Benefit-cost Analysis of Risk Reduction Options for the Aleutian Island Risk Assessment

Final

Prepared for

Nuka Research & Planning Group, Inc.

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Abbreviations

BCA	Benefit-cost analysis
BCR	Benefit-cost ratio
EPA BOSCEM	Environmental Protection Agency Basic Oil Spill Cost Estimation Model
MARCS	Marine Accident Risk Calculation System
NPV	Net present value
O&M	Operating and maintenance
RRO	Risk reduction option

1 Introduction

Northern Economics, Inc. conducted a benefit-cost analysis (BCA) in support of the evaluation of the risk reduction options (RROs). The BCA attempted to estimate and compare costs and benefits across several impact categories under the baseline (without proposed RROs) and alternative (with RROs) using the 16 representative accident scenarios identified in Phase A and over the study period 2009–2033. Impact categories examined include cost of spilled oil, oil spill cleanup costs, cost of fatalities and injuries, cost of vessel and cargo damage, environmental damage, and socioeconomic costs. Estimation of costs for these impact categories relied on existing cost models, Phase A task reports, and cost data from previous oil spills. Neither a predictive model nor vessel damage cost data could be found in existing literature; as a result, costs and benefits for this category are not included in this analysis. Further, damage to foreign-flagged vessels do not represent costs to U.S. society (unless those costs are somehow passed along to U.S. consumers), so damage to vessels of the largely foreign-flagged fleet travelling through Aleutian Island waters may not warrant inclusion in this analysis.

Baseline costs consist of those incurred to society through the impact categories identified above. Costs under the alternative consist of capital and operating and maintenance (O&M) costs associated with the implementation of the RROs. Benefits under the alternative take the form of reduced spill frequency and severity, which translate to avoided impact category costs.

Key results of this analysis include the following:

- The net present value (NPV) of estimated life-cycle costs under the alternative is approximately $156.1 million, while the NPV of estimated benefits is $4.0 billion. This yields a benefit-cost ratio (BCR) for the alternative of 25.4. Largely driving this positive BCR are estimated avoided socioeconomic costs (i.e. benefits) of nearly $3.8 billion. Excluding socioeconomic benefits from the analysis yields a BCR of 0.93 (see Table 10 and Table 12).
- The estimated benefits and costs for spill scenario 9 exert a preponderant effect on the calculation of the BCR when aggregated across the 16 scenarios. This is because the estimated median frequency of Scenario 9, from Phase A, is two orders of magnitude greater than that of any other spill scenario. Exclusion of the benefits and costs associated with all scenarios other than Scenario 9 results in a decrease in the BCR, while exclusion of Scenario 9 yields a substantial increase in the BCR (see Table 12).
- This analysis estimates that the BCR is particularly sensitive to the variable inclusion or exclusion of Scenario 9 (and the other 15 scenarios), as well as changes in the assumed impact of RROs on the reduction in risk. The BCR appears substantially less sensitive to changes in the discount rate.
- This analysis depends heavily on the estimated impacts of approved RROs on the reduction of spill frequency and severity for the 16 scenarios. A lack of expert assessment of the specific effects of individual RROs on the reduction in spill frequency or severity for individual spill scenarios represents a key limitation of this analysis.

The remainder of this document is divided into three sections. Section 2 details the calculation of costs across impact categories under both the baseline and alternative. This section documents methodologies used to estimate the mitigation of risk attributable to the implementation of the RROs, as well as cost bases for estimating baseline and alternative costs for the 16 spill scenarios. Section 3 includes both life-cycle and benefit-cost analyses for the alternative, as well as sensitivity analysis of the effects on the BCR of excluding socioeconomic benefits, changing the composition of spill scenarios under analysis, adjusting the assumed degree to which RROs impact spill frequency or severity, and shifting the discount rate. Finally, Section 4 documents key limitations of this analysis.

2 Calculation of RRO Benefits

This section details the reduction in estimated annual costs attributable to the various relevant benefit/cost impact categories as a consequence of the implementation of the RROs. These categories include the value of spilled oil, oil spill cleanup costs, environmental damages, socioeconomic impacts, and avoided fatalities. This section further documents for each category the methodologies used to calculate both the estimated annual cost without RROs and the estimated reduction in spill frequency and severity under the alternative. For each scenario and impact category, the difference between estimated costs without and with the RROs represents RRO benefits. All values have been adjusted to 2009 U.S. dollars.

It is worth noting that various techniques exist for estimating the costs of oil spills, whether real or hypothetical. Oil spill cost analyses increasingly are considering cleanup costs, environmental damages, and socioeconomic losses separately (Etkin, 2004; Liu and Wirtz, 2006; Kontovas et al., 2010). For these three cost impact categories, selection of the most appropriate estimation methodology depended largely on availability of data. This analysis documents where shortcomings in data exist and are likely to increase the margin of error in the estimation of the BCR. Further, in Section 3.3, this analysis tests the sensitivity of the BCR to changes in assumed or calculated values that may be among the sources of greatest error.

2.1 Estimation of Accident Frequencies and Reduction of Risk

Sections 2.1.1 and 2.1.2 document the methodologies and sources used to calculate the estimated probabilities of the 16 spill scenarios occurring under the baseline and alternative. Existing literature and best judgment were used to predict the degree to which RROs would impact both the frequency and severity of oil spills, thus enabling the estimation of a single risk modifying multiplier. This process was followed for each of the 16 scenarios, allowing for scenario-specific variation in the degree to which the RROs would impact risk.

2.1.1 Baseline Frequencies and Severity

AIRA Phase A, Task 6, used the Marine Accident Risk Calculation System (MARCS) to estimate a frequency for each of the 16 scenarios. Task 6 also included a projection of 1.439 accidents with a spill per year, as well as median frequencies of the occurrence of each of the 16 representative spill scenarios. Across the 16 scenarios, median frequencies ranged from 1.0×10^{-6} to 1.0 accidents per year. Together, the median frequencies summed to 1.110 (ERM 2011b). As shown in Table 1, this analysis reconciled these two figures by dividing each scenario's median frequency by 1.110 and then multiplying it by 1.439. This approach generated weighted median frequencies for each scenario, which subsequently were applied to the calculation of costs under the baseline (without RROs) and alternative (with RROs) for each cost impact category.

