensity of oil to cause acute toxicity,
        - the propensity of oil to cause mechanical injury, and
        - its persistence.
    - The *SVS* is determined by summing vulnerability scores for habitats, birds, mammals, marine fish, shellfish, salmon, and recreational use for the sub-region and most sensitive season impacted by the spill.
2. Marine and estuarine habitats are ranked and scored for *Habitat Vulnerability Score (HV)* for relative vulnerability to oil spills on a 1:5 scale (*HV* = 5, greatest vulnerability, *HV* = 1, least vulnerability). These scores are based on:
    - presence of living public resources at risk,
    - predicted sensitivity to acute toxicity,
    - predicted sensitivity to mechanical injury, and
    - persistence effects of oil based on energy regime of the habitat and propensity to entrain oil.

    a. *Habitat Vulnerability Score* = habitat vulnerability to oil's propensity to cause impact, varies by habitat type.

- Habitats are divided into 37 habitat types under categories (marine intertidal, marine subtidal, estuarine intertidal, estuarine subtidal), and each type is given 3 habitat vulnerability scores:
  - acute toxicity,
  - mechanical injury potential, and
  - persistence.
- These are identified in each cell in the habitat grid for the sub-region.
- If seagrass or kelp are present, that portion of habitat is considered a separate habitat type. The habitat vulnerability score is multiplied by a factor of 1.5 if seagrass or kelp are present.
- The *Habitat Vulnerability Score* for a particular sub-region is determined by averaging all the *Habitat Vulnerability Scores* in the sub-region based on the Habitat Grid.

b. Marine bird vulnerability score, varies by sub-region and season.
c. Marine mammal vulnerability score, varies by sub-region and season.
d. Marine fish vulnerability score, varies by sub-region and season.
e. Shellfish vulnerability score, varies by sub-region and season.
f. Salmon vulnerability score, varies by species, habitat type and season.
g. Recreation vulnerability score, varies by sub-region and season.

3. The *SVS* for the sub-region is calculated by summing the averaged *HVS* to the sum of the vulnerability scores for marine birds, marine mammals, marine fish, shellfish, salmon and recreational use.
4. The *SVS* for the zone is an area weighted average of the values for all the sub-regions contained within the zone.

2.6 Impact Risk Model Methodology for Estuarine and Marine areas of Washington (Western Columbia River)

Relative impact scores for the Columbia River Estuary using the WCS were calculated follows:

1. The Columbia River Estuary has been divided into a 1 km^2 grid, with scores for each oil type and season
   a. Bird, mammal, fish, invertebrate, habitat and human use sensitivities have been evaluated and rated within each cell.
   b. Marine and estuarine habitats are ranked and scored for relative vulnerability to oil spills on the same 1:5 scale as the system used for the rest of Washington State.
2. The *Vulnerability Score* (*VS*) is then derived by
   a. The *VS* for a particular cell is determined by summing the sensitivity scores assigned to each cell for bird, fish, mammal, invertebrate, habitat and human use resources.
   b. These scores are averaged for each season over the entire area.
3. Final scores for each zone (*per gallon)* are then derived for the Columbia River Estuary based on oil type, *SVS(season),* and range of spill volume (assuming no credit for spill cleanup.)

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The relative impact score, on a scale of 1-50 (as a relative scale), employed the equations and scores included in the WCS statute (using procedures in WAC 173-183-810):

$$0.2 * SVS_j\ (OIL_{AT} + OIL_{MI} + OIL_{PER}) \tag{6}$$

where:

$SVS_{,j}$ = spill vulnerability score (from WAC 173-183-500(3), Equation 7)
0.2 = multiplier to adjust score to the 1-50 range
j = the most sensitive season affected by the spill
OIL_{AT} , OIL_{MI} , and OIL_{PER} are as defined above (Table 5).

