*L*ower *D*uwamish *W*aterway *G*roup

Port of Seattle / City of Seattle / King County / The Boeing Company

Appendix L
Estimation of Short-term Effectiveness Metrics

Final Feasibility Study

Lower Duwamish Waterway
Seattle, Washington

FOR SUBMITTAL TO:

The U.S. Environmental Protection Agency
Region 10
Seattle, WA

The Washington State Department of Ecology
Northwest Regional Office
Bellevue, WA

October 31, 2012

Prepared by: AECOM

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Memorandum

Date: October 31, 2012

To: Lower Duwamish Waterway Group

From: AECOM

Subject: Estimation of Short-term Effectiveness Metrics, Feasibility Study for the Lower Duwamish Waterway

Introduction

This memorandum presents the methods and key metrics used for evaluating short-term effectiveness of the remedial alternatives developed in Section 8 and evaluated in Sections 9 and 10 of the Lower Duwamish Waterway (LDW) feasibility study (FS). The U.S. Environmental Protection Agency (EPA) Region 10 *Clean and Green Policy* (EPA 2010a) states that the environmental benefits of federal cleanup programs may be enhanced by promoting technologies and practices that are sustainable. Specific objectives of the Green Remediation policy are to: 1) protect human health and the environment by achieving remedial action goals; 2) support sustainable human and ecological use and reuse of remediated land; 3) minimize impacts to water quality and water resources; 4) reduce air toxics emissions and greenhouse gas production; 5) minimize material use and waste production; and 6) conserve natural resources and energy. EPA's green remediation policies and guidelines will be consulted in the development of specific mitigation measures and in the adoption of sustainable practices during the remedial design phase.

The scope of this study is to evaluate and compare the potential impacts of the remedial alternatives with respect to key metrics and to identify best practices for their mitigation. This analysis was performed on an MS Excel platform and utilized metrics associated with the following factors:

- Gas emissions
  - Carbon dioxide (CO_2) emissions
  - Carbon monoxide (CO) emissions
  - Nitrogen oxides (NO_x) emissions
  - Sulphur oxides (SO_x) emissions
  - Particulate matter with a diameter of 10 micrometers (µm) or less (PM_{10}) emissions
- Workplace accidents
  - Expected number of accidents during remediation activities
  - Expected number of deadly accidents during remediation activities
- Energy consumption
- Carbon footprint
- Resources consumed and disposal capacity utilized.

Section 9 evaluates these metrics for each remedial alternative under *Short-term Effectiveness, Environmental Impacts*. Section 9 also includes information about additional short-term effectiveness metrics, such as release of contaminants into the water column during dredging and potential mitigation measures.

Calculation Approach for Short-term Effectiveness Metrics

Remediation Activities Evaluated

Various activities associated with the active remedial alternatives under consideration for the LDW were subdivided into primary, secondary, and tertiary activities, as depicted in Figure L-1 (EPA 2009). Short-term effectiveness analyses were developed for the primary and secondary activities, but were not developed for tertiary activities.

Brief summaries of the primary, secondary, and tertiary activities are provided below:

- Primary Activities (On-site Work)
  - Cap with clean sand material using barge-mounted derrick crane/bucket and barge-mounted precision excavator.
  - Dredge sediments using barge-mounted derrick-crane/bucket and barge-mounted precision excavator.
  - Transload sediment to the off-loading facility by barge and tugboat. Handle dredged material on the barge using front-end loaders. Off-load the material at the transloading area (by crane) into containers and load containers onto trucks.
- Secondary Activities (Off-site Work)
  - Transport containers by truck to railcar intermodal facility followed by rail transport to regional landfill (as one loaded trip and one unloaded trip). Off-load containers from railcar to trucks for transport to the landfill cell.
  - Transport clean sand and aggregate from quarry to the LDW.
- Tertiary Activities (Not Included in the Short-term Effectiveness Analyses)
  - Mining of aggregate for capping, enhanced natural recovery (ENR), and residuals management
  - Manufacturing of construction equipment; construction materials, fuels, lubricants, staging equipment, and support facilities
  - Transport workers to/from site
  - Electricity generation for consumption at the site
  - Landfill management.

All of the equipment in the primary and secondary activities is assumed to be operated using hydrocarbon fuels.

Tertiary activities are those activities that are not directly related to the on-site activities but that are related to the overall remedy at the site. These include construction and staging equipment, site preparation, site closure, support facilities, and materials necessary to implement the active remedial alternatives. These activities are outside the scope of the short-term effectiveness analyses as described by Toffoletto et al. (2005) and Cadotte et al. (2007). Noise factor calculations are also beyond the scope of the short-term effectiveness analyses and are not included in this FS because industry-related exposure factors are not readily available. Management of a landfill is also beyond the scope of the FS because it is managed as an operations requirement by the landfill. Electricity consumed on site is not included in the short-term effectiveness metrics because it is considered to be a small portion of the total energy used on site.

Inventory of Metrics

Air pollutant emissions include estimates of CO_2 emissions, the most important greenhouse gas (GHG), followed by water vapor, NO_x, CO, SO_x, and PM_{10}. These estimates are calculated using an emission factor approach, where the emission factors represent the mass of pollutant emitted per unit of activity and are normally referred to as “default” emissions. The major uncertainty for an emission factor is related to the degree of similarity between the target equipment/process the factor is used for and the equipment/process the factor was derived from. Estimation of activity (e.g., throughput, operating hours, etc.) requires knowledge of the equipment and facilities involved. Usually, emission factors estimate CO_2 emissions more accurately than CO, NO_x, SO_x, and PM_{10} emissions, whose estimates are affected by specific characteristics of the fuel, equipment, and the operating conditions (World Resource Institute 2007).

Energy consumption refers to thermal and electrical energy consumption. Thermal energy consumption arises from fuel combustion, based on the average heating value for diesel fuel (158 megajoules per gallon [MJ/gal]), and it is directly related to the amount of diesel fuel consumed during the project. Electrical energy consumption is related to the electricity purchased from the grid and is estimated as the product of equipment power demand and utilization time.

Workplace accidents represent the expected number of work-related accidents and deaths during the activities. This information is calculated using available data for workplace activities similar to those planned for the remediation of the LDW.

