The Utilization and Effectiveness of Sediment Recontamination Prevention Measures at Superfund Sites: The Lower Duwamish River Waterway Early Action Area Terminal 117, Seattle, Washington

Railin Peterson

A Thesis

Submitted in partial fulfillment of the requirements for the degree of

Master of Marine Affairs

University of Washington

2013

Committee:

Tom Leschine

David Fluharty

Program Authorized to Offer Degree:

School of Marine and Environmental Affairs

Abstract

Large aquatic Superfund sites often have sediment recontamination issues due to difficulties with pollutant source control, dynamic natural environments and shortfalls in the regulatory systems. The Lower Duwamish Waterway in Seattle, Washington is an example of a large estuarine Superfund site where clean up actions have occurred and more are proposed and potential recontamination threatens the permanence of proposed remedies. Contaminants threaten human and environmental health and recontamination and recontamination prevention can cost millions of dollars, most of which must come from public agencies. Terminal 117, located in the Lower Duwamish Waterway, is selected as a case study to identify regulatory and other issues contributing to recontamination. The objective of this study is to examine two questions: Is recontamination likely to occur at the Lower Duwamish Waterway Terminal 117 site? If so, why are source control efforts not able to prevent recontamination?

To assess whether recontamination is likely to occur at the T-117 site this thesis looks at what guidance and laws are available to help prevent recontamination, then reviews the T-117 pollution source control plans and actual source control actions to assesses whether the guidance is being followed. In addition to a literature and technical document review, a dozen professionals working on the LDW Superfund site were interviewed, including federal, state and local agency representatives, citizen group representatives and private sector lawyers and consultants. Research indicated that recontamination is likely to occur at the T-117 site. Potential recontamination may be attributed to technological limitations, environmental and political complexities and failing to identify and/or control pollution sources. To reduce the occurrence of potential recontamination this assessment recommends mandating knowledge

sharing for project managers, creating more effective federal guidance on source control methods, and reexamining the achievability of cleanup standards.

Acronyms

ARAR	Applicable or Relevant and Appropriate Requirements
BMP	Best Management Practice
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
COC	Chemical of Concern
CSL	Cleanup Screening Level
CSO	Combined Sewer Overflow
CSTAG	Contaminated Sediments Technical Advisory Group
CWA	Clean Water Act
EAA	Early Action Area
Ecology	Washington State Department of Ecology
EE/CA	Engineering Evaluation/Cost Analysis
EPA	U.S. Environmental Protection Agency
FS	Feasibility Study
LDW	Lower Duwamish Waterway
LDWG	Lower Duwamish Waterway Group
MTCA	Model Toxics Control Act
NPDES	National Pollutant Discharge Elimination System
NRRB	National Remedy Review Board
NPL	National Priorities List
PAH	Polycyclic Aromatic Hydrocarbon
PBDE	Polybrominated Diphenyl Ether
PCB	Polychlorinated Diphenyl
PRP	Potentially Responsible Party
QAPP	Quality Assurance Program Plan
RCRA	Resource Conservation and Recovery Act
RvAL	Removal Action levels
RI	Remedial Investigation
RI/FS	Remedial Investigation/Feasibility Study
RM	River Mile
ROD	Record of Decision
SAIC	Science Applications International Corporation
SCAP	Source Control Action Plan
SCWG	Source Control Work Group
SMS	Washington State Sediment Management Standards
SQS	Sediment Quality Standard
T-117	Terminal 117
TCRA	Time Critical Removal Action
TSCA	Toxic Substances Control Act
USACE	U.S. Army Corps of Engineers
USEPA	U.S. Environmental Protection Agency

Table of Contents

Part I: Superfund and the Recontamination Issue

Figures

Tables

Part I: Superfund and the Recontamination Issue

Introduction:

Sediments at large aquatic Superfund sites often exhibit recontamination where concentrations of some contaminants rise above cleanup standards after remediation actions have been implemented. Recontamination not only means a project fails to achieve long-term goals, it also prolongs the exposure of the environments and communities to harmful contaminants and leads to higher project costs. At some large Superfund sites that have contaminated sediments, costs have soared to nearly one billion dollars. Some of the reasons recontamination occurs include technological limitations, environmental and political complexities and failing to identify and/or control pollution sources.

The National Research Council which studied the effectiveness of dredging at contaminated sediments sites and concluded that many large contaminated sediment sites can take decades to remediate, will encounter unforeseen conditions, and present tremendous technical challenges and uncertainties (NRC, 2007). Steven Nadeau, a lawyer in the field, found sediment recontamination occurs all over the nation (Nadeau, 2007) and that the existing national guidance lacks the details necessary to transfer risk management principles into technical practice (Nadeau, 2011).

A report by Nadeau and Skaggs (2007) identified twenty documented cases of sediment recontamination; a table of recontaminated sites is presented in Appendix A, Table A3. The

Lower Duwamish Waterway (LDW) in Seattle, Washington is an example of a large estuarine Superfund site, which has undergone significant source control efforts in an attempt to prevent continued contamination. However, Environmental Protection Agency (EPA) and the Washington State Department of Ecology (WA DOE) Superfund Project Managers now say that due to unidentified sources, atmospheric deposition and limited technologies and resources, it is likely the Lower Duwamish Waterway Superfund site will exhibit recontamination after cleanup remedies are conducted (Flint and Thomas, 2013).

One of the Early Action Areas in the LDW, Terminal 117 (T-117) is selected as a case study in this document to identify issues contributing to recontamination. Two questions are examined in this thesis: Is recontamination likely to occur at the Lower Duwamish Waterway Terminal 117 site? If so, why are source control efforts not able to prevent recontamination? To assess whether recontamination is likely to occur at the T-117 site this thesis looks at what guidance and laws are available to help prevent recontamination, then reviews the T-117 pollution source control plans and actual source control actions to assesses whether the guidance is useful, effective and being followed. In addition to a literature and technical document review, a dozen professionals working on the LDW Superfund site were interviewed including federal, state and local agency representatives, citizen group representatives and private sector lawyers and consultants.

The case study is organized into two parts. Part I (Chapters one through three) provides background on the experience of using the Superfund Process and Part II (Chapters four through seven) focuses on the specifics of the T-117 Site in Seattle, Washington. In Part I, Chapter one discusses what the Comprehensive Environmental Response Compensation and Liability Act (CERCLA) is, when and why it came to be and the progression of the law since it was first established along with some common critiques. The second chapter informs the reader on the causes and prevalence of recontamination and why recontamination is a problem that should concern everyone. Chapter two then goes on to summarize the traditional regulatory frameworks by which Superfund recontamination is governed. Chapter three looks at written guidance on pollution source control, which every agency working on the LDW is expected to follow; in addition it covers what makes an effective policy using literature by policy analysts including Weimer and Vining (2011), and Koontz and Thomas (2006). In Part II Chapters four through seven hone in on what is occurring at the LDW site and in particular, the T-117 site. Chapter four introduces the LDW and the T-117 site location, history and progress. Chapter five delves more deeply into source control actions and the use of National guidance documents. Chapter six discusses the challenges with preventing recontamination and Chapter seven looks to the future of the T-117 site and presents some recommendations that were expressed by agency representatives and refined through the author's research. Provided recommendations include mandating knowledge sharing for project managers, creating more effective federal guidance on source control methods, and reexamining the achievability of cleanup standards.

Section 1: Superfund

The purpose of this Chapter is to provide the reader with an understanding of the enactment, implementation and site remediation process under Superfund. Information provided in this chapter will be built upon in Chapters two through seven to help assess why recontamination is occurring at Superfund sites with contaminated sediments.

On December 11, 1980, the Comprehensive Environmental Response, Compensation, and liability Act (CERCLA) (Title 40 CFR Part 300) also known as Superfund was passed in response to the toxic legacy left behind by the industrial revolution. Under CERCLA a physical piece of land, a section of a waterbody or a combination of both land and water can be listed on the National Priorities List (NPL), meaning the area contains high levels of toxic chemicals in the soil, sediment or water that require cleanup under the federal law. Each Superfund site is unique with a distinct set of challenges. The law was written with a simple Superfund site in mind, a site which has a confined pollution source such as waste packaged in drums, a defined area likely bounded within a fence and an isolated contaminated media such as soils (interview - EPA representative, 2013).