The mean for all cells in the gridded area was used:

$$SVS_j = (VS_1 + VS_2 + \ldots\ldots + VS_x)/x \tag{7}$$

$$VS_{i,j} = BSS_{i,j} + FSS_{i,j} + MSS_{i,j} + ISS_{i,j} + HSS_{i,j} + HUS_{i,j} \tag{8}$$

where:

VS_i = vulnerability score for cell i for a particular season
x = number of cells in the grid
BSS = bird sensitivity score (Appendix 6 of Chapter 173-183 WAC)
FSS = fish sensitivity score (Appendix 6 of Chapter 173-183 WAC)
MSS = mammal sensitivity score (Appendix 6 of Chapter 173-183 WAC)
ISS = invertebrate sensitivity score (Appendix 6 of Chapter 173-183 WAC)
HSS = habitat sensitivity score (Appendix 6 of Chapter 173-183 WAC)
HUS = human use sensitivity score (Appendix 6 of Chapter 173-183 WAC)

2.7 Impact Risk Model Methodology for Lakes, Rivers and Streams

According to Chapter 173-183 WAC, the relative impact score for spills into inland lakes, rivers and streams should be calculated as follows:

$$PG_s = 0.08 * SVS * (OIL_{AT} + OIL_{MI} + OIL_{PER}) \tag{9}$$

$$SVS = FVS * HI \tag{10}$$

where:

PG_s is the per gallon impact risk score for streams, rivers and lakes;
SVS = Spill vulnerability score [from WAC 173-183-600(3)];
OIL_{AT} = Acute Toxicity Score for Oil [from WAC 173-183-340];
OIL_{MI} = Mechanical Injury Score for Oil [from WAC 173-183-340]; and
OIL_{PER} = Persistence Score for Oil [from WAC 173-183-340].
0.08 = multiplier to adjust to the 1-50 range;
FVS = Freshwater Vulnerability Score; and
HI = habitat index.

The values of OIL_{AT} , OIL_{MI} , and OIL_{PER} are the same as for the estuarine and marine zones (Table 5). The rating factor used for the inland model is 0.08 to adjust to a relative, non-monetary, scale of 1-50.

To derive a FVS (Freshwater Vulnerability Score), freshwater streams, rivers, lakes, and portions thereof, are classified into 5 water types based on water quality, uses and support of fish and other aquatic life. The rating of biological and recreational resources ranges from 1 to 5, where 5 represents the most sensitive category and 1 represents the least sensitive category as follows:

Freshwater Vulnerability Score (FVS):

5 = "Type 1 waters"
4 = "Type 2 waters"
3 = "Type 3 waters"
2 = "Type 4 waters"
1 = "Type 5 waters"

We were unable to identify a state-wide database with water types classified. Based on WAC 222-16-031 Interim Water Typing System, most waters would be Type 1. Thus, for the present application we set the Freshwater Vulnerability Score at 5, for “Type 1 waters”. As a result, the water type classification is not a discriminating factor in the risk ratings developed for inland waters.

In order to account for that degradation prior to assessing the impact of a spill, a habitat index (*HI*) was calculated to represent existing stream conditions. The HI measures the amount of stream degradation from natural conditions and is calculated using the following formula:

$$\text{Habitat Index } (HI) = [(P1+P2+P3+P4+P5+P6)\div Np]\ [f1*f2*f3] \qquad (11)$$

where:

P1 = barriers to natural fish movement
P2 = urbanization
P3 = condition of riparian vegetation
P4 = condition of floodplain
P5 = land use of watershed
P6 = flow alteration
Np = number of P parameters used to calculate HI
f1 = channel modifications
f2 = impoundment
f3 = water quality

From examination of the definitions of these variables, we made the following changes to the definitions of the *P* and *f* variables. These changes were based on the scoring definition for each variable, defined below, because we believe these definitions are more consistent with the scoring definitions.

P6 = ~~flow alteration~~ = impoundment
f2 = ~~impoundment~~ = water quality
f3 = ~~water quality~~ = streambed condition

Below is an outline of the model for calculating *HI*. We eliminated two of the P variables and made one of the f values constant, because data required to accurately represent the intent was too fine scale for this study.

P3 = condition of riparian vegetation
P4 = condition of floodplain
f3 = streambed condition

Such fine scale data is appropriate for an individual spill, but for statistics with large numbers of spills, we found there was not sufficient statewide data to allow us to represent the information appropriately. Due to this elimination, *Np=4* is used on the Habitat Index equation. The factor *f3* is not a discriminating factor in the risk ratings developed for inland waters.