Carbon footprint, for the purpose of this FS, is defined as the forested area necessary to absorb the CO_2 produced during the remediation activities, based on the sequestration rate for Douglas fir. Carbon is stored by plants as they photosynthesize atmospheric CO_2 into plant biomass. Subsequently, some of this plant biomass is indirectly stored as soil organic carbon during decomposition processes. The sequestration rate is a function of the form of biomass as dry matter (dm) and usually estimated as 2.02 grams (g) CO_2/1 g dm, and the annual vegetation growth rate. For Douglas fir, the sequestration rate is 2.09 metric tons of CO_2 sequestered per acre per year.

Input Data Requirements

Two categories of data were compiled to perform the short-term effectiveness analyses: background and site-specific (Goedkoop et al. 2008a). The background data are comprised of generic factors and constants found in databases and literature. The site-specific data relate to the manner in which the remedial alternatives are assumed to be implemented (e.g., number and characteristics of equipment, labor requirements, production rates, and transportation distances).

Background data used for the calculations were obtained mostly from EPA (1995a, 1995b) and the U.S. Department of Labor (USDOL 2007, 2008). In particular, the EPA report documents gas emission factors related to different sources (stationary internal combustion engines or mobile sources), dust emission equations for heavy construction and plowing operations, and transport on paved and unpaved roads.

The metrics were calculated based on the activities scheduled for each remedial alternative. Background data and site-specific data, as classified for the planned activities, are reported in Tables L-1 and L-2, respectively.

Results

Table L-3 presents the summary output for the remedial alternatives. Alternative 2R-CAD results in the lowest GHG (CO_2) emissions (approximately 17,000 metric tons). Alternative 6R is estimated to result in the highest GHG emissions (approximately 140,000 metric tons). Table L-3 also includes other air pollutant emissions, the energy required to excavate and transport material, and the required landfill volume needed to dispose of the dredged material generated by each of the remedial alternatives. The air emissions, energy consumption, and landfill space used increase in proportion to the dredged volume of the alternatives. In general, the combined-technology alternatives (indicated by a “C”) result in fewer emissions, use less landfill space, and consume less energy than the removal-emphasis alternatives (indicated by an “R”).

This table also estimates the carbon footprint for each alternative expressed in acre-years, where one acre-year represents the amount of CO_2 sequestered by one acre of Douglas fir forest for one year. This results in Alternative 2R-CAD having the lowest carbon footprint (approximately 4,000 acre-years) and Alternative 6R having the largest carbon footprint (approximately 33,000 acre-years).

Although workplace accidents have not been traditionally considered, short-term effectiveness analyses should evaluate social, economic, and environmental concerns. Workplace accidents are a realistic outcome of remedial activities, and the number of accidents is assumed to be proportional to the duration of remedial activities.

Table L-4 summarizes the CO_2 emissions for the remedial alternatives and possible best management practices (BMPs) that all the remedial alternatives could apply to minimize the carbon footprint during construction. The pie charts in Table L-4 represent the percentage of CO_2 produced by each activity (i.e., dredging, transloading, transporting, dredging, capping, and miscellaneous) for each remedial alternative. Miscellaneous activities include emissions from small-scale construction equipment (e.g., front-end loaders). The percentages of CO_2 emissions for each activity category are similar among the various remedial alternatives. As noted in the table, higher percentages of CO_2 emissions are associated with dredging (14 to 32%) and transportation of dredged material to the disposal facility (44 to 69%).

Discussion

In general, particulate and CO_2 air emissions are generated through internal combustion in construction equipment, and dust created by transportation and construction activities. SO_x emissions depend on the sulphur content of the fuel. If the sulphur content of the fuel is reduced, then SO_x emissions will decrease.

The primary source of particulate and CO_2 air emissions is fuel consumption during on-site and off-site activities. Transportation accounts for the largest portion of these emissions. The FS assumes that rail and barge transport will be used to the maximum extent possible. Rail and barge transport is the most efficient way to reduce project emissions for both particulates and CO_2, as compared to long-haul trucking.

The EPA publication *Clean Fuel & Emission Technologies for Site Cleanup* (EPA 2010b) identifies a number of BMPs for reducing air emissions. These BMPs generally fall into four categories:

- Effective operation and maintenance to ensure efficiency of vehicles and field equipment
- Advanced diesel technologies

- Alternative fuels and fuel additives
- Fuel-efficient or alternative fuel vehicles.

All of these BMPs are potentially applicable for remedial alternatives in the LDW to reduce CO_2 and particulate air emissions. A reduction in CO_2 emissions can be achieved by using biodiesel in the smaller construction equipment (e.g., front-end loaders). The use of biodiesel is limited to small-scale equipment because of its solvent properties. When first introduced into an existing system, biodiesel will remove deposits within the fuel tank and fuel lines, clog existing filters, and thereby create waste and safety issues. This causes biodiesel to be impractical for use in large-scale equipment, especially at higher grades of biodiesel[1] (NBB 2010). Some electric dredges are currently in use that would reduce emissions associated with dredging activities; however, this technology is new and not widely used. Electric dredges would also require further construction design and might not be applicable to the entire LDW because of navigation restrictions. Examples of advanced diesel technologies include retrofitting diesel engines with diesel particulate filters. Fuel-efficient or alternative fuel vehicles such as small trucks or hybrid cars may be considered for site management and monitoring activities.

SO_x emissions depend on the sulphur content of the fuel. For SO_x, 95% of emissions are in the form of SO_2, with 1% to 5% being SO_3. If the sulphur content of the fuel is reduced through emission controls or fuel refinements such as low sulphur fuel, then SO_x emissions will decrease. Emissions of CO, NO_x, and PM_{10} are primarily generated through the operation of construction and transportation equipment. CO is present in exhaust gases and is a result of incomplete fuel combustion. NO_x refers to the composite of nitric oxide (NO) and nitrogen dioxide (NO_2). NO_x forms through thermal fixation and chemical bond conversion, both of which take place during combustion. PM_{10} is generated in two ways. The first is through internal combustion in construction equipment, and the second is dust generated by transportation and construction activities. The best way to reduce GHG and particulate emissions is through the use of BMPs, as described here.