On a national level Superfund is implemented by the United States Environmental Protection Agency (EPA). The original goal of the act was to assign cleanup liability to identified polluters and provide a trust fund (the Superfund) for contaminated sites where the primary polluters either cannot be identified or lack resources to implement a cleanup. Liability is strict, several and retroactive meaning an organization or multiple organizations can be held liable for the entire cleanup even if the organization contributed only a fraction of the toxins and even if the pollution occurred prior to CERCLA implementation.

In the 1980s and early 1990s the Law received significant negative reviews from both industry and government (GAO, 2008). A majority of reviews indicated that the Superfund program was too costly and progress was too slow. Policy analysts have noted significant improvements to the implementation of Superfund since it was first established however (Barnett, 1994; Nakamura, 2003; National Research Council, 2007). In particular, collaboration and negotiations have improved and administrative costs have declined (GAO, 2008).

Three categories of Superfund removal actions exist including emergency, time-critical and non-time critical. Categories are based on human and environmental exposure and intensity of the hazardous contaminant. Under an emergency removal action, preparation of a solution is required within hours of emergency identification and direction to isolate the contamination from the public. Under the time-critical status, removal actions should start within six months and under non-time critical status planning will likely take longer than six months (Wagner, 1994). It should be noted that many cleanups, regardless of the designated category, take longer than these timelines suggest.

The Superfund site response action generally follows a nine-step process, which is not necessarily sequential. The steps included are outlined below in Table 1.

Table 1. Superfund Site Response Action Process

Preliminary Assessment/Site Inspection	Investigations of site conditions. If the release of hazardous substances requires immediate or short-term response actions, these are addressed under the Emergency Response program of Superfund.
National Priorities List (NPL) Site Listing Process	A list of the most serious sites identified for possible long-term cleanup.
Remedial Investigation/Feasibility Study	Determines the nature and extent of contamination. Assesses the treatability of site contamination and evaluates the potential performance and cost of treatment technologies.
Record of Decision	Explains which cleanup alternatives will be used at NPL sites. When remedies are estimated to exceed 25 million dollars, they are reviewed by the National Remedy Review Board.
Remedial Design/Remedial Action	Preparation and implementation of plans and specifications for applying site remedies. The bulk of the cleanup usually occurs during this phase. All new fund-financed remedies are reviewed by the National Priorities Panel.
Construction Completion	Identifies completion of physical cleanup construction, although this does not necessarily indicate whether final cleanup levels have been achieved.
Post Construction Completion	Ensures that Superfund response actions provide for the long-term protection of human health and the environment. Included here are Long-Term Response Actions (LTRA), Operation and Maintenance, Institutional Controls, Five-Year Reviews, Remedy Optimization.
National Priorities List Deletion	Removes a site from the NPL once all response actions are complete and all cleanup goals have been achieved.
Site Reuse/Redevelopment	Information on how the Superfund program is working with communities and other partners to return hazardous waste sites to safe and productive use without adversely affecting the remedy.

Source: EPA, 2011. Website: http://www.epa.gov/superfund/cleanup/. Accessed May 30, 2013.

EPA Superfund staff follow nine criteria when choosing a remediation plan to achieve the cleanup goal. These criteria include:

- Overall protection of human health and the environment;
- Compliance with state sediment management standards;
- Long-term effectiveness and permanence;

- Reduction of toxicity, mobility, or volume;
- Short-term effectiveness;
- Implementability;
- Cost; and
- State and community acceptance (EPA, http://www.epa.gov/lawsregs/laws/cercla.html)

Superfund regulations do not have codified numerical cleanup standards but instead require compliance with applicable or relevant and appropriate (ARARs) environmental and health requirements, which are chosen by project managers at each cleanup site and are frequently subjects of negotiation among involved parties. The chosen standards are based on the future proposed use of the site; proposed residential uses will require stricter standards than a site proposed for industrial use. In addition, state regulations may play a role in setting cleanup standards at a Superfund site.

On October 17th 1986 CERCLA was amended via the Superfund Amendments and Reauthorization Act (SARA) (42 U.S.C. 9601). The goals of SARA were to emphasize the importance of permanent remedies and innovative remediation technologies; require Superfund actions to adhere to the standards and requirements of other state and federal environmental laws and regulations; create new enforcement authorities and settlement tools; increase State involvement; encourage focusing cleanup actions on human health and increasing citizen participation in decision making (EPA, 2011c). In addition, the Act increased the trust fund to 8.5 million dollars (EPA, 2011c).

1.1 Stakeholders, Actors and Institutions

The actors involved in Superfund remediation are EPA regional staff and potentially responsible parties (PRP), which have been identified through pollution analysis. In aquatic areas PRPs often include but are not limited to local municipalities and ports. While EPA and responsible parties are the obvious actors overseeing site planning and remediation, Superfund projects can greatly affect local communities, especially in cases similar to the LDW in Seattle, where minority communities live, recreate and pursue subsistence fishing in the vicinity of the project area.

Other federal, State and local laws come into play when investigating, planning, remediating and monitoring Superfund sites. The Clean Water Act (CWA) was passed in 1972 to regulate discharges of pollutants into United States waters and to implement surface waters quality standards. Under the Clean Water Act point source pollutant discharges into navigable waters are illegal unless permitted (EPA, 2013a). National Pollutant Discharge Elimination System (NPDES) permits, which are issued under the CWA, regulate many of the discharges that enter into waterbodies and waterways and have thus become a method of source control for many sites. When a Superfund site is remediated the project needs to follow total maximum daily load (TMDL) standards under the CWA. In addition, Superfund projects need to follow state laws. In Washington, Superfund cleanups follow the Sediment Management Standards (SMS) under the Washington State Model Toxic Control Act (MTCA). The role other regulations play in the LDW Superfund process is discussed further in Chapter three.

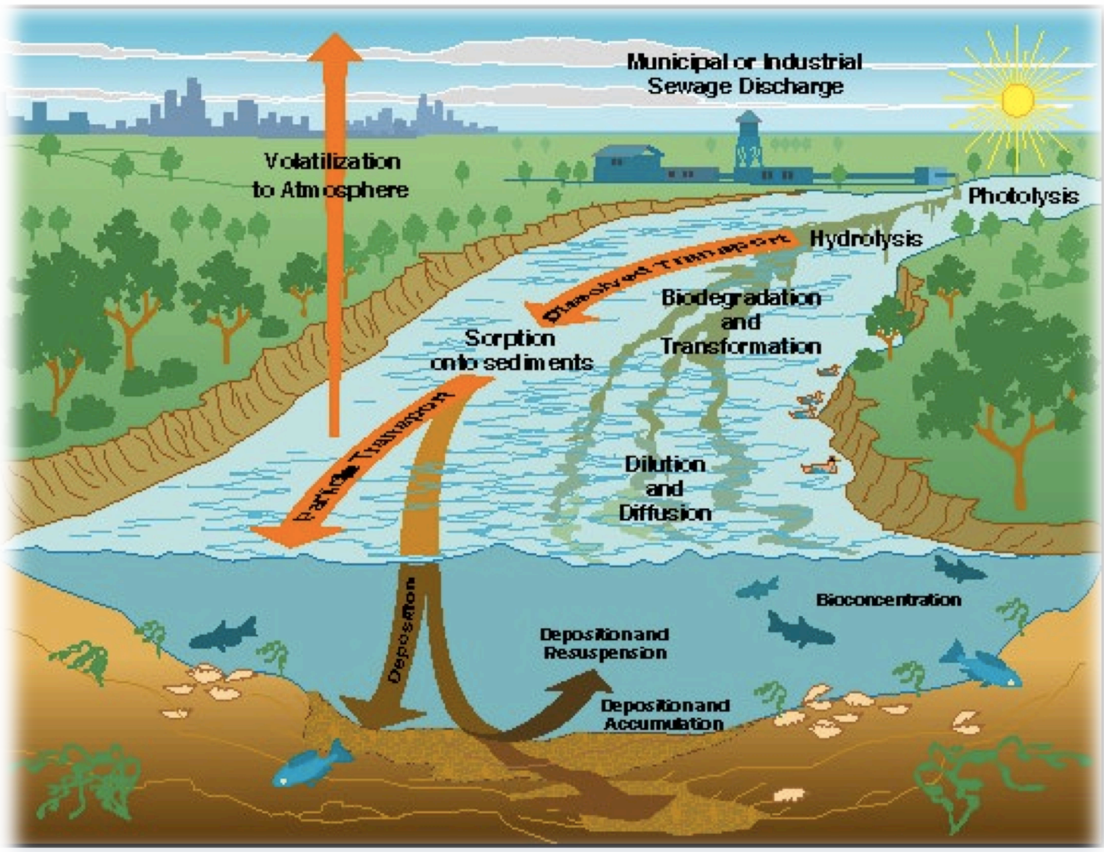
Section 2: The Problem of Sediment Recontamination and the Regulatory Framework

This Chapter describes recontamination and then discusses governance frameworks that may influence the occurrence of Superfund recontamination events. The governance frameworks discussed include command and control, decentralization, bureaucratic governance, and evaluation. The chapter concludes with a discussion of how various stakeholders can influence decisions made during the Superfund process.