We also altered one of the variables, *f1 = ~~channel modification~~ = health of salmon and steelhead runs*, as the channel modifications are too fine scale for us to find statewide data. However, the calculation of the scoring in the statute uses the channel modification information as an index of net fish reduction. We changed this factor to use the health of the salmon and steelhead runs as a proxy for the fish reduction and channel modification. Our resulting Habitat Index equation is

$$\text{Habitat Index } (HI) = [(P1+P2+P5+P6) \div Np]\ [f1 * f2] \quad (12)$$

where:

P1 = barriers to natural fish movement
P2 = urbanization
P5 = land use of watershed
P6 = impoundment
Np = number of P parameters used to calculate HI = 4
f1 = channel modifications
f2 = water quality
f3 = streambed condition = 0.8.

Below is a description of the impact model as implemented in this study. In order to perform the calculation for Habitat Index (HI), each individual parameter was determined by geographic area using Geographical Information System (GIS) databases, and a score developed by each WRIA (2). An area-weighted average *HI* score by zone (as defined by Table 2) was calculated from the watershed scores.

<u>Barriers to natural fish movement (*P1*)</u>

According to WCS: Barriers, to some degree, limit the free passage of fish upstream, thus limiting the ability of streams to recover. The scoring of this parameter is based on the influence of barriers in the natural dispersal of fish populations. The rating is based on the height of barriers in the watershed (Table 6). To analyze this, the fish barrier data from the Washington Department of Fish and Wildlife (WAFW) were used. These data contain the full dataset on dams from the Washington Department of Ecology (http://www.ecy.wa.gov/services/gis/data/data.htm; ECY) and the Washington Department of Transportation (WDOT fish) barrier data.

The locations of fish barriers are in Figure 3.

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Table 6. Scoring of Barriers to Natural Fish Movement (*P1*).

RATING	QUALIFICATION
10	No manmade obstructions to free upstream passage of fish
8	No dams or other structures causing a vertical drop of more than 30 cm (1 foot) during low flow
5	No dams or other structures causing a vertical drop of more than 91 cm (3 feet) during low flow
3	No dams or other structures causing a vertical drop of more than 3 m (10 feet) during low flow
0	One to several dams or other structures each causing a drop of more than 3 m (10 feet) during low flow

The number and mean height of fish barriers within each watershed (or WRIA) boundary, using the ECY GIS layer of WRIA boundaries (Figure 3), were calculated and used to assign the *P1* score for the watershed. The score (Table 6) was assigned based on the mean height of barriers in the WRIA, excluding barriers on the Columbia and Snake Rivers. The Columbia and Snake River zone and the Lake Union-Washington zone were rated on their own, with a score of 0, because there are significant barriers to fish passage in these two zones.

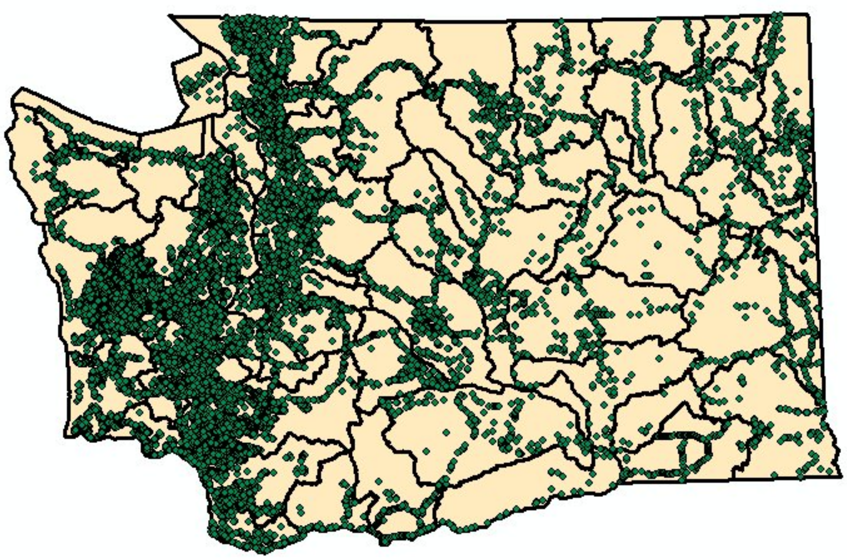

Figure 3. Coverage of Washington State Fish Barrier Data (WDFW). These Fish Barrier data include the WDOT fish barrier data, the ECY dams information and other fish barrier data.