BMPs that can be specified during remedial design to further increase short-term effectiveness include:

- Recycle uncontaminated materials removed from the LDW (i.e., metals, construction debris, tires, etc.).
- Limit on-site vehicle speed to reduce particle suspension and increase fuel efficiency (EPA 2008a).
- Select properly sized and powered equipment.
- Based on availability, consider Tier 2 engines for equipment (likely to have a cost premium associated with this option).
- Select fuel-efficient equipment/vehicles and alternative fuel vehicles (electric, hybrid, compressed natural gas) (EPA 2010b).
- Select equipment fitted with advanced emission control systems (diesel oxidation catalyst, diesel particulate matter filter, partial diesel particulate filter, diesel multi-stage filter, selective catalytic reduction) (EPA 2010b).
- Select efficient modes of transportation for movement of materials (e.g., rail/barge vs. truck transport).

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[1] Biodiesel grades range from B2 (containing 2% biodiesel and 98% diesel fuel) up to B100 (containing 99.9% biodiesel).

- Optimize the transloading process by selecting efficient modes of transportation for movement of materials (e.g., rail vs. truck transport).
- Select lower GHG-emitting fuel sources (e.g., biodiesel) for small equipment and trucks.
- Use ultra-low sulphur fuel in site equipment to reduce SO_x emissions.
- Provide alternatives to diesel-powered generators for use during construction.
- Research salvage of existing structures.
- Impose idling restrictions on construction equipment to increase fuel efficiency and reduce GHG emissions.
- Conduct routine equipment and vehicle maintenance.
- Accurately delineate contaminated sediment and sediment management areas to minimize dredging volume.
- Perform construction sequentially in a manner intended to reduce unnecessary movement of construction equipment.
- Analyze various alternative technologies that could reduce energy consumption, waste, and emissions.
- Select a landfill that collects methane (EPA 2010a).
- Incorporate sustainable site design (EPA 2010a).
- Use Environmental Management System (EMS) practices (EPA 2010a).
- Survey on-site for potential material to backfill excavated/capped areas and re-use on-site material when possible (EPA 2008b).
- Select equipment and processes that minimize water use, and promote reuse and water conservation.
- Adopt environmentally preferable purchasing practices (construction products and other miscellaneous items).
- Select suitable types of equipment and vehicles capable of handling alternative fuels (ultra low sulphur diesel, biomass-based renewable fuel) and fuel additives (emulsified diesel, cetane enhancers) to improve fuel economy and lower GHG emissions (EPA 2010b).
- Select reused, reusable, recycled, and recyclable materials to the greatest extent practical.
- Purchase renewable energy credits.
- Use additional environmental training and meetings for construction personnel to address environmental concerns.
- Select contractors/subcontractors that use EMS practices.

A number of the operation and maintenance BMPs may be applicable to all of the remedial alternatives during construction. These include:

- Reduce vehicle idling.
- Maintain equipment.

- Follow transportation and site management plans that emphasize fuel efficiency and proper fuel handling.
- Obtain materials and equipment locally to minimize shipping and mobilization distance.
- Encourage construction personnel to carpool to and from the site.

As shown in Table L-4, the portions of the pie chart that will likely be most influenced in terms of CO_2 reduction are the miscellaneous and transportation activity categories because small-scale equipment and trucks are associated with these activities. By using biodiesel in small-scale equipment/trucks and following the BMPs listed above, some reductions in CO_2 emissions may be achieved. CO_2 emissions could be reduced by approximately 3% (for all the activities combined for a given remedial alternative) by using B20 grade biodiesel (20% biodiesel). For the other activities depicted in the pie chart, BMPs such as the use of biodiesel are likely to have insignificant effects in terms of CO_2 reduction because of the nature of heavy equipment and transportation conveyances used to perform these activities.

Another aspect of construction is ensuring the safety of all personnel. To prevent accidents, safety BMPs such as the following could be used:

- Complete a safety plan and ensure that all personnel are familiar with it.
- Provide proper safety equipment.
- Perform daily safety tailgate meetings to discuss potential hazards.
- Perform regular safety audits.
- Maintain a Site Safety Officer on-site at all times.

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Table L-1 Background Input Data

1 DREDGING			
Description	Units	Value	References
Emission factor for CO_2	lb/gal	26.635	*SimaPro 7 Database Manual: The Franklin US98 LCI Library* - Inland Vessel transportation (Goedkoop et al. 2008b)
Emission factor for CO	lb/gal	0.13	
Emission factor for NO_x	lb/gal	0.31	
Emission factor for SO_x	lb/gal	0.04	
Emission factor for PM_{10}	lb/gal	0.45	
Emission factor for CO_2	lb/gal	29.168	*SimaPro 7 Database Manual: The Franklin US98 LCI Library* - Excavation with a hydraulic digger (Goedkoop et al. 2008b)
Emission factor for CO	lb/gal	0.1447	
Emission factor for NO_x	lb/gal	0.3417	
Emission factor for SO_x	lb/gal	0.04627	
Emission factor for PM_{10}	lb/gal	0.0489	
Work accidents rate for inland water freight transportation	accidents/ worker/year	0.03600	*U.S. Department of Labor (Industry Injury and Illness Data, 2007 - Supplemental News Release Tables SNR05)*
Deadly work accidents rate for water transportation	accidents/ worker/year	0.00030	*U.S. Department of Labor,* Bureau of Labor Statistics, Census of Fatal Occupational Injuries, 2008
Work accidents rate for heavy and civil engineering construction	accidents/ worker/year	0.05100	*U.S. Department of Labor (Industry Injury and Illness Data, 2007 - Supplemental News Release Tables SNR05)*
Deadly work accidents rate for operating engineers and other construction equipment operators	accidents/ worker/year	0.00011	*U.S. Department of Labor,* Bureau of Labor Statistics, Census of Fatal Occupational Injuries, 2008
Energy content of diesel fuel	MJ/gal	158.041	Commonly accepted heating values for diesel fuel

Table L-1 Background Input Data (continued)

2 TRANSLOADING			
Description	Units	Value	References
Emission factor for CO_2	lb/gal	24.4	*U.S. Life Cycle Inventory Database:* Airborne emissions from transportation fuel combustion- Barge – Diesel (EPA 1995b)
Emission factor for CO	lb/gal	0.0307	
Emission factor for NO_x	lb/gal	0.311	
Emission factor for SO_x	lb/gal	0.00539	
Emission factor for PM_{10}	lb/gal	0.00771	
Work accidents rate for inland water freight transportation	accidents/ worker/year	0.03600	*U.S. Department of Labor (Industry Injury and Illness Data, 2007 - Supplemental News Release Tables SNR05)*
Deadly work accidents rate for water transportation	accidents/ worker/year	0.00030	*U.S. Department of Labor,* Bureau of Labor Statistics, Census of Fatal Occupational Injuries, 2008
Work accidents rate for heavy and civil engineering construction	accidents/ worker/year	0.05100	*U.S. Department of Labor (Industry Injury and Illness Data, 2007 - Supplemental News Release Tables SNR05)*
Deadly work accidents rate for operating engineers and other construction equipment operators	accidents/ worker/year	0.00011	*U.S. Department of Labor,* Bureau of Labor Statistics, Census of Fatal Occupational Injuries, 2008
Energy content of diesel fuel	MJ/gal	158.041	Commonly accepted heating values for diesel fuel