2.1 Sediment Recontamination

Recontamination can occur after a Superfund site is remediated and is characterized by the existence of contamination in sediment, soils or water at concentrations above set remediation levels. There are several possible causes of site recontamination. First, poor dredging methods can resuspend buried contaminated sediments into the water column. Resuspension can increase or release the toxins in post-construction water samples. Further, contaminated sediments may resettle onto clean sediments. These resettled contaminants are referred to as residuals (Bridges et al. 2010). Second, upstream contaminated sediments can flow downstream into remediated areas. Third, pollutions sources such as Combined Sewer Overflow Systems (CSO) may not be properly controlled prior to beginning cleanup and fourth, cap failure has occurred at some sites from various environmental or anthropogenic events releasing contaminants under the cap into the environment. The fate of contaminants in a river system is depicted below in Figure 1.

Figure 1. Fate of Contaminants in a River



Source: Website: http://pubs.usgs.gov. Accessed May 30, 2013.

An analysis of sediment sites where recontamination has occurred "indicated that 20 areas where dredging [and] or capping remedies had been completed were recontaminated from outside sources, primarily by combined sewer outfalls (CSOs), unremediated upland areas, and adjacent and upstream unremediated areas" (Nadeau and Skaggs 2007). A list generated by Nadeau and Skaggs (2007) identified twenty-two sites nation-wide where post cleanup recontamination has occurred (See Appendix A, Table A.3 for a full list).

CERCLA was written for a "simple" Superfund site with distinct boundaries around contamination and isolated pollution sources. The LDW, along with Superfund sites at Portland

Harbor, OR and Commencement Bay, Washington are not simple sites that conform to this ideal. The pollution sources are complex and sometimes unidentifiable; there is not one isolated medium but mobile sediments and waters, and contaminated upland soils. "Addressing contaminated sediment sites is often more complex and costly than sites with soil or groundwater contamination alone" (Bridges et al. 2011). Sediment cleanup efforts can take from eight to more than twenty years (Bridges et al., 2012). A broad understanding of the complexity and uncertainty associated with contaminated sediment at aquatic Superfund sites did not emerge for more than thirty years after the Superfund program was developed (Bridges et al. 2011).

The sources of contamination at aquatic sites are not isolated but instead seem to endlessly expand as the atmosphere and tributaries are identified as additional sources of contamination. Urban estuary sites located at the bottom of a watershed have had occurrences of sediment recontamination due to the difficulty in controlling a great diversity of potential pollution sources, which often include stormwater, atmospheric deposition and upstream water and sediment sources. In addition, some state and local agency personnel interviewed feel there is a lack of directives on source control and recontamination prevention.

Even though sediment remediation has been implemented and evaluated for several decades, significant remaining uncertainties compromise the ability to confidently predict the outcomes of a cleanup measure (Bridges et al., 2010). Several guidance documents regarding pollution source control have been released by federal agencies (USEPA, 1998; USEPA, 2002 and USEPA 2005); however these guidance documents may not be sufficient to prevent recontamination events (Bridges, et al., 2010). The physical scale of the recontamination issue is national; most if not all of the major rivers in the United States have parts that have been designated as Superfund sites and have been or are at risk of recontamination. There is an urge to move forward with remediation projects, but pollution source identification and control can be a lengthy process.

2.2 Recontamination Governance Frameworks

Superfund relies on a command and control regulatory governance framework implemented under a decentralized system at the regional level of EPA offices. The command and control framework which is used for assigning liability is not likely effective at prevent recontamination. CERCLA was primarily designed to assign liability for contamination remediation, and the issue of recontamination is not clearly regulated under Superfund. There have been attempts to remedy the issue through EPA agency guidance memorandums (USEPA, 1998; USEPA, 2002; and USEPA, 2005).

In aquatic sites pollutants are highly mobile and site contamination is more difficult to link to a single source or responsible party. While command and control mechanisms may work well when dealing with situations where a violation is clearly identified, they are not as effective in dealing with non-point sources of pollution or rapidly changing technologies (Gunningham, 1998). In addition, CERCLA is not the only law that influences remediation outcomes; recontamination prevention depends on other regulations, both federal and state, to control current sources coming into the system.

Decentralization

Decentralization under Superfund has benefits but can also contribute to failure. Policy analysis literature has encouraged accommodating heterogeneity by designing flexibility and decentralization into policy (Weimer and Vining, 2011). A benefit of decentralization is that implementation can be tailored to more realistically meet the needs of both the site conditions and the local socio-political and economic environment. The disadvantage is that delegating out enforcement from the central authority may mean less guidance and directive.

The success of a policy's implementation can be influenced by four general factors: the logic of the policy, the incentives to implement the policy, the nature of the cooperation required and the availability of skilled people to manage the implementation (Weimer and Vining, 2011). The logic of the policy considers the "results chain" or the reasonableness of the underlying theory and what theory connects policy to intended outcomes. Do the hypothesis/assumptions lead to a realistic chain of events toward outcomes? While flexibility and decentralization work to encompass a wide variety of situations, they can also leave room for exploitation and in the case of Superfund may provide too loose a structure to accomplish the chain of behaviors that is needed to carry the policy from intentions to desired outcomes. A significant gap exists between national CERCLA guidance and its implementation (Nadeau, 2011), which is often referred to as the principal-agent problem (Weimer and Vining, 2011).

Superfund sites have many types of chemicals and many pollution sources, which often require tailored cleanup methodologies. "Due to the unique nature of each waste site, remediation decisions are intentionally decentralized" (Daley et al., 2004); decisions and controls are delegated to EPA regional offices. Recognizing that nonpoint source pollution is a major "contributor to environmental degradation has led some to conclude that centralized, federally controlled efforts are insufficient to solve many environmental problems" (Koontz and Thomas, 2006). Superfund implementation on a regional scale allows project managers to tailor implementation to address the needs and environmental variables in each area.

At the same time regulatory decentralization is a challenge when it comes to source control. In part, because relying on local implementation excludes learning gained from other national sediment recontamination prevention efforts. Existing national guidance "lacks the specificity and detail needed to transform key concepts into technical practice, i.e., the "how to" of implementing risk management principles in the process of developing, evaluating, selecting, and implementing remedies for sites" (Nadeau, 2011). While Superfund has many implementation tools in its toolbox, there is little statutory guidance for assembling those tools into a coherent program; decisions are left up to regional offices (Nakamura 2003). Multiple agency representatives interviewed stated that there was a lack of guidance on source control methods (Interview - WA DOE Representative, 2013 (Thomas); Interview - City of Tacoma Representative, 2013). In addition, a national perspective indicated that agencies in Region 10 are the leaders in understanding the importance of source control (Interview - Nadeau, 2013). Local agency staff have been forced to test and create source control methodologies to fill a policy gap unfulfilled at the national level.

2.3 Bureaucratic Governance

The rigidity of bureaucratic structures may make it more difficult to adjust policy processes to accommodate for changing situations or new knowledge. While EPA has published guidance memorandums on how to prevent recontamination occurrences, bureaucratic rigidity may work to prevent the agency from responding to the new information and direction without prescriptive regulations. As an example, EPA Region 10 staff identified a policy gap several years ago, which may take decades to rectify. Atmospheric deposition of chemicals of concern (COC) such as PCBs and pthalates is becoming a greater concern and a recognized issue. However, these chemicals are not seen as an air quality issue and therefore are not monitored under the Clean Air Act (CAA) even though they cause secondary environmental impacts when deposition occurs on terrestrial and aquatic surfaces. Puget Sound Clean Air Agency (PSCAA), a local agency, is responsible for regulating air emissions from the businesses surrounding the LDW. "PSCAA's regulations are mainly based on human respiratory health risk, which may not be protective of sediments in terms of atmospheric deposition" (Thomas et al, 2012). Currently there is no regulatory trigger allowing enforcement and regulatory authority over air emissions of the LDW COCs.