Urbanization (*P2*)

According to WCS: Urban development has historically had negative habitat effects on freshwater ecosystems. The percent of urban development in a watershed directly influences siltation, riparian abuse, and water quality deterioration. The scoring of this parameter was based on the percent of urbanization in the stream watershed (Table 7).

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Table 7. Scoring of Urbanization (*P2*).

RATING	QUALIFICATION
10	Less than 5 percent of the watershed in urban development
8	Five to 10 percent of the watershed in urban development
5	Ten to 40 percent of the watershed in urban development
3	Forty to 70 percent of the watershed in urban development
0	Seventy to 100 percent of the watershed in urban development

The 2001 National Land Cover Database (NLCD) was used for this analysis. The NLCD categories for "Developed, Low Intensity", "Developed, Medium Intensity", and "Developed, High Intensity" were used. Totals areas of these three categories were summed and divided by the total WRIA area to estimate the percentage of urban development in the WRIA.

Condition of Riparian Vegetation (*P3*)

According to WCS: Riparian vegetation is important to seventy percent of the animal and bird species in Washington for some part of their life cycle. It also exerts thermal regulatory and thermal controls for the aquatic system. The scoring of this parameter is based on the percent of banks that are protected by effective riparian vegetation (Table 8). As noted above, a rating for Riparian Vegetation was not included.

Table 8. Scoring of Riparian Vegetation (*P3*).

RATING	QUALIFICATION
10	Ninety to 100 percent of the banks are protected by appropriate perennial vegetation
8	Sixty to 90 percent of the banks are protected by appropriate perennial vegetation
5	Forty to 60 percent of the banks are protected by appropriate perennial vegetation
3	Ten to 40 percent of the banks are protected by appropriate perennial vegetation
0	Zero to 10 percent of the banks are protected by appropriate perennial vegetation

Condition of Flood Plain (*P4*)

According to WCS: The condition of the floodplain forecasts the amount of sedimentation and erosion in the watershed and as such is a primary predictor of stream degradation. The rating of the parameter is described in Table 9. As mentioned above, a rating for the condition of the flood plain was not included.

Table 9. Scoring of Flood Plain (*P4*).

RATING	QUALIFICATION
10	Little or no evidence of active or recent erosion of the floodplain during floods
5	All segments show evidence of occasional erosion of the floodplain. Stream channel essentially intact
0	Floodplain severely eroded and degraded, stream channel poorly defined with much lateral erosion and much reduced flow capacity

Land Use of Watershed (*P5*)

According to WCS: Land use practices exert a great deal of influence on the quality of the aquatic habitat. The rating of this parameter is as described in Table 10.

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Table 10. Scoring of Land use of watershed (*P5*).

RATING	QUALIFICATION
10	More than 80 percent of the watershed protected by timber, improved pasture, terraces, or other conservation practices
8	Sixty to 80 percent of the watershed protected by timber, improved pasture, terraces, or other conservation practices
5	Forty to 60 percent of the watershed protected by timber, improved pasture, terraces, or other conservation practices
3	Twenty to 40 percent of the watershed protected by timber, improved pasture, terraces, or other conservation practices
0	Zero to 20 percent of the watershed protected by timber, improved pasture, terraces, or other conservation practices

To develop a score, land cover maps delineated by watershed (WRIA) boundary were analyzed. Maps and GIS data are available at ECY and USGS websites, respectively: http://www.ecy.wa.gov/services/gis/maps/wria/lc/lc.htm; http://landcover.usgs.gov/show_data.php?code=WA&state=Washington (specifically http://edcftp.cr.usgs.gov/pub/data/landcover/states/)
From these maps, forested areas are easy to determine. However, areas of "improved pasture" can not be determined from normal pasture, nor can we determine terraces or other conservation practices. Hence, our scores were based on the percentage cover of Evergreen Forest and Mixed Forest over each WRIA as proxies for the percentage of each WRIA protected.