Table L-1 Background Input Data (continued)

3 TRANSPORTATION			
Description	Units	Value	References
Emission factor for CO_2	lb/gal	24.4	*U.S. Life Cycle Inventory Database:* Airborne emissions from transportation fuel combustion- Medium-Heavy-Duty Truck – Diesel (EPA 1995b)
Emission factor for CO	lb/gal	0.0389	
Emission factor for NO_x	lb/gal	0.163	
Emission factor for SOx	lb/gal	0.00539	
Emission factor for PM_{10}	lb/gal	0.0282	
Emission factor for CO_2	lb/gal	24.4	*U.S. Life Cycle Inventory Database:* Airborne emissions from transportation fuel combustion- Locomotive – Diesel (EPA 1995b)
Emission factor for CO	lb/gal	0.0632	
Emission factor for NO_x	lb/gal	0.642	
Emission factor for SOx	lb/gal	0.00539	
Emission factor for PM_{10}	lb/gal	0.016	
Emission factor for CO_2	lb/gal	24.4	*U.S. Life Cycle Inventory Database:* Airborne emissions from transportation fuel combustion- Barge – Diesel (EPA 1995b)
Emission factor for CO	lb/gal	0.0307	
Emission factor for NOx	lb/gal	0.311	
Emission factor for SOx	lb/gal	0.00539	
Emission factor for PM_{10}	lb/gal	0.00771	
Work accidents rate for general freight trucking, local	accidents/ worker/year	0.05200	*U.S. Department of Labor (Industry Injury and Illness Data, 2007 - Supplemental News Release Tables SNR05)*
Deadly work accidents rate for truck transportation	accidents/ worker/year	0.00026	*U.S. Department of Labor,* Bureau of Labor Statistics, Census of Fatal Occupational Injuries, 2008
Work accidents rate for rail transportation	accidents/ worker/year	0.02200	*U.S. Department of Labor (Industry Injury and Illness Data, 2007 - Supplemental News Release Tables SNR05)*
Deadly work accidents rate for rail transportation	accidents/ worker/year	0.00006	*U.S. Department of Labor,* Bureau of Labor Statistics, Census of Fatal Occupational Injuries, 2008
Work accidents rate for inland water freight transportation	accidents/ worker/year	0.036	*U.S. Department of Labor (Industry Injury and Illness Data, 2007 - Supplemental News Release Tables SNR05)*

Table L-1 Background Input Data (continued)

3 TRANSPORTATION			
Description	Units	Value	References
Deadly work accidents rate for water transportation	accidents/ worker/year	0.000299	*U.S. Department of Labor,* Bureau of Labor Statistics, Census of Fatal Occupational Injuries, 2008
Energy content of diesel fuel	MJ/gal	158.041	Commonly accepted heating values for diesel fuel

4 SEDIMENT CAPPING			
Description	Units	Value	References
Emission factor for CO_2	lb/gal	29.168	*LCA Database Manual:* The Franklin US98 LCI Library - Excavation model -Excavation Hydraulic digger (Cadotte et al. 2007)
Emission factor for CO	lb/gal	0.1447	
Emission factor for NO_x	lb/gal	0.3417	
Emission factor for SO_x	lb/gal	0.04627	
Emission factor for PM_{10}	lb/gal	0.0489	
Emission factor for CO_2	lb/gal	26.635	*SimaPro 7 Database Manual: The Franklin US98 LCI Library* - Inland Vessel transportation (Goedkoop et al. 2008b)
Emission factor for CO	lb/gal	0.13	
Emission factor for NO_x	lb/gal	0.31	
Emission factor for SO_x	lb/gal	0.04	
Emission factor for PM_{10}	lb/gal	0.45	
Work accidents rate for inland water freight transportation	accidents/ worker/year	0.03600	*U.S. Department of Labor (Industry Injury and Illness Data, 2007 - Supplemental News Release Tables SNR05)*
Deadly work accidents rate for water transportation	accidents/ worker/year	0.00030	*U.S. Department of Labor,* Bureau of Labor Statistics, Census of Fatal Occupational Injuries, 2008
Work accidents rate for heavy and civil engineering construction	accidents/ worker/year	0.05100	*U.S. Department of Labor (Industry Injury and Illness Data, 2007 - Supplemental News Release Tables SNR05)*
Deadly work accidents rate for operating engineers and other construction equipment operators	accidents/ worker/year	0.00011	*U.S. Department of Labor,* Bureau of Labor Statistics, Census of Fatal Occupational Injuries, 2008
Energy content of diesel fuel	MJ/gal	158.041	Commonly accepted heating values for diesel fuel

Table L-1 Background Input Data (continued)

4 SEDIMENT CAPPING			
Description	Units	Value	References
Emission factor for CO_2	lb/gal	29.168	*LCA Database Manual:* The Franklin US98 LCI Library- Excavation model -Excavation Hydraulic digger (Cadotte et al. 2007)
Emission factor for CO	lb/gal	0.1447	
Emission factor for NO_x	lb/gal	0.3417	
Emission factor for SO_x	lb/gal	0.04627	
Emission factor for PM_{10}	lb/gal	0.0489	
Emission factor for CO_2	lb/gal	26.635	*SimaPro 7 Database Manual: The Franklin US98 LCI Library* - Inland Vessel transportation (Goedkoop et al. 2008b)
Emission factor for CO	lb/gal	0.13	
Emission factor for NO_x	lb/gal	0.31	
Emission factor for SO_x	lb/gal	0.04	
Emission factor for PM_{10}	lb/gal	0.45	
Work accidents rate for inland water freight transportation	accidents/ worker/year	0.03600	*U.S. Department of Labor (Industry Injury and Illness Data, 2007 - Supplemental News Release Tables SNR05)*
Deadly work accidents rate for water transportation	accidents/ worker/year	0.00030	*U.S. Department of Labor,* Bureau of Labor Statistics, Census of Fatal Occupational Injuries, 2008
Work accidents rate for heavy and civil engineering construction	accidents/ worker/year	0.05100	*U.S. Department of Labor (Industry Injury and Illness Data, 2007 - Supplemental News Release Tables SNR05)*
Deadly work accidents rate for operating engineers and other construction equipment operators	accidents/ worker/year	0.00011	*U.S. Department of Labor,* Bureau of Labor Statistics, Census of Fatal Occupational Injuries, 2008
Energy content of diesel fuel	MJ/gal	158.041	Commonly accepted heating values for diesel fuel