Incorporating redundancy into a regulatory scheme may help to offset bureaucratic rigidity. Policy design and decision making requires prediction, "because the world is complex, we must expect to err" (Weimer and Vining, 2011). In Superfund cleanup projects managers use technical models to determine the results of a specific cleanup action. Dynamic environmental conditions, especially at large sediment cleanup sites, and environmental and technical uncertainty limit the accuracy of these predictions regarding remediation performance (Bridges, 2010). The inaccuracy of these models affects decision-making and should be considered throughout the decision making process. Therefore it is important to build mechanisms into a policy that allow the detection and correction of poor outcomes. Regulatory redundancy, for example, while wasteful at times, can also help to ensure a task is accomplished as originally intended. The implementation of both MTCA and CERCLA at the same site may be seen as redundant but the simultaneous implementation also means that both WA DOE and USEPA are working at the same time to accomplish similar goals under different laws and regulatory and oversight structures.

When considering the tenuousness of making a linking chain of actions to connect the policy to desired outcomes, it may be helpful to use redundancy in the implementation process to ensure a possible weak link continues the chain of behaviors to the desired outcome. In our case, this weak link may be ensuring all pollution sources are identified and removed from the system, thus preventing the possibility of recontamination. Weimer and Vining (2011) suggest the policy maker create a backup plan to take effect if the implementer's plan does not suffice.

The Washington State MTCA can complement and reinforce Superfund. In addition, the CWA, CAA, TSCA and RCRA help to support and compensate for Superfund and MTCA's lack of source control methodology guidance. As an example, TSCA was used to enforce cleanup of a building called the Rainier Commons in the LDW watershed which had paint that was leaching PCBs (interview – EPA representative, 2013, interview – WA DOE representative, 2013, WA DOH, 2010).

2.4 Monitoring and Evaluation

Monitoring compliance and implementing enforcement actions are also necessary in making command and control regulations a strong tool (Gunningham, 1998). It is costly and difficult to use enforcement, "most regulatory regimes have insufficient resources to monitor compliance with any degree of adequacy" (Gunningham, 1998). In addition, when there are a large number of variables from one Superfund project to another it can be hard to determine whether failure was caused by the policy (guidance) or whether failure should be attributed to another issue such as poor technology, environmental complexity or the project team's failure to adhere to guidance. Further, if policy is evaluated and determined to be ineffective, there needs to be an avenue with which to alter the policy or repeal it (Weimer and Vining, 2011). Superfund has been revised and methods continue to be reworked as the policy is used; the issue of repeal is beyond the scope of this study.

While the source control process has resulted in many outputs in the form of written plans, reports and meetings, such activities are not necessarily well correlated with environmental outcomes. There is little research linking outputs and outcomes (Koontz and Thomas, 2006). Defining and measuring regulatory effectiveness is a difficult task, especially in coming up with performance measures for programs with multiple goals and where success is primarily defined in terms of risk reduction (Gunningham, 1998) as is the case with Superfund. Risk reduction in itself can be difficult to quantify.

Due to a constantly changing environment and the matrix of policy processes involved in Superfund remediation, it would be difficult if not impossible to link particular outcomes to particular aspects of the policy process. Recent monitoring plans for all aquatic Superfund sites nation-wide require post-construction biological contamination monitoring such as fish tissue sampling in hopes of linking cleanup actions to biological improvements (USEPA, 2005) and therefore risk reduction.

2.5 Community and Stakeholder Influence

Industry, community and environmentalists generally have different views of what standards qualify as clean or safe enough. While communities and environmentalists may believe Superfund projects should all strive to reach a contaminant free environment this goal comes with costs. It can be important to consider the impact on industry and economic cost of Superfund cleanups. Coercing industry and municipalities into cleanups is easier when the task is smaller and less costly. Divvying up the cleanup task in itself can be extremely time consuming and costly to the agency, meaning more public resources go into the Superfund task and the contaminants remain in the waterway for longer periods of time (an example of transaction costs).

A potentially responsible party may volunteer to investigate and conduct cleanup actions early in the Superfund process to improve public relations and avoid high litigation costs. There are multiple Early Action Area (EAA) sites in and along the LDW waterway where no one has volunteered due to strict cleanup standards and the extremely high costs of remediation. If a PRP doesn't volunteer to remediate a site EPA needs to undertake assignment of liability, which is a litigious task and is not taken on in some cases due to lack of agency resources. Another factor to consider is that businesses tend to avoid economic centers like Port areas in Seattle where Superfund sites are active (Interview – Nadeau, 2013, Interview – Port of Seattle Representative, 2013).

From a national perspective some people say EPA Region 10 has more stringent cleanup standards than other parts of the country. Washington State revised its Sediment Management

Standards under MTCA in February 2013 to require natural pre-anthropogenic cleanup action levels such as what would exist in an undeveloped area before any anthropogenic sources were introduced.. Several agencies and industry representatives consider new standards to be unattainable since all incoming water, sediment and atmospheric deposition sources contain contaminant levels that are higher than pre-anthropogenic levels (Nadeau, 2012, Interview – Port of Seattle Representative, 2013). Industry representatives have expressed the opinion that companies are more likely to settle down and stay in eastern states where environmental regulations are less stringent and the cost of business is lower (Interview - Port of Seattle Representative, 2013 and Interview-Nadeau, 2013).

2.6 Summary of Regulatory Frameworks

Remediation strategies are, in part, based on results of pollution investigation reports and feasibility studies. Decisions are likely not made solely based on science; differences in stakeholder goals can lead to choices based on principles other than what science indicates may be the best environmental option. The concepts in this chapter including: linking outputs to outcomes; incorporating redundancy to strengthen the results chain; incorporating policy evaluation; and considering all stakeholder opinions are all vital to source control and recontamination prevention policy and will be revisited in Chapters six and seven when looking at the effectiveness of recontamination prevention guidance at the case study site.

Section 3: Guidance on Pollution Source Control

3.1 Federal Government Steps to Reduce the Risks of Recontamination Events

There have been attempts to remedy the sediment recontamination issue through USEPA guidance memorandums (USEPA, 1998; USEPA, 2002 and USEPA, 2005), as well as a United States Army Corps of Engineers (USACE) sediment dredging guidance memorandum in 2008. This Chapter reviews EPA source control guidance documents to understand their role in recontamination prevention. Understanding of the guidance will be used in Chapter five to assess whether EPA guidance was utilized at the T-117 case study site, how the guidance was followed and applied, the extent to which the guidance appears to be useful and whether federal guidance will be effective in preventing future recontamination.

EPA's 1998 Contaminated Sediment management strategy document states that it is important that point and nonpoint sources of contamination be identified and controlled prior to initiating remediation (EPA, 1998). The 2002 *Principles for Managing Contaminated Sediment Risks at Hazardous Waste Sites* (USEPA 2002b) guidance has eleven risk management principles, the first of which is "control sources early". However, this guidance document also states that a lack of complete source control identification cannot be used as an excuse to postpone remediation action.

Nadeau identified that "by knowing the effectiveness of source control prior to implementing sediment cleanups, the risk of having to revisit recontaminated areas is greatly reduced" (Nadeau, 2007). The USEPA's 2005 document *Contaminated Sediment Remediation Guidance for Hazardous Waste Sites* (USEPA 2005) advised Superfund site managers to consider the potential for recontamination when deciding remediation actions by including source control measures. The Guidance suggests phasing remediation actions if there is doubt regarding the effectiveness of source control.

EPA's Technology Innovation and Field Services Division attempts to publish annually a Superfund Remedy Report (EPA Website: http://www.clu-in.org/asr/) that summarizes treatment and source control strategies, the status of progress at Superfund sites and the use of treatments in relation to site completion status. There is also a database for site remediation methods on EPA's Contaminated Site Clean-Up Information webpage (http://www.clu-in.org/) that provides some information on specific cleanups that have been conducted including media, chemicals of concern (COCs), and amount of media removed or treated.

3.2 Guidance Memorandums

USEPA's 1998 Guidance

In 1998 EPA published *EPA's Contaminated Sediment Management Strategy* that focuses on four goals including:

- Preventing more sediments from becoming contaminated [on a national scale];
- Reducing the volume of existing contaminated sediments;
- Ensuring toxic sediments are disposed of in an environmentally sound manner and;
- Developing scientifically sound sediment management tools for pollution prevention, source control, remediation and dredged material management (USEPA, 1998).

Source control guidance in the document focuses on managing nonpoint pollution sources through issuing federal funds to states, and creating programs like the Coastal Zone Act

Reauthorization Amendments, Clean Lakes Cooperative Agreements with States, and State action plans.