<u>Flow alteration (*P6*) ("Impoundment" under our new organization)</u>

According to WCS: Alteration of the natural flow regime can frequently alter habitat conditions that are necessary for certain behavioral and ecological needs of species. The rating of this parameter is described in Table 11. To analyze this, the impoundment volumes from the Washington Dept. of Ecology Dam Safety Unit were used. The data lists all the storage volumes (as acre-feet) of all the dams in the State of Washington. Areas impounded were not available (which would have allowed a direct calculation of percentage impounded), so calculations for the "Impoundment" factor were based on the ratio of mean storage volume to WRIA area, i.e. storage per unit area of the watershed. The ratios were multiplied by 100 to bring them into the range of the ratings in Table 11 and the calculated results were scored.

Table 11. Scoring of Flow alteration (*P6*).

RATING	QUALIFICATION
10	Less than 1 percent of the watershed controlled by impoundments and/or less than 50 percent of the watershed controlled by farm ponds
8	One to 30 percent of the watershed controlled by impoundments and/or less than 50 percent of the watershed controlled by farm ponds
5	Sixty to 95 percent of the watershed controlled by impoundments and/or less than 50 percent of the watershed controlled by farm ponds
3	Sixty to 95 percent of the watershed controlled by impoundments and/or less than 50 percent of the watershed controlled by farm ponds
0	Ninety-five to 100 percent of the watershed controlled by impoundments and/or less than 50 percent of the watershed controlled by farm ponds

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Habitat Alteration Functions (*F*)

Each habitat alteration function (*F*) has the power to reduce the habitat quality rating, dependent on the type and extent of alteration. Functions are expressed on a scale of 0 to 1.0.

Channel modifications (*F1*)

According to WCS: Channel modification can have a dramatic effect on the ability of a stream to provide for a diversity of habitats. This parameter is rated as

$$Channel\ Modification\ (F_1) = 1.0 - (SM*FR) \quad (13)$$

where:

F_1 = *Channel modification rate*
SM = Percent stream reach modified, expressed as a decimal
FR = Percent fish reduction, expressed as a decimal

Scoring for this parameter in WCS is in Table 12. For the present analysis we used information from the WFS on the health of salmon and steelhead from the 2002 Salmonid Stock Inventory (SASI) runs to indicate the health of streams in each watershed (http://wdfw.wa.gov/fish/sassi/intro.htm). With these data, the health of the salmon and steelhead runs is evaluated as one of four measures. We list the measures and new scoring for f1 in Table 13. The average SASI was computed for each WRIA. For WRIAs with no data available, or the stocks are of unknown status, the average of surrounding WRIAs was used in order to make a continuous field over the State. A value was also assigned to the Columbia and Snake Rivers.

Table 12. Scoring for Percent Fish Reduction (*F1*) in WCS.

Channel Modification	% Fish Reduction
Clearing, Snagging	25
Channel realignment	80
Channel paving	90

Table 13. Scoring of the health of salmon and steelhead runs. This is the scoring basis for *F1* in the present application.

RATING QUALIFICATION	
10	Run is considered healthy
7	Run is significantly reduced
3	Run is in critical condition
0	Run is extinct

Water quality (*F2*)

According to WCS: Water quality exerts a variety of detrimental and/or beneficial effects on the aquatic ecosystem. The scoring for this parameter in WCS is described in Table 14. To develop a score for the present model, 2004 303(d) Impaired and Threatened Water Body Maps by WRIA boundary was used (http://www.ecy.wa.gov/services/gis/maps/wria/303d/303d.htm). The scores assigned to each water quality class are in Table 15. The average score for each WRIA was then determined. A value was also assigned to the Columbia and Snake Rivers.

Table 14. Scoring of Water quality (*F2*).

RATING	QUALIFICATION
1.0	Stream water unpolluted. No pollutants detected by standard methods
0.8	Occasional above normal levels of one or more water pollutants usually present, but detectable only by analysis
0.5	Occasional visible signs of oversupply of nutrients or other pollutants detected by analysis
0.4	Occasional fish kills averaging about every 4 years or more
0.2	Occasional fish kills occurring more often than every 4 years
0.0	Grossly polluted waters with fish kills occurring annually or more frequently

Table 15. Scoring for Water Quality using the 303(d) ratings.