Table L-1 Background Input Data (continued)

5 MISCELLANEOUS			
Description	Units	Value	References
Emission factor for CO_2	lb/gal	29.168	*LCA Database Manual:* The Franklin US98 LCI Library- Excavation model -Excavation Hydraulic digger (Cadotte et al. 2007)
Emission factor for CO	lb/gal	0.1447	
Emission factor for NO_x	lb/gal	0.3417	
Emission factor for SO_x	lb/gal	0.04627	
Emission factor for PM_{10}	lb/gal	0.0489	
Work accidents rate for heavy and civil engineering construction	accidents/ worker/year	0.05100	*U.S. Department of Labor (Industry Injury and Illness Data, 2007 - Supplemental News Release Tables SNR05)*
Deadly work accidents rate for operating engineers and other construction equipment operators	accidents/ worker/year	0.00011	*U.S. Department of Labor,* Bureau of Labor Statistics, Census of Fatal Occupational Injuries, 2008
Energy content of diesel fuel	MJ/gal	158.041	Commonly accepted heating values for diesel fuel

CARBON FOOTPRINT			
Description	Units	Value	References
CO_2 absorbed	$g_{CO2}/g_{biomass}$	2.02	Assumes 55% carbon in the total biomass of Douglas fir (Alfredo Provini et al., Ecologia Applicata, 2003, and Zhou & Hemstrom 2009).
Sequestration rate for Douglas fir in Pacific Coast	metric ton dm/acre year	2.09	Representative Carbon Sequestration Rates and Saturation Periods for Key Agricultural & Forestry Practices (EPA 2010c)

Notes:

Distance: average distance is the total distance travelled; one way is the distance to the landfill from the site (will be doubled for calculations).

CO = carbon monoxide; CO_2 = carbon dioxide; dm = dry matter; EPA = U.S. Environmental Protection Agency; gal = gallon; lb = pound; MJ = megajoules; NO_x = nitrogen oxides; PM_{10} = particulate matter with a diameter of 10 µm or less; SO_x = sulphur oxides.

Table L-2 Site-specific Data Input for the Remedial Alternatives

1 DREDGING													
Description	Equipment	Units	Alt 2R-CAD[a]	Alt 3C	Alt 4C	Alt 5C	Alt 6C	Alt 2R	Alt 3R	Alt 4R	Alt 5R	Alt 5R-T[b]	Alt 6R
Volume removed below -10 ft MLLW[c]	barge-mounted derrick crane	cy	809,245	368,429	516,868	564,757	1,234,251	438,245	572,773	863,588	1,237,489	1,237,489	2,957,381
Volume removed above -10 ft MLLW[d]	barge-mounted backhoe	cy	146,082	122,810	172,288	188,252	411,417	146,082	190,925	287,862	412,496	412,496	985,793
Fuel consumption	barge-mounted derrick crane	gal/hr	25	25	25	25	25	25	25	25	25	25	25
	barge-mounted backhoe	gal/hr	10.6	10.6	10.6	10.6	10.6	10.6	10.6	10.6	10.6	10.6	10.6
	survey boat	gal/hr	8	8	8	8	8	8	8	8	8	8	8
Dredging rate[e]	barge-mounted derrick crane	cy/hr	55	55	55	55	55	55	55	55	55	55	55
	barge-mounted backhoe	cy/hr	39	39	39	39	39	39	39	39	39	39	39
Total time required for survey operation	survey boat	hr	918	472	663	724	1,584	562	735	1,108	1,588	1,588	3,795
Number of Water Equipment Operators	—	worker	3	3	3	3	3	3	3	3	3	3	3
Number of Construction Equipment Operators	—	worker	3	3	3	3	3	3	3	3	3	3	3

Table L-2 Site-specific Data Input for the Remedial Alternatives (continued)

2 TRANSLOADING													
Description	Equipment	Units	Alt 2R-CAD[a]	Alt 3C	Alt 4C	Alt 5C	Alt 6C	Alt 2R	Alt 3R	Alt 4R	Alt 5R	Alt 5R-T[b]	Alt 6R
Volume transloaded[f]	tug/barge	cy	955,326	491,239	689,156	753,009	1,645,668	584,326	763,698	1,151,450	1,649,985	1,237,489	3,943,174
Offloading volume material to lined containers[g]	derrick crane	cy	274,326	491,239	689,156	753,009	1,645,668	584,326	763,698	1,151,450	1,649,985	1,237,489	3,943,174
Fuel consumption	tug full engine	gal/hr	85	85	85	85	85	85	85	85	85	85	85
	derrick crane	gal/hr	25	25	25	25	25	25	25	25	25	25	25
Distance from the site to the offloading area	tugs	miles	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2
Speed	tugs	miles/hr	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6
Barge capacity	barge	cy	1,600	1,600	1,600	1,600	1,600	1,600	1,600	1,600	1,600	1,600	1,600
Offloading rate by derrick crane[e]	derrick crane	cy/hr	110	110	110	110	110	110	110	110	110	110	110
Number of water equipment operators	—	worker	3	3	3	3	3	3	3	3	3	3	3
Number of construction equipment operators	—	worker	3	3	3	3	3	3	3	3	3	3	3

Table L-2 Site-specific Data Input for the Remedial Alternatives (continued)