USEPA's 2002 Guidance

The February 12, 2002 recontamination prevention memorandum titled *Principles for Managing Contaminated Sediment Risks at Hazardous Waste Sites* was written by the USEPA's Office of Solid Waste and Emergency Response Division. The guidance is directed toward Superfund Policy managers and RCRA Senior Policy Advisors. The 2002 document focuses on [environmental and human health] risk-based management and risk-based goals by outlining eleven risk management principles that project managers, on-scene coordinators and RCRA corrective action project managers should consider when planning and implementing actions (USEPA, 2002). The eleven risk management principles are listed in the table below.

Table 2. EPA's 2002 Risk Management Principles

Principle Number 1	Control sources early.
Principle Number 2	Involve the community early and often.
Principle Number 3	Coordinate with states, local governments, tribes, and natural resource trustees.
Principle Number 4	Develop and refine a conceptual site model that considers sediment stability.
Principle Number 5	Use an iterative approach in a risk-based framework.
Principle Number 6	Carefully evaluate the assumptions and uncertainties associated with site characterization data and site models.
Principle Number 7	Select site-specific, project-specific, and sediment-specific risk management approaches that will achieve risk-based goals.
Principle Number 8	Ensure that Sediment Cleanup Levels are Clearly Tied to Risk Management Goals.
Principle Number 9	Maximize the effectiveness of institutional controls and recognize the limitations.
Principle Number 10	Design remedies to minimize short-term risks while achieving long-term protection.
Principle Number 11	Monitor during and after sediment remediation to assess and document remedy effectiveness

Source: USEPA. 2002. Principles for Managing Contaminated Sediment Risks at Hazardous Waste Sites. OSWER Directive 9285.6-08. February 12, 2002.

To control sources early, the 2002 guidance document recommends identifying direct and indirect continuing sources of significant contamination to the sediments of concern; then to assess which sources can be controlled and by what mechanisms. In addition, prioritize sources by their relative risk and look to other agencies and institutions for information. When selecting a response action to address identified sources, managers should evaluate the potential for future recontamination from these sources. The second and third guidance principles may help in identifying "potential human and ecological exposures, as well as in understanding the societal and cultural impacts of the contamination and of the potential response options" (EPA, 2002). Early and frequent community involvement may facilitate the acceptance of Agency decisions (EPA, 2002).

The fourth principle is, develop and refine a conceptual site model that considers sediment stability. "The conceptual site model should be prepared early and used to guide site investigations and decision-making" and should be updated when new information becomes available. The conceptual site model should be robust, considering all known and suspected pollution sources, types of media and pathways and potentially compromised human and ecological uses (EPA, 2002). EPA has produced additional guidance regarding developing conceptual site models including the May 1998 EPA *Guidelines for Ecological Risk Assessment* (Federal Register 63(93) 26846-26924), the 1997 Superfund Guidance *Ecological Risk Assessment Guidance for Superfund: Process for Designing and Conducting Ecological Risk Assessments* (EPA 540-R-97-006), and the 1989 *Risk Assessment Guidance for Superfund (RAGS), Volume 1, Part A* (EPA 540-1-89-002).

Principle five is Use an Iterative Approach in a Risk-based framework. This means testing the hypotheses in light of the conclusions and re-evaluating the assumptions regarding the site characteristics as new information becomes available and maintaining the focus on the primary goal of reducing risks.

> "At complex sediment sites, site managers should consider the benefits of phasing the remediation. At some sites, an early action may be needed to quickly reduce risks or to control the ongoing spread of contamination. In some cases, it may be appropriate to take an interim action to control a source, or remove or cap a hot spot, followed by a period of monitoring in order to evaluate the effectiveness of these interim actions before addressing less contaminated areas" (EPA, 2002).

Principle six is to carefully evaluate the assumptions and uncertainties associated with site characterization data and site models. The guidance encourages evaluating the limitations and uncertainties of various models used for data analysis and contaminant quantification extrapolations. However it is cautioned to not use the "wait-and-see" approach when there is enough information to move forward or when eminent risks provide cause for moving forward quickly. Imperfect knowledge should not be used as an excuse to stall decision-making.

The seventh principle encourages selecting a site-specific, project-specific, and sediment-specific risk management approach to achieve risk-based Goals. "EPA's policy has been and continues to be that there is no presumptive remedy for any contaminated sediment site, regardless of the contaminant or level of risk" (EPA, 2002). There is no default risk management option that is applicable to all sites or types of pollution or all types of sites. All remedies that could potentially meet the needs of the project (dredging or excavation, in-situ capping, in-situ treatment, monitored natural recovery) should be considered. Both temporal and spatial aspects of the site, as well as the potential for risk reduction should be compared under each remedy option. Often, it is a combination of remedies that will work best (EPA, 2002).

The eighth principle is to ensure the sediment cleanup levels are clearly tied to risk management goals. To measure success "effect endpoints" should be something other than simply a reduction in chemical concentrations; outcomes should relate directly to the health of the system such as estimates of wildlife reproduction or benthic macroinvertebrate indices. The ninth principle: maximize the effectiveness of institutional controls and recognize their limitations, reminds managers that "institutional controls seldom limit ecological exposures" (EPA, 2002). It is important to have educational components included in programs designed to limit human fish intake. However, an institutional control does not likely prevent people from being exposed to toxins and therefore is not a sufficient excuse to postpone remediation.

Number ten recommends designing remedies to minimize short-term risks while achieving long-term protection. The principle also encourages consideration of the societal and cultural impacts each alternative can have; including impacts on water recreation, traffic, noise pollution, air pollution, commercial fishing, and tribal rights and uses (EPA, 2002). Principle eleven is to monitor during and after sediment remediation to assess and document remedy effectiveness.

The 2002 guidance also discusses implementation and requires large sites to have a written document discussing how the eleven principles were considered. The required written document is intended to explain how required strategies were followed instead of explaining technical methods for source control. The documents only recommend actions and are not enforced or enforceable. However, the steps fit in well with the normal CERCLA process.

USEPA's 2005 Guidance

The 2005 guidance document, *Contaminated Sediment Remediation Guidance for Hazardous Waste Sites*, discusses the considerations that should be undertaken when designing and conducting a feasibility study and/or remedy selection for a contaminated sediment site (EPA, 2005). The document touches on the principles outlined in the 2002 guidance document. The 2005 document adds that understandable information regarding the safety of contaminated water related activities should be available for the communities that use or are near to the water body. In addition, significant opportunities should be given to these communities to be involved in EPA's decision-making process for sediment cleanup (EPA, 2005).

A site-specific assessment of transport potential for both contaminated and non-contaminated sediments, including both scales and rates of transport, can be important to determining if there may be a change in recontamination risk from these sources. Considering if cleaner sediment is burying contaminated sediment quickly or if erosion is likely to re-expose contaminants in the future clues the investigator/ planner into considering these impacts to the future remediation outcomes and remediation rates. The 2005 guidance outlines the pros and cons of each of three types of cleanup methods: 1) monitored natural recovery; 2) in-situ capping; and 3) dredging and excavating. It also provides guidance on proper monitoring procedures.

3.3 Advisory Group and Review Board

Another federal asset, beyond the guidance outlined above, is the Contaminated Sediments Technical Advisory Group (CSTAG), a technical advisory group whose responsibility is to monitor progress and provide advice on a small number of large, complex, or controversial contaminated sediment Superfund sites. Membership includes a representative from each EPA region and two representatives from the Army Corps of Engineers' Research and Development Center. Members participate in monthly conference calls, two to four meetings a year and occasionally visit Superfund sites. After a CSTAG meeting occurs on a particular site the CSTAG will make recommendations to the responsible parties. The CSTAG does some coordination with the National Remedy Review Board (NRRB). The LDW is not a site that CSTAG monitors. On designated sites an on-scene coordinator helps to manage the Superfund project in accordance with the eleven risk management principles presented in EPA's 2002 guidance. The purpose of the group is to encourage national consistency in the way projects are managed and to provide a venue for monitoring and evaluating the largest and/or most complex contaminated sediment sites (USEPA, 2011a).

EPA created the NRRB in 1996 as part of a reform package designed to improve the Superfund program to be faster, fairer, and more efficient. NRRB reviews proposed Superfund cleanup decisions to make sure they are consistent with Superfund law, regulations, and guidance. The NRRB is composed of EPA managers and technical and policy staff who are familiar with Superfund remedy selection issues (USEPA, 2011b).