As shown in Table 1, the weighted median frequency for Scenario 9 is two orders of magnitude greater than that of any other scenario. As a result, the estimation of the reduction in costs under spill Scenario 9 due to the implementation of the RROs exerts a preponderant influence over the calculation of the aggregated reduction in costs across all scenarios. Section 3.2 presents BCR results with all 16 scenarios included, while Section 3.3 isolates the specific influences of Scenario 9 and the other 15 scenarios on the calculation of the BCR. It is important to note that Phase A MARCS modeling analysis did not divide the study area into sub-regions. As a result, the MARCS frequency estimate for a particular scenario is based on that scenario's specific ship type/oil type/spill volume combination but is not location specific (ERM, 2011b).

Table 1. Estimated Median Frequencies of 16 Representative Oil Spill Scenarios

Oil Spill Scenario	Location	Type of Incident	Median Frequency	Weighted Median Frequency
1	North Unimak Pass	Container Ship Collision	0.01	0.0130
2	North Unimak Pass	Bulk Carrier Collision	0.01	0.0130
3	North Unimak Pass	Crude Oil Tanker Collision	0.0001	0.0001
4	North Unimak Pass	Product Tanker Collision	0.0001	0.0001
5	North Unimak Pass	Tank Barge Collision	0.01	0.0130
6	Sanak Island	Container Ship Drift Grounding	0.01	0.0130
7	Sanak Island	Bulk Carrier Drift Grounding	0.01	0.0130
8	Sanak Island	Crude Oil Tanker Drift Grounding	0.01	0.0130
9	Sanak Island	Tank Barge Drift Grounding	1	1.2960
10	Holtz Bay, Attu Island	Container Ship Drift Grounding	0.01	0.0130
11	Holtz Bay, Attu Island	Bulk Carrier Drift Grounding	0.01	0.0130
12	Holtz Bay, Attu Island	Crude Oil Tanker Drift Grounding	0.0001	0.0001
13	Holtz Bay, Attu Island	Product Tanker Grounding	0.01	0.0130
14	Adak Island	Tank Barge Grounding	0.000001	0.0000
15	Adak Island	Container Ship Drift Grounding	0.01	0.0130
16	Urilia Bay	Bulk Carrier Drift Grounding	0.01	0.0130
Total			**1.110301**	**1.439**

Source: ERM, 2011b; Northern Economics calculations of weighted median frequencies.

2.1.2 Alternative Scenario Frequencies and Severity

The difference in value or cost in the baseline and alternative scenarios for a given impact category constitutes the benefits accrued as a result of the implementation of the RROs. A key challenge to calculating the reduction in value/cost for the various impact categories was estimating the degree to which RROs would reduce risk. This analysis relied on qualitative and quantitative analyses from Phase A documents, as well as recently updated information regarding the specific characteristics of selected RROs, to assign both a frequency and severity risk reduction score for each cost impact category and to each RRO that could directly impact risk. As considerable variation exists in the nature of each spill scenario, risk reduction values were assigned separately for each scenario. Scores ranged from zero to three, with a score of zero indicating no reduction in either frequency or severity and a score of three indicating a 30 percent reduction. It is assumed that the RROs that may directly impact risk are limited to vessel monitoring, tank storage barge and helicopter lightering (considered in combination), nearshore task force, spill response and salvage, emergency towing, and offshore routing.

Table 2 illustrates for spill scenario 6 (container ship drift grounding off Sanak Island, 128,100 gallons of Bunker C fuel spilled), specifically, how frequency and severity mitigation scores were assigned to each RRO and, in turn, how these values were used to calculate RRO modifier values for each cost category. As shown in Table 2, a risk mitigation score of 3 equates to a risk modifier value of 0.7. Frequency and severity modifier values are calculated individually by multiplying together all of the risk modifier values in a particular column, and the overall cost category RRO modifier value is calculated by multiplying together the frequency and severity risk modifier values.

Table 2. Derivation of RRO Modifiers by Cost Impact Category, Spill Scenario 6

RRO	Spilled Oil		Cleanup Costs		Environmental Impact		Socioeconomic Impact		Injuries/ Fatalities	
	Freq	Sev	Freq	Sev	Freq	Sev	Freq	Sev	Freq	Sev
	Risk Mitigation Scores									
Vessel Monitoring	3	2	3	2	3	2	3	2	3	0
Storage Barge/ Lightering	0	2	0	2	0	2	0	2	0	0
Nearshore Task Force	0	2	0	2	0	2	0	2	0	2
Spill Response/ Salvage	0	3	0	3	0	3	0	3	0	0
Emergency Towing	3	2	3	2	3	2	3	2	3	2
Offshore Routing	2	2	2	2	2	2	2	2	2	2
	Risk Modifier Values									
Vessel Monitoring	0.7	0.8	0.7	0.8	0.7	0.8	0.7	0.8	0.7	1.0
Storage Barge/ Lightering	1.0	0.8	1.0	0.8	1.0	0.8	1.0	0.8	1.0	1.0
Nearshore Task Force	1.0	0.8	1.0	0.8	1.0	0.8	1.0	0.8	1.0	0.8
Spill Response/ Salvage	1.0	0.7	1.0	0.7	1.0	0.7	1.0	0.7	1.0	1.0
Emergency Towing	0.7	0.8	0.7	0.8	0.7	0.8	0.7	0.8	0.7	0.8
Offshore Routing	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Freq/Sev Modifier	0.39	0.23	0.39	0.23	0.39	0.23	0.39	0.23	0.39	0.51
RRO Modifier		0.09		0.09		0.09		0.09		0.20

Source: Det Norske Veritas & ERM – West, Inc., 2011; ERM, 2011a; ERM, 2011b; Northern Economics estimates.