3 TRANSPORTATION													
Description	Equipment	Units	Alt 2R-CAD[a]	Alt 3C	Alt 4C	Alt 5C	Alt 6C	Alt 2R	Alt 3R	Alt 4R	Alt 5R	Alt 5R-T[b]	Alt 6R
Volume transported	truck[h]	cy	274,326	491,239	689,156	753,009	1,645,668	584,326	763,698	1,151,450	1,649,985	1,237,489	3,943,174
	train[i]	cy	274,326	491,239	689,156	753,009	1,645,668	584,326	763,698	1,151,450	1,649,985	1,237,489	3,943,174
	tug/barge[j]	cy	198,208	268,917	470,460	579,232	1,126,528	124,208	263,690	433,330	588,346	1,000,842	1,190,788
Distance	truck (round trip)	miles	12	12	12	12	12	12	12	12	12	12	12
	train (round trip)	miles	568.6	568.6	568.6	568.6	568.6	568.6	568.6	568.6	568.6	568.6	568.6
Fuel consumption	truck	gal/miles	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
	train	gal/miles	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22
	tug	gal/hr	85	85	85	85	85	85	85	85	85	85	85
Load capacity	truck	cy	20	20	20	20	20	20	20	20	20	20	20
	railcar	cy	67	67	67	67	67	67	67	67	67	67	67
Transportation rate	tug	cy/hr	122.7	122.7	122.7	122.7	122.7	122.7	122.7	122.7	122.7	122.7	122.7
Speed	truck	miles/hr	40	40	40	40	40	40	40	40	40	40	40
	train	miles/hr	50	50	50	50	50	50	50	50	50	50	50
Number of trucks used for transportation	truck	—	7	7	7	7	7	7	7	7	7	7	7
Number of operators for truck transportation	—	worker	7	7	7	7	7	7	7	7	7	7	7
Number of operators for rail transportation	—	worker	8	8	8	8	8	8	8	8	8	8	8
Number of water equipment operators	—	worker	2	2	2	2	2	2	2	2	2	2	2

Table L-2 Site-specific Data Input for the Remedial Alternatives (continued)

4 SEDIMENT CAPPING													
Description	Equipment	Units	Alt 2R-CAD[a]	Alt 3C	Alt 4C	Alt 5C	Alt 6C	Alt 2R	Alt 3R	Alt 4R	Alt 5R	Alt 5R-T[b]	Alt 6R
Volume placed below -10 ft MLLW	barge-mounted derrick crane[k]	cy	470,946	188,241	329,322	405,462	788,569	86,946	184,583	303,331	411,842	411,842	833,551
	precision excavator[k]	cy	18,631	40,338	70,569	86,885	168,979	18,631	39,554	65,000	88,252	88,252	178,618
Volume placed above -10 ft MLLW	precision excavator[k]	cy	18,631	40,338	70,569	86,885	168,979	18,631	39,554	65,000	88,252	88,252	178,618
Fuel consumption	barge-mounted derrick crane	gal/hr	25	25	25	25	25	25	25	25	25	25	25
	precision excavator	gal/hr	10.6	10.6	10.6	10.6	10.6	10.6	10.6	10.6	10.6	10.6	10.6
	survey boat	gal/hr	8	8	8	8	8	8	8	8	8	8	8
C = Capping placement rate [e]	barge-mounted derrick crane	cy/hr	163	163	163	163	163	163	163	163	163	163	163
	precision excavator	cy/hr	128	128	128	128	128	128	128	128	128	128	128
Total time required for survey operation	survey boat	hr	145	196	343	423	822	91	192	316	429	429	869
Number of water equipment operators	—	worker	3	3	3	3	3	3	3	3	3	3	3
Number of construction equipment operators	—	worker	3	3	3	3	3	3	3	3	3	3	3

Table L-2 Site-specific Data Input for the Remedial Alternatives (continued)

5 MISCELLANEOUS														
Description	Equipment	Units	Alt 2R-CAD[a]	Alt 3C	Alt 4C	Alt 5C	Alt 6C	Alt 2R	Alt 3R	Alt 4R	Alt 5R	Alt 5R-T[b]	Alt 6R
Volume	loader[l]	cy	274,326	491,239	689,156	753,009	1,645,668	584,326	763,698	1,151,450	1,649,985	1,237,489	3,943,174
Fuel consumption	loader	gal/hr	7	7	7	7	7	7	7	7	7	7	7
Excavation rate[e]	loader	cy/hr	200	200	200	200	200	200	200	200	200	200	200
Number of construction equipment operators	—	worker	2	2	2	2	2	2	2	2	2	2	2

Notes:

1. Values used in all calculations were not rounded.

a. Alternative 2R-CAD assumes that 370,000 cy of sediment will be dredged to construct the CAD. This extra sediment is assumed to be disposed of at the open water disposal site in Elliott Bay. 311,000 cy of contaminated sediment will be placed in the CAD, reducing the amount of sediment sent to the landfill. 74,000 cy of clean import capping material will be used to cover the CAD.
b. Alternative 5R-Treatment assumes that half of the volume dredged in Alternative 5R will be suitable for soil washing. Half of the sediment that undergoes treatment is assumed to require off-site disposal, the other half is assumed to be clean sand. This results in Alternative 5R-T transporting 25% less sediment to the landfill than 5R. Emissions or energy consumed by the soil washing process were not calculated because data required for these calculations were not available.
c. This volume represents the volume of sediment below -10 ft MLLW to be dredged (assumed to be 75% of total dredged material).
d. This volume represents the volume of sediment above -10 ft MLLW to be dredged (assumed to be 25% of total dredged material). This is the volume that the tug/barge combination transports from the dredge site to the transloading facility.
e. Dredge and cap equipment rates are consistent with those developed in Appendix I with exclusion of the effective working time factor (see Tables I-5 and I-6 of Appendix I). The offloading rate by derrick crane was assumed to be twice the derrick crane dredging rate. The loader production rate was based on the 100 HP loader/ 2 cy bucket capacity provided in the SiteWise™ Tool for Green and Sustainable Remediation developed jointly by U.S. Navy, U.S. Army Corps of Engineers, and Battelle (SiteWise™ Version 2.0).
f. This is the volume of dredged material that is barged from the dredging site to the transloading facility except for Alternative 2R-CAD. In Alternative 2R-CAD, approximately 371,000 CY is assumed to be transported to the DMMP site in Elliott Bay for open water disposal.
g. This is the volume of dredged material offloaded from the barge by a derrick crane at the transloading facility.
h. This is the volume of dredged material that is transported by truck from the transloading facility to the train transfer station in Seattle, WA (8 miles round trip), and further transferred by truck from the landfill offloading site to the landfill cell in Roosevelt, WA (4 miles round trip).
i. This is the volume of material transferred from the train transfer station in Seattle, WA to the offloading facility in Roosevelt, WA.
j. This is the volume of clean capping material barged in from the commercial quarry to the project site.
k. These volumes represent the volume of clean material for capping, ENR, and backfill required. The material is assumed to be placed by barge mounted derrick crane below -10 ft MLLW (assumed to be 70% of total material), precision excavator below -10 ft MLLW (assumed to be 15% of total material), and precision excavator above -10 ft MLLW (assumed to be 15% of total material).
l. This is the volume of contaminated sediment to be handled by a front end loader at the landfill facility.