3.4 Non-CERCLA Source Control Frameworks in Use at the LDW

In addition to CERCLA, other regulatory frameworks that can be used to clean up existing polluted media are the Resource Conservation and Recovery Act (RCRA), Toxic Substances Control Act (TSCA), Model Toxics Control Act (MTCA) and the Sediment Management Standards (SMS). MTCA is a Washington State law implemented in 1989 to enforce cleanup of contaminated sites. The Act was passed to avoid what the state saw as confusion and delays associated with CERCLA and was designed to be a streamlined process (WA DOE, 2007). Since MTCA is also used extensively in regulating the LDW Superfund site, an Ecology Representative was asked if the MTCA regulations provided any source control guidance and the answer was "no". Source control is only mentioned once in the regulations (Ecology Representative, 2013). In addition there are no source control guidance documents under MTCA aside from those that have been published specifically for a listed site. Ecology defers to the existing EPA source control guidance (Ecology Representative, 2013).

Direct discharges are regulated under the CWA, NPDES and Washington State Water Pollution Control Act [RCW 90.48]. Table 1 in the 2012 *Lower Duwamish Waterway Source Control Strategy* presents an extensive overview of the various regulatory laws and frameworks that exist to manage each pollution source pathway. In-water transport of contaminated sediments has the fewest regulatory frameworks, two each including the State MTCA (RQC 70.105D) and the Hazardous Waste Toxic Reduction (RCW 70.105) regulations. Please see Appendix A, Table A.1 for the full *Regulatory Authorities Applicable to Source Pathway* table. Municipal stormwater permits, industrial stormwater general permits, municipal (sanitary) wastewater permits and CSO permits, and CWA Section 401 water quality certifications for small scale permitted activities, all of which fall under the CWA, greatly help to regulate ongoing and proposed discharges.

It is important to recognize that as long as these permitted discharges exist, pollution sources to the LDW will always be above natural levels (Interview – Nadeau, 2013). The efforts EPA has put into guidance documents demonstrates that recontamination has been recognized as problem, and over a period of many years successive attempts have been made to refine and sharpen advice on how to deal with it. However, the regulations and guidance do not necessarily form a well-integrated unified ecosystem based management approach. There are state MTCA standards, and federal CWA and CAA standards, which are not easily directed toward the elimination of potential recontamination sources at Superfund sites, which need to be address. Further, there is urgency under CERCLA to move forward with site cleanup actions as demonstrated in USEPA's 2002 guidance which states that a lack of complete source control identification cannot be used as an excuse to postpone remediation action. In addition, there is a deep-seated philosophy that each site is unique and requires tailor-made remediation strategies. The "guidance" is only that, not a set of rules to follow. Understanding the guidance and challenges at aquatic Superfund sites starts to shed light on why recontamination is endemic to marine and riverine Superfund sites.

Part II: Case Study – Terminal 117 Early Action Area, Lower Duwamish River Water, Seattle, Washington

Section 4: The Case Study: Terminal 117

Chapter four introduces the history and Superfund designation of the LDW and then introduces the reader to the case study site, Terminal 117, which is located within the LDW. In 2001 a five and a half mile stretch of the LDW was designated as a Superfund site (Zhaler, 2009). The Washington State Department of Ecology (Ecology) added the site to the Washington State Hazardous Sites List on February 26, 2002 (DOE Toxics cleanup program, 2004; Thomas et al, 2012) meaning under Washington State Law this site also has legal cleanup requirements. The LDW Superfund site is located in Washington's Puget Sound, south of downtown Seattle. The area is heavily industrialized and is surrounded by the densely urbanized greater Seattle area. The Duwamish Waterway is characterized by a multitude of uses including industrial, marine transit, recreational and subsistence fishing; in addition, the residential community of South Park abuts a portion of the waterway.

The waterway has undergone significant anthropogenic change over the last century, including dredging, straightening, removing freshwater supplies and extensive pollutant loading by industrial waste, sewage overflows and urban stormwater runoff contaminants. Decades of unregulated industrial waste dumping straight into the river brought both waters and sediments to toxic levels (Simenstad, 2004; Arcadis, 2007; Lower Duwamish Waterway Group, 2010). While current environmental regulations prohibit dumping industrial waste into public waters, there are still toxic substances in sediments, stormwater, surface water, groundwater and on land parcels along the river that are leaching into the waterway (Clarke, 2008; Starks, 2001; Environmental Partners et al. 2009). In the LDW the primary responsible parties have been identified and Early Action Sites have been designated.

4.1 History

Between 1910 and 1913 the river was dredged to accommodate ships coming into The Port of Seattle. Tributaries were diverted, piped through culverts and filled over. Dredging and filling the waterway generated approximately 100 ha of deep-water habitat and decreased shallow and flat habitats by eighty-eight percent (Blomberg et al., 1988). The Duwamish and Elliott Bay estuary has become heavily populated over the last 150 years. South Park farms were replaced with "warehouses, manufacturing plants, businesses, freeways, and utilities" (Zhaler, 2009) ending Seattle's farming era.

With the increase of industry and Boeing aircraft manufacturing during World War II, people moved into the South Park area for work (Zhaler, 2009). Over the years the estuary became highly contaminated from industrial pollutants and urban contaminants from the surrounding city. A technical report from 1945 details industrial and non-industrial contaminants which were routinely and allowably discharged into the LDW including acid tanks, local raw sewage, oil, gasoline, carbide and other liquids (Foster, 1945).

By "1940, eight direct sewer outfalls and four combined sewer overflows discharged into the estuary and twelve documented industrial effluents were building a legacy of metal (chromium, cadmium, copper, lead, zinc), pentachlorphenol (PCP), polychlorinated biphenyl (PCB), polycyclic aromatic hydrocarboms (PAH), and halogenated hydrocarbon contamination" (Simenstad, 2004). Since the 1950s, water pollution regulations and toxic remediation efforts have significantly reduced raw waste discharges (Simenstad, 2004).

4.2 Initial CERCLA Steps at the LDW

In 2000 there was an Administrative Order of Consent between the Washington State Department of Ecology, EPA and the Lower Duwamish Waterway Group (LDWG) (Crete Consulting Inc. et al, 2012), which assigned sediment cleanup to EPA; and source control and anything above ordinary high water to Ecology. LDWG is composed of the City of Seattle, the Port of Seattle, King County and the Boeing Company.

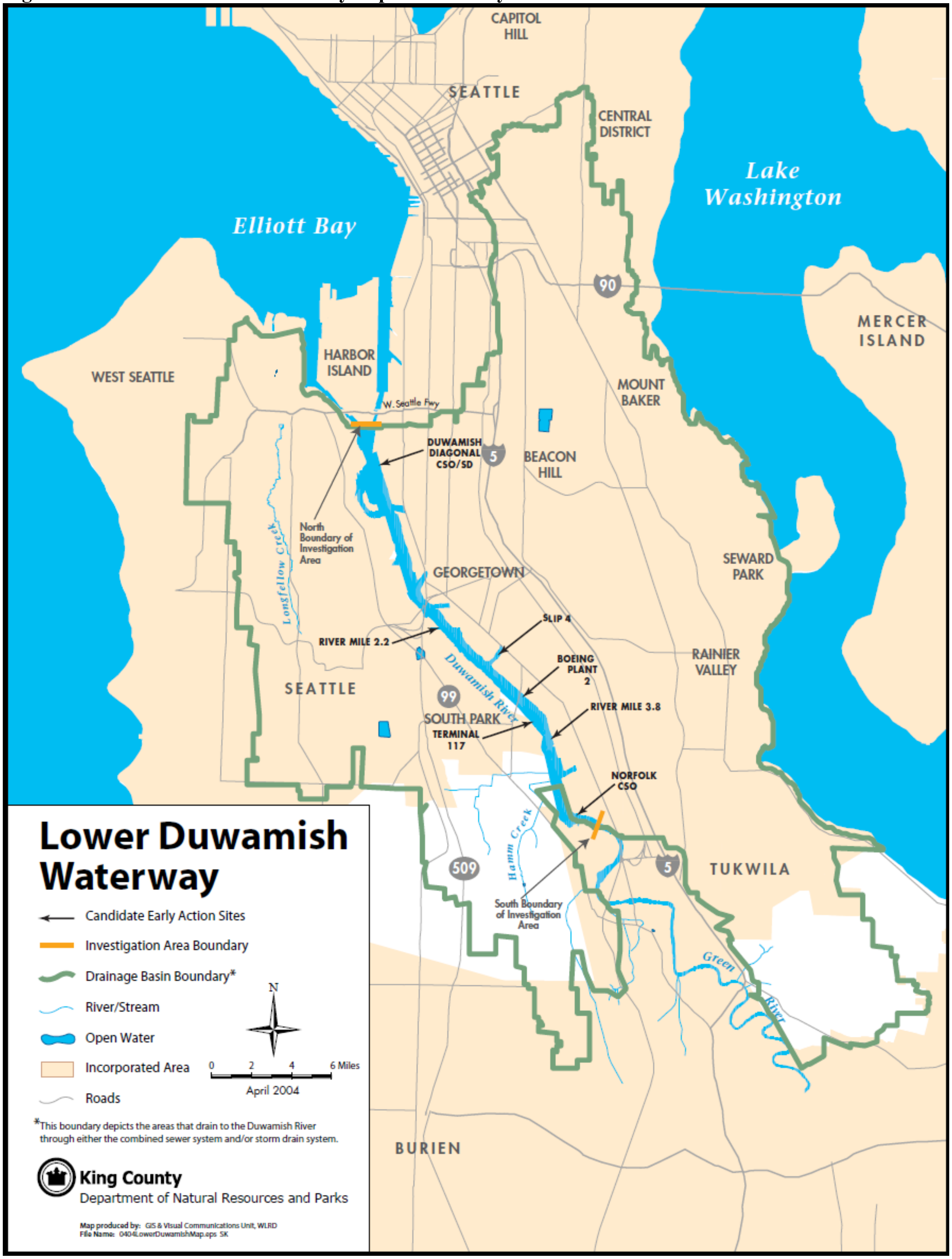
Federal guidance recommends phasing cleanup actions on very complex sites, which may include setting early action areas. "The main objective for conducting an early action is accelerating risk reduction" (Bridges et al., 2012) in a contaminated hot spot. During the remedial investigation, seven early action candidate sites were proposed by the Lower Duwamish Waterway Group as presented in Table 3 and Figure 2.