It is important to note that, in many cases, selection of a risk mitigation value represented best judgment based on limited available information. For example, this analysis broadly assumes that the oil storage barge and helicopter lightering service would mitigate the severity of a smaller spill to a greater degree than a larger spill, *ceteris paribus*. Invariably, RROs would impact spill frequency and severity in a more heterogeneous manner than is assumed in this analysis; however, precise estimation of the specific risk-mitigating effects of particular RROs across 16 spills with unique characteristics extends beyond the scope of this analysis. Limited sensitivity analysis was performed to estimate the impact of both higher and lower risk modifying values on the calculation of the BCR. Section 3.3 specifies these values and presents their corresponding BCR results.

2.2 Impact Categories

The remainder of this section documents the calculation of costs under the baseline and alternative for each cost impact category. The difference between costs (aggregated across the 16 representative spills) under the baseline and alternative represents RRO benefits. This analysis estimates substantial reductions in costs as a result of the implementation of the RROs across impact categories, but socioeconomic benefits alone constitute 96 percent of total estimated benefits.

2.2.1 Spilled Oil

This analysis used historical and projected prices of medium crude oil (Brent Spot price), diesel fuel, and Bunker C fuel from the Energy Information Administration (2013) to calculate the value of spilled oil with and without the proposed RROs for each of the 16 scenarios. For each scenario, the baseline value of oil spilled was calculated by multiplying the number of gallons of oil/fuel spilled by the price per gallon in a given year and then by the probability of the scenario occurring in a given year under the baseline. This value was then multiplied by the RRO modifier to calculate the value of spilled oil under the alternative. The difference between the former and latter values represents the benefits provided by the RROs.

Table 3 shows how benefits attributable to the adoption of the RROs are calculated for one year within the study time period (in this case, 2015). This analysis estimates that the RROs yield an annual decline in the value of spilled oil close to $7.0 million. As with other impact categories, the preponderance of this benefit is due to a decline in the estimated volume and value of oil spilled under Scenario 9.

Table 3. Value of Spilled Oil for 16 Spill Scenarios under Baseline and Alternative (Year 2015 Only)

Oil Spill Scenario	Spill Volume (1,000 gal)	Price ($/gal)	Baseline Probability	Baseline Value of Spilled Oil	RRO Modifier	Alternative Value	Benefits
1	128.1	$1.71	0.0130	$2,836	0.26	$732	$2,104
2	766.2	$1.71	0.0130	$16,962	0.26	$4,377	$12,585
3	17,979.4	$2.16	0.0001	$5,036	0.26	$1,300	$3,737
4	1,123.7	$3.31	0.0001	$482	0.26	$124	$358
5	1,708.4	$3.31	0.0130	$73,328	0.29	$21,025	$52,303
6	128.1	$1.71	0.0130	$2,836	0.09	$255	$2,581
7	766.2	$1.71	0.0130	$16,962	0.14	$2,383	$14,579
8	17,979.4	$2.16	0.0130	$503,628	0.16	$79,601	$424,027
9	1,708.4	$3.31	1.2960	$7,332,800	0.14	$1,030,206	$6,302,594
10	1,067.6	$1.71	0.0130	$23,634	0.12	$2,732	$20,902
11	766.2	$1.71	0.0130	$16,962	0.12	$1,961	$15,001
12	17,979.4	$2.16	0.0001	$5,036	0.12	$582	$4,454
13	2,291.6	$3.31	0.0130	$98,357	0.15	$14,391	$83,966
14	1,708.4	$3.31	0.0000	$7	0.13	$1	$6
15	1,708.4	$1.71	0.0130	$37,819	0.08	$2,975	$34,843
16	766.2	$1.71	0.0130	$16,962	0.09	$1,525	$15,437
Totals				**$8,153,646**		**$1,164,169**	**$6,989,477**

Source: Det Norske Veritas & ERM – West, Inc., 2010a; Det Norske Veritas & ERM – West, Inc., 2010b; Det Norske Veritas & ERM – West, Inc., 2011; ERM, 2011a; ERM, 2011b; Northern Economics estimates.

2.2.2 Cleanup Costs

This analysis used the Etkin (2000) model to calculate estimated cleanup costs for each of the 16 spill scenarios both with and without the RROs. The model is based on an analysis of oil spill cleanup costs for over 300 spills in 40 countries and takes into account oil type, location, spill size, cleanup methodology, and extent of shoreline oiling to generate a per-tonne[1] cleanup cost figure (Etkin, 2000). For each spill scenario, the per-tonne cost of cleanup was multiplied by the baseline spill volume (in tonnes) and the baseline probability of the scenario occurring to calculate the estimated baseline cleanup cost. This figure was then multiplied by the RRO modifier to calculate the estimated

[1] A tonne commonly is referred to as a metric ton in the United States and is equivalent to 1,000 kilograms, or 2,204.6 pounds.

alternative cleanup cost. The difference between the baseline and alternative cost figures represents the estimated benefits attributable to the implementation of the RROs.

Table 4 displays the modifiers that exhibited variability across spill scenarios but excludes criteria that were consistent across spill scenarios. This latter group includes regional modifiers (i.e. North America, United States), location type (nearshore vs. in-port vs. offshore), and primary cleanup method (dispersants vs. *in-situ* burning vs. mechanical, etc.). This analysis assumed all spills to be nearshore and assigned each scenario a default primary cleanup method modifier of 1.0, as no method(s) was designated most likely for any of the scenarios. The extent of shoreline oiling was estimated using Table 4.5 from the Consequence Analysis Report, Tasks 3 and 4 of the AIRA Preliminary Risk Assessment (ERM 2011a), by multiplying the lowest probability band figure by 0.2 and adding it to the highest probability band figure. The lowest and highest probability band figures represent the extent of shoreline expected to be oiled at confidence levels of less than 10 percent and greater than 90 percent, respectively, per Phase A shoreline oiling modeling results. This analysis assumed the calculation above to be appropriate in estimating the extent of shoreline likely to be oiled at a probability level of 50 percent or greater, as modeling results were not available for this probability band. Using the lowest probability band estimate alone likely would grossly overstate the extent of shoreline oiling; conversely, the highest probability band estimate likely would understate the actual extent of shoreline oiling. Total estimated annual cleanup costs across the 16 scenarios fall from $3.8 billion to $534 million with the implementation of the RROs.