C = combined-technology alternative; CAD = contained aquatic disposal; cy = cubic yard; DMMP = Dredged Material Management Program; ENR = enhanced natural recovery; ft = feet; gal = gallon; HP = horsepower; lb = pound; MLLW = mean lower low water; hr = hour; R = removal emphasis alternative; R-T = removal emphasis with treatment.

Table L-3 Short-term Effectiveness Metrics Summary Output

Summary			Alt 2R-CAD		Alt 3C		Alt 4C		Alt 5C		Alt 6C	
Gas Emission	CO_2 emissions	metric ton	E_{CO2}	17,020	E_{CO2}	18,516	E_{CO2}	26,857	E_{CO2}	29,964	E_{CO2}	64,162
	CO emissions	metric ton	E_{CO}	53	E_{CO}	49	E_{CO}	71	E_{CO}	79	E_{CO}	170
	NO_x emissions	metric ton	E_{NOx}	284	E_{NOx}	364	E_{NOx}	522	E_{NOx}	578	E_{NOx}	1,246
	SO_x emissions	metric ton	E_{SOx}	13	E_{SOx}	9	E_{SOx}	13	E_{SOx}	14	E_{SOx}	30
	PM_{10} emissions	metric ton	E_{PM10}	18	E_{PM10}	15	E_{PM10}	22	E_{PM10}	25	E_{PM10}	53
Energy	Energy consumption	MJ	E	2.28E+08	E	2.56E+08	E	3.72E+08	E	4.15E+08	E	8.89E+08
Landfill	Volume (20% bulking factor)	cy	LF	329,191	LF	589,487	LF	826,987	LF	903,611	LF	1,974,802
Work Accidents	Expected number of accidents during remediation activities	—	N_I	8.94E+00	N_I	1.32E+01	N_I	1.86E+01	N_I	2.04E+01	N_I	4.43E+01
	Expected number of deadly accidents during remediation activities	—	N_F	2.80E-02	N_F	4.28E-02	N_F	6.05E-02	N_F	6.64E-02	N_F	1.45E-01
Carbon Footprint		Acre-Years	EF	4,029	EF	4,384	EF	6,358	EF	7,094	EF	15,190

Notes:

Green text indicates the lowest effects.

Red text indicates the highest effects.

C = combined-technology alternative; CAD = contained aquatic disposal; CO = carbon monoxide; CO_2 = carbon dioxide; cy = cubic yard; µm = micrometer; MJ = megajoule; NO_x = nitrogen oxides; PM_{10} = particulate matter with a diameter of 10 µm or less; SO_x = sulphur oxides.

Table L-3 Short-term Effectiveness Metrics Summary Output (continued)

Summary			Alt 2R		Alt 3R		Alt 4R		Alt 5R		Alt 5R-T		Alt 6R	
Gas Emission	CO_2 emissions	metric ton	E_{CO2}	20,167	E_{CO2}	27,318	E_{CO2}	41,525	E_{CO2}	59,196	E_{CO2}	51,226	E_{CO2}	139,421
	CO emissions	metric ton	E_{CO}	55	E_{CO}	74	E_{CO}	112	E_{CO}	160	E_{CO}	138	E_{CO}	379
	NO_x emissions	metric ton	E_{NOx}	410	E_{NOx}	547	E_{NOx}	830	E_{NOx}	1,185	E_{NOx}	973	E_{NOx}	2,806
	SO_x emissions	metric ton	E_{SOx}	10	E_{SOx}	13	E_{SOx}	20	E_{SOx}	28	E_{SOx}	26	E_{SOx}	66
	PM_{10} emissions	metric ton	E_{PM10}	17	E_{PM10}	23	E_{PM10}	35	E_{PM10}	50	E_{PM10}	44	E_{PM10}	118
Energy	Energy consumption	MJ	E	2.79E+08	E	3.78E+08	E	5.75E+08	E	8.28E+08	E	7.07E+08	E	1.93E+09
Landfill	Volume (20% bulking factor)	cy	LF	701,191	LF	916,438	LF	1,381,740	LF	1,979,982	LF	1,484,987	LF	4,731,809
Work Accidents	Expected number of accidents during remediation activities	—	N_I	1.54E+01	N_I	2.03E+01	N_I	3.06E+01	N_I	4.39E+01	N_I	3.40E+01	N_I	1.05E+02
	Expected number of deadly accidents during remediation activities	—	N_F	5.00E-02	N_F	6.58E-02	N_F	9.94E-02	N_F	1.42E-01	N_F	1.11E-01	N_F	3.39E-01
Carbon Footprint		Acre-Years	EF	4,775	EF	6,468	EF	9,831	EF	14,015	EF	12,128	EF	33,008

Notes:

Green text indicates the lowest effects.

Red text indicates the highest effects.

CO = carbon monoxide; CO_2 = carbon dioxide; cy = cubic yard; µm = micrometer; MJ = megajoule; NO_x = nitrogen oxides; PM_{10} = particulate matter with a diameter of 10 µm or less; R = removal emphasis alternative; R-T = removal-emphasis with treatment; SO_x = sulphur oxides.