RATING	QUALIFICATION
1.0	"AA" Outstanding water quality.
0.9	"A" Excellent water quality.
0.7	"B" Good water quality
0.5	"C" Fair water quality

Streambed condition (F3)

According to WCS: The condition of the substrate habitat can be altered in such a way as to reduce the effective habitat available to the aquatic community as a whole. This parameter is ranked as shown in Table 16. As discussed earlier, the data required to score this parameter are not available for a statewide analysis. Instead, we have estimated a constant value of 0.8 for streambed condition as a conservative measure (neither very high nor very low and providing a median score for all WRIAs). The values for Lake Union / Lake Washington were assigned those of surrounding WRIA 8, Cedar-Sammamish, except that *P1* = 0, as noted above.

Table 16. Scoring of Streambed Condition (*F3*).

RATING	QUALIFICATION
1.0	No apparent unstable material in channel with substrate of bedrock, boulders, rubble, gravel or firm alluvium
0.9	Traces of unstabilized silt, sand, or gravel in quiet areas or large pools with firm substrate
0.8	Quiet areas covered with unstable materials, deep pools restricted to areas of greatest scour
0.7	Pools shallow, filled with silt, sand or gravel, riffles contain noticeable silt deposits
0.5	Streambed completely covered by varying thicknesses of transported material such as silt, sand and gravel
0.0	Stream channel nearly or completely filled with unconsolidated, transported material; no surface flow except during floods

2.8 Impact Risk Model Methodology for Wetlands

According to Chapter 173-183 WAC, the rating factor for spills into inland freshwater wetlands should be calculated as follows:

$$PG_w = 10 * SVS * (OIL_{AT} + OIL_{MI} + OIL_{PER}) \quad (14)$$

$$SVS = WVS \quad (15)$$

where:

PG_w = the per gallon impact risk score for wetlands;
SVS = Spill vulnerability score;
OIL_{AT} = Acute Toxicity Score for Oil [from WAC 173-183-340];
OIL_{MI} = Mechanical Injury Score for Oil [from WAC 173-183-340]; and
OIL_{PER} = Persistence Score for Oil [from WAC 173-183-340].
10 = multiplier to adjust to the 1-50 range; and
WVS = wetlands vulnerability score (from WAC 173-183-710)

In WAC 173-183, wetlands vulnerability is based on wetlands classification as Category I, II, III or IV (see WAC-173-183-710). Table 17 outlines the scoring for Wetland Vulnerability Score (*WVS*). Although wetlands category data was available by county in some cases (e.g. Thurston Country provided wetland coverages), statewide wetlands data indicating the above categories were not available. Thus, we assumed a conservative Category III with a score of 3 points for *WVS*. The values of OIL_{AT} , OIL_{MI} , and OIL_{PER} are the same as for the estuarine and marine zones (Table 5).

Table 17. Scoring of the wetland categories.

RATING	QUALIFICATION
5	Category I wetlands
4	Category II wetlands
3	Category III wetlands
1	Category IV wetlands

2.9 Impact Risk Model – Combined Score for All Freshwaters (by WRIA and Zone)

The weighted mean score for the streams-lakes impact score and the wetlands impact score were calculated, and combined with as an area-weighted average for each WRIA. Areas of water bodies were calculated from the US Geological Survey National Hydrography 100k Dataset. The area of open water in inland areas, not including marine and estuarine waters, was used as an estimate of the surface area of lakes in each WRIA. The area of streams and lakes in the WRIA was the sum of open waters (lakes) and streams, not including the eastern Columbia and Snake rivers main stems. The area of wetlands in this coverage was also calculated for each WRIA.