Table 3. LDW Early Action Sites

Early Action Area Number	Site Location/Description
EAA 1	Duwamish/Diagonal combined sewer overflow and storm drain (CSO/SD) on the east side of the waterway (river mile [RM] 0.4 – 0.6).
EAA 2	RM 2.2, on the west side of the waterway, south of the 1st Ave South Bridge.
EAA 3	Slip 4 (RM 2.8).
EAA 4	Located south of Slip 4, on the east side of the waterway, just offshore of the Boeing Plant 2 and Jorgensen Forge properties (RM 2.9 to 3.7).
EAA 5	Terminal 117/Malarkey, located at approximately RM 3.6, on the west side of the waterway.
EAA 6	RM 3.8, on the east side of the waterway.
EAA 7	Norfolk CSO (RM 4.9 – 5.5), on the east side of the waterway

Source: DOE Toxics Cleanup Program, 2004

Figure 2. Lower Duwamish Waterway Superfund Early Action Areas.



Source: King County. April 2004. Website: http://www.kingcounty.gov/environment /wastewater /Duwamish- waterway/CleaningUpDuwamish/Challenges.aspx. Accessed May 31, 2013.

The primary chemicals of concern (COCs) include polychlorinated biphenyls (PCBs), arsenic, carcinogenic polycyclic aromatic hydrocarbons (cPAHs), and dioxins/furans (EPA, 2013b). It will likely take another decade or longer before moving forward with the proposed river-wide cleanup plan. However, some Early Action Areas (EAA), including T-117 are scheduled for remediation work to begin in the Spring and Summer of 2013.

4.3 Terminal 117

EAA 5, Terminal 117, is located along the old Malarkey Asphalt property, along the west side of the LDW and within unincorporated King County. The Port of Seattle and the city investigated this site to determine the extent of contamination. The primary toxin of concern at this site is PCBs (Cargill, 2005). In October 2006, EPA completed an emergency time-critical removal action (TCRA) to address high concentrations of PCBs in soils found upland of the site area. On the TCRA site there were four sediment removal areas which were backfilled with clean soil and covered in a filter fabric and then covered with an asphalt cap (Aracdis, 2007). There has been post-cleanup long-term monitoring of sediment, seep and groundwater. Monitoring showed that PCBs from the upland soils continued to impact the marine sediments (Aracdis, 2007), which will be addressed in the final proposed cleanup (Crete, 2012).

T-117 was operated by an asphalt company called Malarkey Asphalt from 1937 to 1993. The site contained PCBs, asbestos, and heavy metals. The Port of Seattle owned the fifty feet of shoreline along the Malarkey property and purchased the Malarkey site after the business closed. Malarkey Asphalt Company is bankrupt and therefore only its insurance company is contributing funds to the site's remediation.

Agencies participating in source control efforts at the T-117 EAA include the Port of Seattle, City of Seattle, EPA and Ecology. The Port of Seattle became a PRP because it purchased the T-117 site in 1999. The Port is responsible for remediation actions onsite and in intertidal areas. The City of Seattle's Seattle Public Utilities is a PRP because it sold PCB laden oils to Malarkey Asphalt which was located on the T-117 parcel. Seattle Public Utilities is responsible for cleaning up upland streets around the site. See Figures 3 and 4 below for T-117 site aerials. Ecology and EPA provide oversight. While the 2006 time critical upland removal action was conducted quickly, the signs of onsite pollution continuing to act as a pollution source to marine sediments should trigger additional precaution during future remediation actions.

Section 5: The Source Tracing Strategy at T-117

This chapter starts by introducing the general pollution source control strategy at the T-117 site, then the chapter moves on to discuss how source control was implemented and how the potential for recontamination was assessed in the Early Action/Coat Analysis (EE/CA). The chapter ends by reviewing whether all of the federal source control guidance was applied.

5.1 The General Source Control Strategy

This section describes key tools that are used to prevent recontamination both at the T-117 site and throughout the LDW. The three main steps utilized for source control and recontamination prevention include business inspections, source tracing and upland site assessment and cleanup.

Business Inspections

Business inspections are used to influence the proper handling of materials and to teach pollution prevention practices, and compliance with permits and jurisdictional codes. Most business inspections find that further actions need to be taken to either control a discharge or to reduce the potential for future discharges to the LDW (Cargill, 2007). During inspections King County, City of Seattle and DOE staff advise businesses of possible ways to reduce or eliminate hazardous materials from their operations. Recurring inspections are necessary to ensure continued permit and regulatory compliance especially when considering business staff turnover (Interview- City of Seattle Representative, 2013).

Source Tracing

To trace pollution sources, soil samples are collected and analyzed from storm drains and catch basins. Source tracing methods have been used to identify sites with PCBs in soils and building materials. A number of source tracing samples are also taken during business inspections. In the following chapter sampling details and illustrative figures are presented regarding the T-117 case.

Upland site assessment and cleanup

The third part of source control efforts is investigating and identifying upland properties and sites that have potential for contributing pollution sources to the Superfund site through erosion, groundwater, stormwater or surface water runoff. When an upland area is identified as being a probable pollution source, Ecology or EPA will issue a legal order requiring the nature and extent of contamination to be characterized as well as the development of a plan to cleanup the site. The long-term goal of source control is to prevent recontamination of sediments after cleanup actions have occurred (Thomas et al, 2012). Ecology plans to reassess its source control plan every five years or as needed.

CSO events are a major source of contaminants to the LDW, which also affect the T-117 site. The City of Seattle has approximately twenty-five CSO events a year citywide and King County has approximately thirty countywide, which include both sewage and industrial waste (City of Seattle Representative, 2013). One of the next big steps in reducing this source would be a consent decree between EPA, Seattle and King County to bring the CSO systems into control, meaning there will only be one CSO event a year in the City's jurisdiction and one event per year in the County's jurisdiction (Interview - King County Representative, 2013). This will be accomplished by increasing the CSO system's capacity and figuring out how to regulate the flow coming into the system.

Source control will likely never end but will be a continual process to try to bring background levels lower and keep potential sources under control (Interview – WA DOE Representative). To assist with source control, Ecology has asked the City of Seattle, King County and EPA to develop five-year and long-term source control plans (Thomas et al, 2012).

5.2 Applying Source Control at T-117

In July 2005 Ecology published the *Lower Duwamish Waterway Source Control Action Plan for the Terminal 117 Early Action Area*, which characterized sources of contamination that could potentially impact sediments adjacent to T-117 and proposed actions to investigate, address, track and report identified sources. In 2007 it was decided that there would be an annual source control report summarizing source control actions undertaken on the Lower Duwamish River Waterway. Each annual source control document includes a section on the T-117 site. These are summarized in this Chapter to understand whether source control actions followed source control guidance and to help assess whether these actions will help to prevent recontamination at T117.