Table 4. Estimated Cleanup Costs for 16 Spill Scenarios under Baseline and Alternative

Oil Spill Scenario	Oil Type Modifier	Spill Size Modifier	Shoreline Oiling Modifier	Estimated Baseline Cost ($1,000)	RRO Modifier	Estimated Alternative Cost ($1,000)	Benefits ($1,000)
1	0.71	0.27	1.06	$75.5	0.26	$19.5	$56.0
2	0.71	0.15	0.61	$144.5	0.26	$37.3	$107.2
3	0.55	0.01	1.06	$2.7	0.26	$0.7	$2.0
4	0.18	0.05	0.61	$0.2	0.26	$0.0	$0.1
5	0.18	0.05	0.61	$25.6	0.29	$7.3	$18.3
6	0.71	0.27	0.61	$43.5	0.09	$3.9	$39.6
7	0.71	0.15	0.61	$144.5	0.14	$20.3	$124.2
8	0.55	0.01	0.61	$155.6	0.16	$24.6	$131.0
9	0.18	0.05	0.61	$2,560.9	0.14	$359.8	$2,201.1
10	0.71	0.05	0.61	$67.1	0.12	$7.8	$59.3
11	0.71	0.15	0.61	$144.5	0.12	$16.7	$127.8
12	0.55	0.01	0.61	$1.6	0.12	$0.2	$1.4
13	0.18	0.05	0.61	$34.3	0.15	$5.0	$29.3
14	0.18	0.05	1.06	$0.0	0.13	$0.0	$0.0
15	0.71	0.05	0.61	$107.4	0.08	$8.4	$98.9
16	0.71	0.15	1.06	$251.0	0.09	$22.6	$228.4
Totals				$3,758.7		$534.1	$3,224.5

Source: Det Norske Veritas & ERM – West, Inc., 2010a; Det Norske Veritas & ERM – West, Inc., 2010b; Det Norske Veritas & ERM – West, Inc., 2011; ERM, 2011a; ERM, 2011b; Etkin, 2000; Northern Economics estimates.

2.2.3 Environmental Damage

This analysis used the natural resource damage award of $644,017 from the M/V Kuroshima spill as the basis for estimating environmental damage costs for the 16 representative spill scenarios. Estimated environmental damage costs for each of the scenarios were adjusted based on relative spill volumes and oil types, applying modifiers from the Etkin (2000) cleanup cost model.

Table 5 compares oil type, spill size, and RRO modifiers used to calculate estimated baseline and alternative environmental damage costs for the 16 scenarios. By way of comparison, the oil type and spill size modifiers for the Kuroshima spill are 0.71 and 0.65, respectively. Total estimated baseline environmental damages in Table 5 are $1.2 million, compared to $0.2 million with the RROs implemented.

Table 5. Estimated Environmental Damage Costs for 16 Spill Scenarios under Baseline and Alternative

Oil Spill Scenario	Ratio to Kuroshima Spill Volume	Oil Type Modifier	Spill Size Modifier	Estimated Baseline Cost ($1,000)	RRO Modifier	Estimated Alternative Cost ($1,000)	Benefits ($1,000)
1	3.3	0.71	0.27	$13.6	0.26	$3.5	$10.1
2	19.6	0.71	0.15	$45.1	0.26	$11.6	$33.5
3	461.0	0.55	0.01	$0.5	0.26	$0.1	$0.4
4	28.8	0.18	0.05	$0.0	0.26	$0.0	$0.0
5	43.8	0.18	0.05	$8.5	0.29	$2.4	$6.1
6	3.3	0.71	0.27	$13.6	0.09	$1.2	$12.4
7	19.6	0.71	0.15	$45.1	0.14	$6.3	$38.8
8	461.0	0.55	0.01	$54.7	0.16	$8.6	$46.0
9	43.8	0.18	0.05	$850.4	0.14	$119.5	$731.0
10	27.4	0.71	0.05	$21.0	0.12	$2.4	$18.5
11	19.6	0.71	0.15	$45.1	0.12	$5.2	$39.9
12	461.0	0.55	0.01	$0.5	0.12	$0.0	$0.5
13	58.8	0.18	0.05	$11.4	0.15	$1.7	$9.7
14	43.8	0.18	0.05	$0.0	0.13	$0.0	$0.0
15	43.8	0.71	0.05	$33.5	0.08	$2.6	$30.9
16	19.6	0.71	0.15	$45.1	0.09	$4.1	$41.1
Totals				$1,188.4		$169.5	$1,018.9

Source: Det Norske Veritas & ERM – West, Inc.; 2011; Etkin, 2000; Northern Economics estimates.

2.2.4 Socioeconomic Impact

The AIRA Phase B Technical Proposal identifies avoided environmental damage, including socioeconomic costs, as one of the primary benefit/cost impact categories whose estimation should inform calculation of a BCR for the proposed project (Nuka Research & Planning Group, LLC, 2012). The Environmental Protection Agency Basic Oil Spill Cost Estimation Model (EPA BOSCEM) was developed for the U.S. EPA Oil Program and provides for the estimation of socioeconomic costs of actual and hypothetical spills. The model was developed through analysis of historical cost data from oil spill case studies and oil spill trajectory and impact analyses (Etkin 2004) and is considered a credible method for estimating total costs of an oil spill among oil spill cost researchers (Kontovas et al, 2010). It is important to note, however, that the sample from which the EPA BOSCEM model was created consisted of spills of at least 50 gallons that resulted in at least one gallon of oil spilled in navigable inland waterways. None of the 16 spill scenarios occurs in inland waterways, and many are likely not to result in any amount of oil ending up in inland waterways. Consequently, the EPA BOSCEM model likely overstates the socioeconomic costs associated with at least some of the 16 spill scenarios.