The surface area of streams was calculated as the length of streams in the WRIA from the US Geological Survey National Hydrography 100k Dataset (http://nhd.usgs.gov/data.html) times an estimate of the mean width of streams in the WRIA. The mean width was calculated from wetted width data collected by the WA DEP from biomonitoring stations located inside each WRIA. The number of biomonitoring stations varied between WIRAs, ranging from 0-14 stations. At each biomonitoring station, data was collected at up to five locations along the stream system. Wetted width is a standard field measurement defined as the actual width of the stream from water edge to water edge. The wetted width data was specific to stream systems consisting of riffles and pools, not from big river systems such as the Colombia or Snake Rivers (which were considered separately). Wetted width data (meters) at each location was compiled and averaged. The most current data set available, which ranged from the late nineteen nineties to 2007, was used. The majority of the data used to determine typical stream width was measured in the late nineteen nineties. The data source was: http://www.ecy.wa.gov/apps/watersheds/wriapages/index.html.

The surface area of the Columbia and Snake Rivers was calculated using polygons for those rivers from the 2001 NLCD coverage (http://landcover.usgs.gov/show_data.php?code=WA&state=Washington; specifically http://edcftp.cr.usgs.gov/pub/data/landcover/states/). The area within or bordering each WRIA was calculated, so that area-weighted scored of *P2*, *P5* and *P6* could be derived for the Columbia-Snake River zone. To do this, the area of the river in each WRIA was weighed by the number of banks in or bordering the WRIA and multiplied by the *P2* (or *P5* or *P6*) score, then summed and divided by the total area (with bank weighing factors) to derive a mean score for the Columbia-Snake River zone.

After the values for each WRIA were calculated, the values for the combined inland areas were calculated from the WRIA data using an area based weighting scheme. The total area of the WRIA was based on the 2001 NLCD coverage.

3. Model Results

Impact risk scores by oil type and season, averaged over all estuarine and marine zones are presented in Table 18. The seasonal variation is relatively small; however, the scores are higher in spring and summer than in fall or winter. The seasonal highs for some resources are balanced by different seasonal patterns for other resources, such that the composite score has only small variation by season. The results for the 12 estuarine and marine zones, by oil type and season, may be found in French McCay et al. (2008).

Table 18. Impact risk scores by oil type and season, averaged over all estuarine and marine zones.

Oil Category	Spring	Summer	Fall	Winter
Crude oils	20.27	19.03	17.76	17.88
Heavy oils	26.56	24.82	23.18	23.36
Light oils	16.04	15.07	13.99	14.05
Gasoline	15.22	14.28	13.34	13.38
Jet fuel	10.12	9.45	8.77	8.81
Organic oils	10.12	9.45	8.77	8.81

Table 19 shows the impact risk scores averaged over the 4 seasons. The impact risk is highest for the heavy fuels, followed by crude oil; lower for light oils and gasoline, which are similar for a given zone; and lowest for jet fuel and non-petroleum oils. This trend is related to the higher persistence and mechanical injury

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scores of the heavier oils, which therefore have more impact on birds, marine mammals, habitats, and recreation then the non-persistent oils. This trend is in agreement with spill impact observations and modeling, in general.

Table 20 shows the summary of the per gallon inland impact risk scores, PG, by zone. Scores by WRIA are available in French McCay et al. (2008). The risk scores are weighed by the relative areas of streams + lakes versus wetlands and the scores for each in the WRIAs. Note that the inland scores do not have a seasonal component.

The results show a similar relative pattern by oil type as for the estuarine and marine scores. The impact risk is highest for the heavy fuels, followed by crude oil; lower for light oils and gasoline, which are similar for a given zone; and lowest for jet fuel and non-petroleum oils. This trend is related to the higher persistence and mechanical injury scores of the heavier oils, which therefore have more impact on birds, mammals, habitats, and recreation then the non-persistent oils.

Table 19. Impact risk scores by estuarine/marine zone and oil type, averaged by all 4 seasons.