Table L-4 Summary of Carbon Dioxide Emissions by Remedial Alternative and Methods to Reduce Emissions

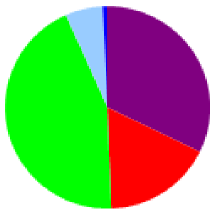
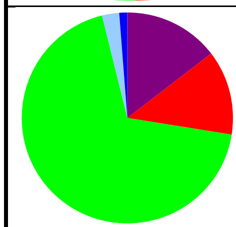
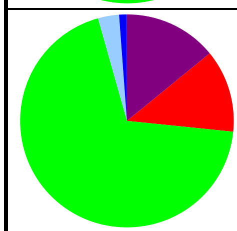
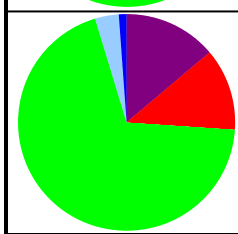
Total Carbon (CO_2) Footprint	Remedial Alternative	CO_2 Amounts (metric tons) (percentage of total[a])						Methods to Reduce/Limit Carbon Footprint and Best Management Practices (BMPs)
		Dredging	Transloading	Transportation	Capping	Miscellaneous	Total	
	Alt 2R-CAD	5,481 (32%)	2,940 (17%)	7,462 (44%)	1,010 (6%)	127 (1%)	17,020	<u>CO_2 Reduction BMPs</u> 1. Use biodiesel in small-scale construction equipment and trucks. <u>Remedial Design BMPs</u> 1. Collect location-specific data. 2. Accurately delineate contaminated sediment and sediment management areas to minimize dredging volume. 3. Perform construction sequentially. 4. Analyze alternative technologies. 5. Select a landfill that collects methane. 6. Incorporate sustainable site design. 7. Use Environmental Management System Practices. 8. Recycle uncontaminated materials. 9. Use renewable energy resources. 10. Limit on-site vehicle speeds. 11. Select properly sized equipment. 12. Select fuel-efficient equipment/vehicles and alternative fuel vehicles. 13. Select equipment fitted with advanced emission control systems. 14. Consider Tier 2 engines for equipment.
	Alt 3C	2,703 (15%)	2,395 (13%)	12,702 (69%)	489 (3%)	227 (1%)	18,516	
	Alt 4C	3,792 (14%)	3,355 (13%)	18,535 (69%)	856 (3%)	319 (1%)	26,857	
	Alt 5C	4,143 (14%)	3,667 (12%)	20,751 (69%)	1,054 (3%)	349 (1%)	29,964	

Table L-4 Summary of Carbon Dioxide Emissions by Remedial Alternative and Methods to Reduce Emissions (continued)

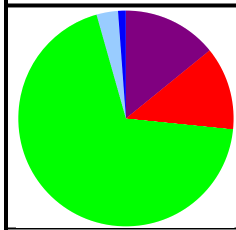
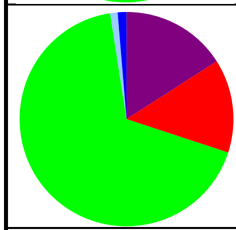
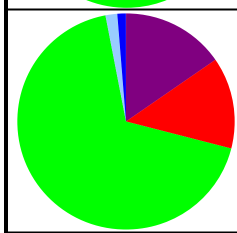
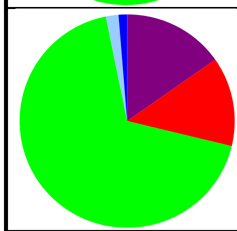
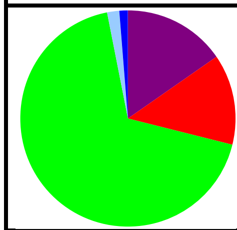
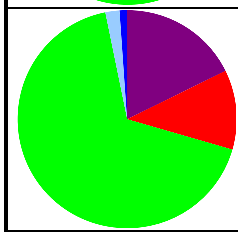
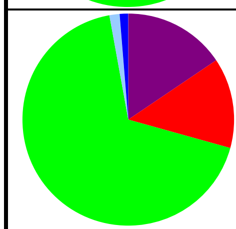
Total Carbon (CO_2) Footprint	Remedial Alternative	CO_2 Amounts (metric tons) (percentage of total [a])						Methods to Reduce/Limit Carbon Footprint and Best Management Practices (BMPs)
		Dredging	Transloading	Transportation	Capping	Miscellaneous	Total	
	Alt 6C	9,055 (14%)	8,012 (12%)	44,283 (69%)	2,050 (3%)	762 (1%)	64,162	15. Select efficient modes of transportation for movement of materials. 16. Select lower GHG emitting fuel sources (i.e. biodiesel). 17. Consider alternatives to diesel-powered generators. 18. Consider salvaging existing structures. 19. Search on-site for potential backfill and reuse on-site material when possible. 20. Select equipment and processes that minimize the usage of water, and promote water reuse and conservation. 21. Adopt environmentally preferable purchasing practices. 22. Select suitable types of equipment and vehicles capable of handling alternative fuels and fuel additives (i.e., ultra low sulphur fuel). 23. Optimization of the transloading process by selecting efficient modes of transportation for movement of materials (e.g., rail vs. truck transport).
	Alt 2R	3,215 (16%)	2,847 (14%)	13,608 (67%)	226 (1%)	271 (1%)	20,167	
	Alt 3R	4,202 (15%)	3,720 (14%)	18,562 (68%)	480 (2%)	354 (1%)	27,318	
	Alt 4R	6,336 (15%)	5,606 (13%)	28,261 (68%)	789 (2%)	533 (1%)	41,525	

Table L-4 Summary of Carbon Dioxide Emissions by Remedial Alternative and Methods to Reduce Emissions (continued)

Total Carbon (CO_2) Footprint	Remedial Alternative	CO_2 Amounts (metric tons) (percentage of total [a])						Methods to Reduce/Limit Carbon Footprint and Best Management Practices (BMPs)
		Dredging	Transloading	Transportation	Capping	Miscellaneous	Total	
	Alt 5R	9,079 (15%)	8,034 (14%)	40,248 (68%)	1,071 (2%)	764 (1%)	59,196	<u>Construction BMPs</u> 1. Impose idling restrictions on construction equipment. 2. Conduct regular equipment and vehicle maintenance. 3. Develop transportation and site management plans that emphasize fuel efficiency and handling.
	Alt 5R-T	9,079 (18%)	6,025 (12%)	34,478 (67%)	1,071 (2%)	573 (1%)	51,226	
	Alt 6R	21,697 (16%)	19,195 (14%)	94,536 (68%)	2,167 (2%)	1,826 (1%)	139,421	

Notes:

Dredging Transloading Transportation Capping Miscellaneous

a. Percentages shown in this table are rounded. Therefore, hand-calculated totals of these percentages may slightly exceed or fall short of 100%.

BMPs = best management practices; C = combined-technology alternative; CAD = contained aquatic disposal; CO_2 = carbon dioxide; GHG = greenhouse gas; R = removal emphasis alternative; R-T = removal-emphasis with treatment.

Figure L-1 Life Cycle of the Remediation Activities Concept Diagram