The EPA BOSCEM model first assigns a per-gallon socioeconomic cost based on the type of oil and spill volume. This base cost figure then can be adjusted upward or downward, depending on the socioeconomic and cultural value ranking of the site that is likely to be impacted. A site with a value rank considered "extreme" is "predominated by areas with high socioeconomic value that may potentially experience a large degree of long-term impact if oiled" (Etkin 2004) and is assigned a modifier value of 2.0. A site with a value rank considered "high" if it is "predominated by areas with medium socioeconomic value that may potentially experience some long-term impact if oiled" and is assigned a modifier value of 1.0.

This analysis relied on qualitative and quantitative socioeconomic impact sensitivity analysis from the AIRA Phase A Consequence Analysis Report to assign cost modifier values to each spill scenario, as shown in Table 6. Site 1 (North Unimak Pass) and Site 6 (Sanak Island), which encompass spill scenarios 1-5 and 16, were each assigned a socioeconomic value rank of "extreme" and associated cost modifier value of 2.0 (ERM 2011a). Per Phase A reports, these sites are likely to witness negative impacts to commercial fisheries, fish processing facilities, and subsistence hunting or fishing areas as a result of respective hypothetical spills. Conversely, the socioeconomic benefits that are quantified in Table 6 represent the estimated mitigation of these negative effects as a result of the implementation of the RROs. This analysis estimates that the annual socioeconomic costs associated with the 16 spill scenarios drops from $314 million to $45 million as a result of the implementation of the RROs. The estimated socioeconomic costs for Scenario 9 (tank barge drift grounding off Sanak Island, diesel spill) alone fall from $263 million to $37 million. This substantial annual benefit largely drives a high estimated BCR for the project as a whole.

Table 6. Estimated Annual Socioeconomic Costs for 16 Spill Scenarios under Baseline and Alternative

		Socioeconomic Modification					
Oil Spill Scenario	Base Cost per Gallon ($)	Value Rank	Cost Modifier Value	Estimated Baseline Cost ($1,000)	RRO Modifier	Estimated Alternative Cost ($1,000)	Benefits ($1,000)
1	$200	Extreme	2	$664.1	0.26	$171.4	$492.7
2	$200	Extreme	2	$3,972.4	0.26	$1,025.1	$2,947.3
3	$60	Extreme	2	$279.6	0.26	$72.2	$207.5
4	$70	Extreme	2	$20.4	0.26	$5.3	$15.1
5	$70	Extreme	2	$3,099.9	0.29	$888.8	$2,211.1
6	$200	Very High	1.7	$564.5	0.09	$50.8	$513.7
7	$200	Very High	1.7	$3,376.5	0.14	$474.4	$2,902.1
8	$60	Very High	1.7	$23,768.1	0.16	$3,756.7	$20,011.4
9	$70	Very High	1.7	$263,490.6	0.14	$37,018.5	$226,472.1
10	$175	Minimal	0.7	$1,695.0	0.12	$196.0	$1,499.1
11	$200	Minimal	0.7	$1,390.3	0.12	$160.7	$1,229.6
12	$60	Minimal	0.7	$97.9	0.12	$11.3	$86.6
13	$70	Minimal	0.7	$1,455.3	0.15	$212.9	$1,242.4
14	$70	Very High	1.7	$0.3	0.13	$0.0	$0.2
15	$175	Very High	1.7	$6,587.3	0.08	$518.3	$6,069.0
16	$200	Extreme	2	$3,972.4	0.09	$357.2	$3,615.2
Totals				**$314,434.5**		**$44,919.4**	**$269,515.2**

Source: Det Norske Veritas & ERM – West, Inc.; 2011; Etkin, 2004; Northern Economics estimates.

2.2.5 Injuries/Fatalities

The RROs accrue benefits in the form of the avoidance of injuries and fatalities. While injury data could not be found, this analysis does assume that Aleutian Island oil spill incidents will result in 0.4 deaths per year. This figure is based on the occurrence of eight fatalities resulting from oil spill incidents in the Aleutian Islands over the 20 years 1987-2006 (Det Norske Veritas & ERM – West, Inc. 2011). This analysis further assumes an even distribution of fatalities across the 16 spill scenarios, before accounting for baseline scenario probabilities. The value of a human life, as published by the U.S. Department of Transportation (2014), is used to calculate an estimated value of deaths for each scenario with and without RROs.

Table 7 outlines the calculation of the estimated value of fatalities for the 16 spill scenarios under the baseline and alternative. The baseline value of fatalities, $211,814, was calculated by multiplying the value of a statistical life (approximately $8.5 million in 2009 dollars) by the probable number of deaths occurring each year as a result of oil spill accidents in Aleutian Island waters (0.4) and dividing by the number of representative oil spill scenarios (16). This analysis estimates that the implementation of the RROs will result in an annual reduction of $209,028 in the value of lives lost because of oil spill accidents.