Zone	Crude oils	Heavy oils	Light oils	Gasoline	Jet fuel	Non-Petroleum
Washington Outer Coast	17.99	23.86	14.34	14.33	9.14	9.14
Grays Harbor	19.05	24.73	14.93	13.98	9.31	9.31
Willapa Bay	21.86	28.51	17.16	16.15	10.72	10.72
Strait of Juan de Fuca	13.28	17.38	10.24	9.24	6.16	6.16
Inner Straits	23.58	30.81	18.96	18.22	11.78	11.78
Rosario Strait and vicinity	19.00	24.87	15.13	14.60	9.56	9.56
Whidbey Basin	19.95	26.09	15.84	15.03	10.01	10.01
Northern Puget Sound	21.68	28.22	17.28	16.41	10.91	10.91
Central Puget Sound	14.87	19.54	11.55	10.98	7.30	7.30
South Puget Sound	18.72	24.41	14.65	14.06	9.30	9.30
Hood Canal	15.05	19.73	11.76	11.07	7.28	7.28
Western Columbia River	19.81	25.64	15.64	14.59	10.01	10.01

The highest impact risk for the inland zones is in the Olympic Peninsula zone, followed by West of Cascades and then East of Cascades. The Columbia-Snake River and Lake Union-Washington have lower scores due to urbanization, fish barriers, and impoundments in the watershed.

Table 20. Per gallon impact risk scores by inland zone and oil type.

Zone	Crude oils	Heavy oils	Light oils	Gasoline	Jet fuel	Non-petro-leum
Lake Union and Lake Washington	8.27	10.71	6.53	6.09	4.18	4.18
Eastern Columbia River and Snake River	10.29	13.32	8.12	7.58	5.20	5.20
Olympic Peninsula	22.11	28.63	17.46	16.29	11.17	11.17
West of Cascades	20.27	26.24	16.00	14.93	10.24	10.24

East of Cascades	15.85	20.53	12.52	11.68	8.01	8.01

4 Discussion and Conclusions

Compensation schedules, like the WCS, are becoming increasingly popular around the world because they provide a clear process to estimate compensation for damages from the spill. Such schedules are available for review by the public, resources trustees, other representatives of the State, and potential spill Responsible Parties.

The effort to develop the WCS was lead by Dr. Tom Leschine (University of Washington) and Mr. Dick Logan (at the time working for WA Department of Ecology). The WCS is intended for use with small spills that do not warrant the full Natural Resource Damage Assessment (NRDA) process. In addition, the range of compensations was set by statute, originally to be $1-50 per gallon spilled (and later updated by statute to $1-100 per gallon). For large spills, this can lead to very large damage results. For example, Chen and Neumann (2001) did an analysis comparing the results for a large spill of 14,508 m^3 (3,832,479 gallons or 91,249 bbls) using the Natural Resource Damage Assessment Model for Coastal and Marine Environments (NRDAM/CME, French et al., 1996) and the WCS (using the $1-50 per gallon basis). Based on their analysis, the NRDAM/CME estimate of costs was US $5,055,516 (or $1.32/gallon) while the WCS estimate of costs was US $136,014,711 (or $35.49/gallon). The simple, conservative estimates in the WCS lead to much higher valuation, which becomes a more significant issue as the size of the spill increases.

There are some other limitations related to the WCS. The table data for birds, habitats, marine fish, recreation, salmon and shellfish were developed by expert opinion, but experts were not available at the time to develop the freshwater tables. Biologists and other resource experts are often concerned that the WCS lack detail. For example biological resources are averages over the three-month season and over the biological zones. Mixing of dissolved oil components into the water column in smaller bodies of water is not considered in the WCS; a spill into a small stream or water body, even 1 m^3 (264 gallon) of gasoline, can achieve concentrations high enough through mixing to be lethal to a large area of the stream or water body. The compensation was also originally based on 1989 US dollars ($1-$50/gallon), which does not provide a fair value in today's monetary values. Hence the statute range was changed to $1-100 per gallon.

However, in this study we were developing a model of relative impact risk. The purpose was not to develop a cost estimate for NRDA or other purposes. Because the approach and risk rating factors are a quantitative method for characterizing impacts based on spill volume, oil effects and vulnerability rankings that is based on expert opinion, the relative impact risk model using these risk factors is a reliable method for the purposes of this study. While the impact score is proportional to spill volume, and so does not reflect the potential lessening of incremental impacts incurred with additional volume spilled at higher spill sizes, it does incorporate the most important factors controlling impact, i.e., the sensitivity and density of the resources in the locations oiled and the oil type, which determines the nature and degree of injury.

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