Table 7. Estimated Value of Loss of Human Life for 16 Spill Scenarios under Baseline and Alternative

Oil Spill Scenario	Baseline Value of Fatalities ($)	Baseline Scenario Probability	Baseline Value of Fatalities ($)	RRO Modifier	Alternative Value of Fatalities ($)	Benefits ($)
1	$211,814	0.0130	$2,745	0.51	$1,406	$1,340
2	$211,814	0.0130	$2,745	0.51	$1,406	$1,340
3	$211,814	0.0001	$27	0.51	$14	$13
4	$211,814	0.0001	$27	0.51	$14	$13
5	$211,814	0.0130	$2,745	0.51	$1,406	$1,340
6	$211,814	0.0130	$2,745	0.20	$551	$2,194
7	$211,814	0.0130	$2,745	0.31	$861	$1,884
8	$211,814	0.0130	$2,745	0.31	$861	$1,884
9	$211,814	1.2960	$274,520	0.31	$86,090	$188,431
10	$211,814	0.0130	$2,745	0.23	$630	$2,116
11	$211,814	0.0130	$2,745	0.23	$630	$2,116
12	$211,814	0.0001	$27	0.23	$6	$21
13	$211,814	0.0130	$2,745	0.29	$797	$1,948
14	$211,814	0.0000	$0	0.26	$0	$0
15	$211,814	0.0130	$2,745	0.20	$551	$2,194
16	$211,814	0.0130	$2,745	0.20	$551	$2,194
Totals			**$304,800**		**$95,772**	**$209,028**

Source: Det Norske Veritas & ERM – West, Inc. 2011; U.S. DOT 2014; Northern Economics estimates)

3 Life-cycle and Benefit-cost Analysis

This section details the composition of NPV of life-cycle costs across RRO categories and provides BCA results for the alternative. The NPV of life-cycle costs for the alternative total approximately $156.1 million, 54 percent of which is constituted by towing services. This analysis estimates that the alternative yields a BCR of 25.4. This figure drops substantially when socioeconomic effects are excluded from its calculation, to 0.93 when estimated benefits are aggregated across all 16 spill scenarios and to 1.7 when spill Scenario 9 is excluded from the analysis.

3.1 Life-cycle Analysis

This section calculates the NPV of life-cycle costs for the alternative over the 2009 to 2033 time period. Life-cycle costs considered include capital and operating costs for each RRO category. This analysis assumes that capital cost items hold no residual value at the end of the period. Results for the NPV of life-cycle costs from 2009 to 2033, as shown in Table 8, indicate that the alternative would have net costs of approximately $156.1 million using a seven percent discount rate, per Office of Management and Budget guidelines (2014).

Table 8. Life-cycle Cost Analysis for Alternative

	Life-cycle Costs (discounted at 7%)		
Year	Capital Costs	Operation & Maintenance Costs	Total LCC
2009	-$4,554,064	-$9,088,831	-$13,642,895
2010	-$4,256,134	-$8,494,235	-$12,750,369
2011	-$3,977,696	-$7,938,537	-$11,916,233
2012	-$3,717,473	-$7,419,194	-$11,136,666
2013	-$3,474,273	-$6,933,826	-$10,408,099
2014	-$2,831,596	-$6,480,211	-$9,311,807
2015	-$2,646,351	-$6,056,272	-$8,702,623
2016	-$2,467,365	-$5,660,067	-$8,127,432
2017	-$2,305,949	-$5,289,782	-$7,595,731
2018	-$2,155,092	-$4,943,722	-$7,098,814
2019	-$1,480,853	-$4,620,301	-$6,101,154
2020	-$1,383,975	-$4,318,038	-$5,702,013
2021	-$1,293,434	-$4,035,550	-$5,328,984
2022	-$1,208,817	-$3,771,542	-$4,980,359
2023	-$1,129,736	-$3,524,805	-$4,654,541
2024	-$881,233	-$3,294,211	-$4,175,444
2025	-$823,582	-$3,078,702	-$3,902,284
2026	-$769,703	-$2,877,291	-$3,646,994
2027	-$719,349	-$2,689,057	-$3,408,406
2028	-$672,289	-$2,513,138	-$3,185,426
2029	$0	-$2,348,727	-$2,348,727
2030	$0	-$2,195,072	-$2,195,072
2031	$0	-$2,051,469	-$2,051,469
2032	$0	-$1,917,261	-$1,917,261
2033	$0	-$1,791,832	-$1,791,832
NPV	-$42,748,964	-$113,331,670	-$156,080,635

Source: RRO cost estimates from Nuka Research & Planning Group, LLC, 2014.

Table 9 disaggregates life-cycle costs by RRO category. The category with the highest NPV of combined capital and O&M costs is towing services ($85.0 million), which accounts for 54 percent of total life-cycle costs. This is not surprising, as the towing services category includes the cost of the tug vessel. Meanwhile, the NPV of life-cycle costs is $43.1 million for oil spill response services, $12.0 million for salvage services, $9.7 million for management, and $6.3 million for prevention and oversight.

Table 9. Life-cycle Costs for Alternative ($1,000)

	Management		Prevention & Oversight		Towing Services		Salvage Services		Oil Spill Response		Total Costs	
Year	Cap	O&M	Cap	O&M	Cap	O&M	Cap	O&M	Cap	O&M	Cap	O&M
2009	23	770	25	497	2,437	4,602	535	551	1,534	2,669	4,554	9,089
2010	22	720	23	464	2,278	4,301	500	515	1,433	2,495	4,256	8,494
2011	20	673	22	434	2,129	4,020	468	481	1,340	2,332	3,978	7,939
2012	19	629	20	406	1,989	3,757	437	449	1,252	2,179	3,717	7,419
2013	18	587	19	379	1,859	3,511	408	420	1,170	2,036	3,474	6,934
2014	0	549	1	354	1,738	3,281	382	393	711	1,903	2,832	6,480
2015	0	513	1	331	1,624	3,066	357	367	664	1,779	2,646	6,056
2016	0	480	0	310	1,514	2,866	332	343	621	1,662	2,467	5,660
2017	0	448	0	289	1,415	2,678	311	320	580	1,554	2,306	5,290
2018	0	419	0	270	1,322	2,503	290	299	542	1,452	2,155	4,944
2019	0	391	0	253	1,236	2,339	245	280	0	1,357	1,481	4,620
2020	0	366	0	236	1,155	2,186	229	262	0	1,268	1,384	4,318
2021	0	342	0	221	1,080	2,043	214	244	0	1,185	1,293	4,036
2022	0	320	0	206	1,009	1,910	200	228	0	1,108	1,209	3,772
2023	0	299	0	193	943	1,785	187	214	0	1,035	1,130	3,525
2024	0	279	0	180	881	1,668	0	200	0	967	881	3,294
2025	0	261	0	168	824	1,559	0	186	0	904	824	3,079
2026	0	244	0	157	770	1,457	0	174	0	845	770	2,877
2027	0	228	0	147	719	1,362	0	163	0	790	719	2,689
2028	0	213	0	137	672	1,272	0	152	0	738	672	2,513
2029	0	199	0	128	0	1,189	0	142	0	690	0	2,349
2030	0	186	0	120	0	1,111	0	133	0	645	0	2,195
2031	0	174	0	112	0	1,039	0	124	0	603	0	2,051
2032	0	162	0	105	0	971	0	116	0	563	0	1,917
2033	0	152	0	98	0	907	0	109	0	526	0	1,792
NPV	101	9,601	111	6,197	27,594	57,383	5,095	6,865	9,847	33,285	42,749	113,332

Source: RRO cost estimates from Nuka Research & Planning Group, LLC, 2014.
Note: Costs are discounted at seven percent. Cap = capital costs. O&M = operating and maintenance costs.

3.2 Benefit-cost Analysis

Benefit-cost analyses typically attempt to capture all benefits and costs accruing to members of society for the various project alternatives. This analysis considers only one alternative, which consists of the implementation of all approved RROs and their collective effects in mitigating both frequency and severity of oil spills. Further, this analysis assumes no marginal increase in revenues under the alternative, despite program participants paying annual dues. The rationale for this assumption is that any revenues obtained from shipping companies whose vessels travel through Aleutian Island waters represent an equivalent cost to society. Thus, as noted previously, benefits consist of avoided costs as a result of the implementation of the RROs, and costs include capital and O&M costs, as documented above.

Table 10 shows the composition of the NPV of estimated benefits and costs, as well as the BCR for the alternative, based on a seven percent discount rate. The BCR of 25.4 for the alternative is driven largely by the avoidance of socioeconomic costs. In fact, avoided socioeconomic costs constitute 96 percent of total benefits under the alternative.

Table 10. Net Present Value and Benefit-Cost Ratio of the Alternative Scenario

Benefit/Cost	Benefits (Avoided Costs)	Life-cycle Costs	Net Benefits	BCR
		($ Millions)		
NPV (7%) – Total	**$3,962.6**	**$156.1**	**$3,806.5**	**25.4**
Capital Costs		$42.7		
O&M		$113.3		
Spilled Oil	$90.3			
Cleanup Costs	$40.2			
Environmental Damage	$12.7			
Socioeconomic Impact	$3,816.8			
Injuries/Fatalities	$2.6			

Source: Det Norske Veritas & ERM – West, Inc., 2010a; Det Norske Veritas & ERM – West, Inc., 2010b; Det Norske Veritas & ERM – West, Inc., 2011; ERM, 2011a; ERM, 2011b; Etkin, 2000; Etkin, 2004; RRO cost estimates from Nuka Research & Planning Group, LLC, 2014; Northern Economics estimates.

3.3 Sensitivity Analysis

Sensitivity analyses were conducted to estimate changes to the BCR resulting from shifts to four factors that were integral to the calculation of the BCR and whose assumed values likely include variable margins of error. These factors include:

- the alternate inclusion or exclusion of socioeconomic costs;
- the extent to which RROs modify oil spill frequency and/or severity;
- the inclusion of all scenarios, only Scenario 9, or all scenarios except Scenario 9; and
- the discount rate.

As noted previously, the value of avoided socioeconomic costs under the alternative constitutes the vast majority of benefits among cost impact categories and greatly inflates the BCR. With socioeconomic costs included, all possible combinations of spill scenario groups, risk modifier values, and discount rates yield a minimum estimated BCR of 17.2 (low risk modification, Scenario 9 only, 10.5 percent discount rate) and a maximum estimated BCR of 29.9 (high risk modification, all scenarios except Scenario 9 included, 3.5 percent discount rate). Since even a BCR of 17.2 generally is considered very high, the remainder of this section discusses only sensitivity analyses in which socioeconomic costs have been excluded.

Adjustments to the discount rate also impacted the BCR to a substantially lesser degree than changes to either the risk modifier values or the range of spill scenarios included. The effects of changes in the discount rate on the BCR are presented in Section 3.3.2, but are not considered in combination with changes to any of the other three factors discussed in this section.

3.3.1 BCR Sensitivity to Risk Modifying Values

Section 2.1.2 documents the methodology and assumptions used to assign risk modifying multiplier values to each RRO that could directly impact risk for each of the 16 spill scenarios. The risk modifier values applied thus far largely reflect best judgment based on a combination of limited qualitative and quantitative information and, consequently, likely are the source of some level of error as they contribute to the calculation of the BCR. Analysis of the sensitivity of the BCR to upward or downward shifts in the risk modifier values is thus warranted.

Table 11 maps risk mitigation scores to risk modifier values under low, medium, and high impact risk modification scenarios,[2] with the medium impact values having been applied in the analysis up to this point. Reductions in both frequency and severity of spills for each scenario were estimated using the low and high impact risk modifier values and following the methodology documented in Section 2.1.2. The resulting RRO modifiers were then used to calculate costs under the baseline and alternative, thus providing for the comparison of estimated BCRs under low, medium, and high impact risk modification scenarios. As changes in risk modification values were observed in combination with the inclusion of different groups of spill scenarios, BCR results of these analyses are presented in Section 3.3.2.

Table 11. Low, Medium, & High Risk Modifier Values

Risk Mitigation Score	Risk Modifier Value		
	Low Impact	Medium Impact	High Impact
0	1.00	1.00	1.00
1	0.95	0.90	0.85
2	0.90	0.80	0.70
3	0.85	0.70	0.55

Source: Det Norske Veritas & ERM – West, Inc., 2011; ERM, 2011a; ERM, 2011b; Northern Economics estimates.

3.3.2 BCR Sensitivity to Changes in Spill Scenario Groups

As noted above, the weighted median frequency of spill Scenario 9 (tank barge drift grounding off Sanak Island, diesel spill of 1.7 million gallons) is two orders of magnitude greater than that of any of the other 15 scenarios, which translates to Scenario 9 heavily influencing calculation of aggregated estimated costs under the baseline and alternative across the 16 scenarios. To isolate the influences of Scenario 9 and the other 15 scenarios on the calculation of the BCR, this analysis alternately excluded Scenario 9 and the other 15 scenarios. Scenario 9 was assigned a probability of zero when excluded, thus greatly increasing the median weighted frequencies of the other scenarios and their respective impacts on the calculation of impact category costs. Likewise, the weighted median frequency of Scenario 9 increased when the remaining 15 scenarios were excluded and assigned probabilities of zero.

[2] It is important to note that the terms low, medium, and high in this context refer only to their degree relative to one another and not to any established standard. It is possible that the degree to which RROs may diminish risk falls outside the range established by the low and high modifier values. The primary value of the alternate use of low and high modifier values is to assess the extent to which the BCR changes as a result of a change in the assumed reduction in risk and not to define a margin of error for the BCR at any measurable level of confidence.

Table 12 presents BCR results for the nine risk modification level/spill scenario group combinations that exclude socioeconomic costs and assume a seven percent discount rate. In comparing BCR estimates across risk modifier impact categories (columns), it is evident that changing risk modifier values by 0.05 yields substantial changes to the BCR. That the difference in BCRs is particularly pronounced between low and medium impact scenarios is explained by the doubling of reduction of risk (either frequency or severity) from the low impact to the medium impact multiplier values (see Table 11). Table 12 also indicates that factors specific to Scenario 9 have a lowering effect on the BCR. This aligns with both Phase A analysis that estimated the total consequence score (an overall measure of spill severity) for Scenario 9 to be the lowest of the 16 scenarios (ERM, 2011b) and oil spill cost models used in this analysis, which project diesel spills to be less costly than crude or bunker fuel spills of equal volume (Etkin, 2000; Etkin, 2004).

Table 12. BCR of Alternative Scenario for Various Risk Modification Levels & Spill Scenario Groups

	Risk Modifier Value		
Spill Scenarios	**Low Impact**	**Medium Impact**	**High Impact**
All	0.65	0.93	1.05
Scenario 9 Only	0.59	0.86	0.96
All Except Scenario 9	1.15	1.65	1.84

Source: Det Norske Veritas & ERM – West, Inc., 2010a; Det Norske Veritas & ERM – West, Inc., 2010b; Det Norske Veritas & ERM – West, Inc., 2011; ERM, 2011a; ERM, 2011b; Etkin, 2000; Etkin, 2004; RRO cost estimates from Nuka Research & Planning Group, LLC, 2014; Northern Economics estimates.

3.3.3 Alternate Discount Rates

Analysis was performed to determine the sensitivity of the BCR to changes in the discount rate. As shown in Table 13, movements in the discount rate from 7 percent to either 3.5 percent or 10.5 percent result in substantial changes in estimated benefits and life-cycle costs, but proportionally smaller shifts in the BCR. Further, this result holds regardless of which group of scenarios (all 16 scenarios, only Scenario 9, or all scenarios except Scenario 9) is included in the analysis. The relatively incremental changes in the BCR largely are a function of the somewhat even division of project costs across the 25-year project timeframe. It is important to note that the results presented in Table 13 reflect the application of mid-range risk modifier values from Table 2, as well as the exclusion of socioeconomic impacts. Additional sensitivity analysis revealed similarly modest effects of discount rate shifts on the BCR when socioeconomic impacts were included, as well as when high and low risk modifier values were alternately applied to the analysis.

Table 13. Net Present Value and Benefit-Cost Ratio of the Alternative Scenario

Discount Rate (%)	Spill Scenario Group	Benefits (Avoided Costs) ($ Millions)	Life-cycle Costs ($ Millions)	Net Benefits ($ Millions)	BCR
3.5	All	$201.8	$208.4	-$6.6	0.97
7.0	All	$145.8	$156.1	-$10.3	0.93
10.5	All	$111.8	$123.2	-$6.6	0.91
3.5	All except 9	$185.0	$208.4	-$23.4	0.89
7.0	All except 9	$133.5	$156.1	-$22.6	0.86
10.5	All except 9	$102.2	$123.2	-$21.0	0.83
3.5	Scenario 9 only	$354.6	$208.4	$146.2	1.70
7.0	Scenario 9 only	$257.5	$156.1	$101.4	1.65
10.5	Scenario 9 only	$198.2	$123.2	$75.0	1.61

Source: Det Norske Veritas & ERM – West, Inc., 2010a; Det Norske Veritas & ERM – West, Inc., 2010b; Det Norske Veritas & ERM – West, Inc., 2011; ERM, 2011a; ERM, 2011b; Etkin, 2000; Etkin, 2004; RRO cost estimates from Nuka Research & Planning Group, LLC, 2014; Northern Economics estimates.

4 Limitations

The quantification of certain benefits integral to this analysis required extensive use of assumptions, likely resulting in variable levels of imprecision depending on impact category. Where they exist, absences or shortcomings in data or methodologies that informed estimation of benefits are documented in previous sections. Further, the specific complexities that contribute to costs of oil spills that occur in Aleutian Island waters may not be accounted for adequately or accurately in the cost quantification models used in this analysis; nor does either model include stated margins of error. Importantly, the EPA BOSCEM model, which informs the estimation of socioeconomic costs, was developed using cost data from spills that resulted in at least some spillage into navigable inland waterways. Many of the 16 spill scenarios may not result in any volume of oil ending up in inland waterways. Thus, socioeconomic losses may be overstated in this analysis.

Another major limitation of this analysis is the lack of expert evaluation of the specific effects of individual RROs on the reduction in spill frequency or severity for individual spill scenarios. This type of evaluation would enhance the precision of estimates of risk mitigation and allow for more meaningful assessment of the economic merits of particular RROs.

The results of this analysis should be viewed in light of these limitations.

5 References

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