Ecology's Confirmed or Suspected Contaminated Sites (CSCS) list is a database of sites for which there is evidence that hazardous substances have been released and may pose a threat to human health or the environment. The Leaking Underground Storage Tank (LUST) list records sites where releases from underground tanks have occurred. Terminal 117, South Park Marina and Basin Oil are all on Ecology's CSCS list and Malarkey is the only site near T-117 on the LUST site. Annual T-117 source control reports discuss investigative actions on the Basin Oil

Company and South Park Marina sites (WA DOE 2007, 2008a, 2008b, 2009 and 2011). Terminal 117, South Park Marina and Basin Oil Company are shown in the aerial in Figure 3 below.

Figure 3. T-117 Early Action Area Study Areas

Source: Aecom et al. 2010. Lower Duwamish Waterway Superfund Site Terminal 117 Early Action Area.

The Basin Oil Company located adjacent to the Malarkey Asphalt site and near the west side of the Duwamish River Waterway on the landward corner of Dallas Ave South and South Donovan Street is not currently contributing funds to the T-117 cleanup nor does the site have a state order. However, the property owner has received violation notices resulting from hazardous waste compliance inspections and has taken several actions to reduce the contamination sources on his property including removing contaminated soils, monitoring onsite groundwater wells, removing an estimated two-hundred fifty drums from the site as well as other creosote debris discovered during excavation actions (Cargill, 2008). In 2008 sampling results at the Basin Oil Company site showed exceedances of some COC (SAIC 2008d). Basin Oil was fined; but it was also determined that the Basin Oil property did not present a significant risk of contaminating T-117 or Dallas Avenue (SAIC, 2010d).

Annually the T-117 source control reports cover actions taken at South Park Marina where a waste pond once existed, as well as other pollutant generating activities (Cargill, 2008). South Park Marina is located just downstream of T-117 on the west side of the Duwamish River on South Orr Street. In June 2009, a Technical Memorandum by SAIC assessed potential sediment recontamination from South Park Marina which concluded that South Park Marina contaminants were not expected to cause additional future exceedances at the T-117 site even though surface sediments at South Park Marina exceeded the SMS criteria for total PCBs (WA DOE, 2009).

5.3 Engineering Evaluation/Cost Analyses

In June 2010 a group of consultants prepared a Revised Engineering Evaluation/Cost Analysis for the T 117 site (Aecom et al., 2010). This document described non-time-critical removal actions (NTCRA) planned for T-117 EAA. The EE/CA also assessed the potential for the recontamination at T-117 EAA during and after the removal actions have been completed, to evaluate the long-term permanence of the removal action.

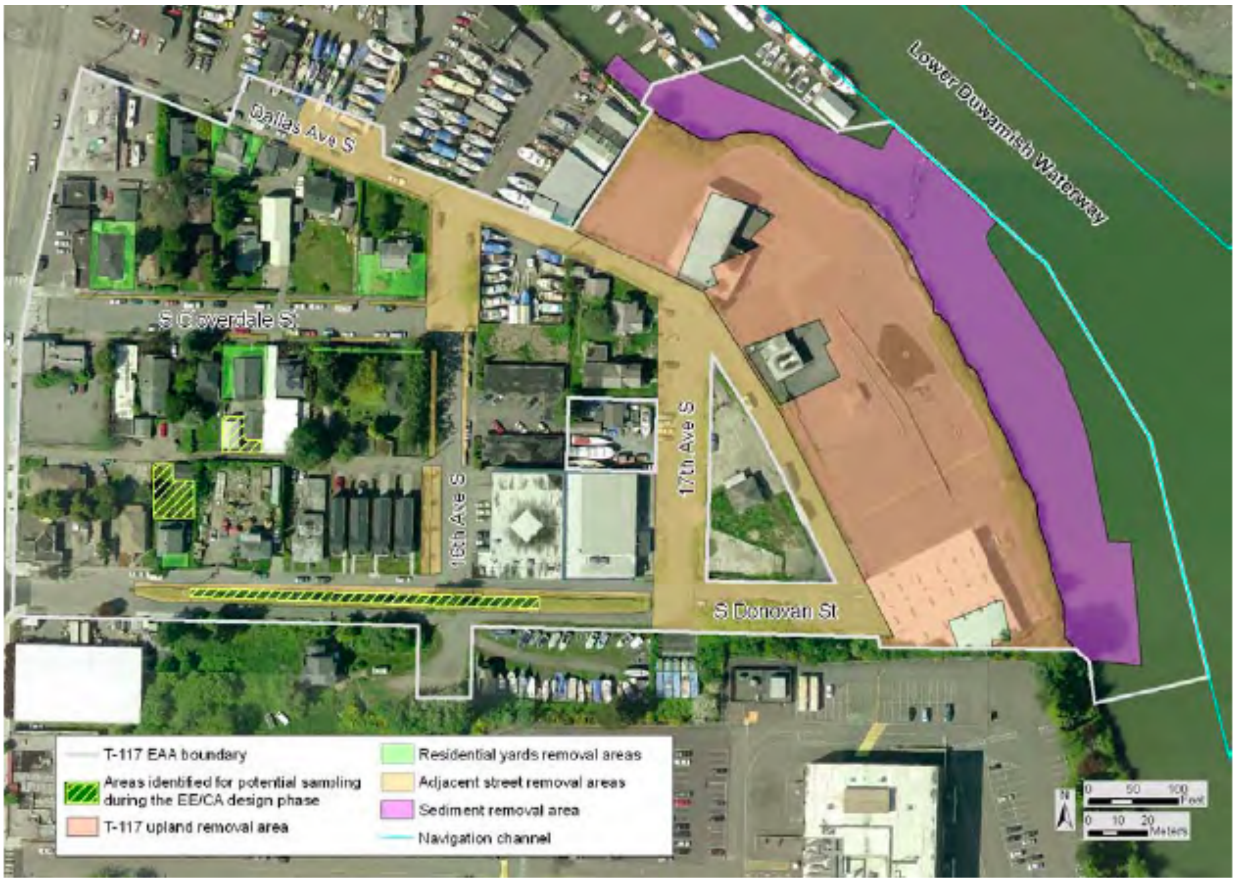
Within the revised EE/CA a streamlined risk evaluation is presented, which used a conceptual site model to identify pollution pathways, sources, potential transport mechanisms, and receptors (e.g., people, fish) within the three T-117 EAA study areas which are shown in Figure 4. The risk evaluation projected that after removal actions have been completed "COC concentrations will be at or below the ecological and human health risk levels established for the T-117 EAA" (Aecom et al. 2010).

Final Remedy Plans

Removal actions include removing upland soils and contaminated intertidal and subtidal sediments to "achieve concentrations at or below specific risk-based levels" (Aecom et al. 2010). Post-remediation proposed uses for the T-117 EAA include shoreline habitat, public access and recreational facilities. Designating recreational and ecological uses for the site means that stringent contamination reduction standards will be required to ensure successful reuse. "Sediment [removal action levels] (RvAL) for the T-117 Sediment Study Area are based on Washington State SMS and EPA risk-based goals developed for the LDW remedial project" (Aecom et al. 2010). At T-117 RvALs are set for groundwater, soils and sediments (Crete, 2012); Table A.2, which lists RvALs can be found in Appendix A.

The removal action objectives for sediments are human heath as it relates to seafood consumption and direct contact; also ecological heath of benthic invertebrates and as it relates to animal species consuming prey with toxins. The only objective of soil removal actions is to protect sediments in the LDW from upland PCBs. The EE/CA states that the planned removal action will meet all the objectives except the one regarding human seafood consumption. The report determined that background levels of PCBs prevent completely eliminating any unacceptable risk from the seafood consumption pathway. However, fish tissue sampling will still be required as part of post-construction monitoring efforts which complies with the eighth principle of EPA's 2002 guidance (USEPA, 2002).

Figure 4. T-117 EAA Sediment and Soil Removal Areas.



Source: Aecom et al. 2010. Lower Duwamish Waterway Superfund Site Terminal 117 Early Action Area.

EE/CA Assessment of Recontamination

The EE/CA concluded that recontamination of T-117 EAA is not likely to occur because the primary sources causing soil contamination will be removed (Aecom et al. 2010 and Peterson, 2013). The EE/CA expects sources from Basin Oil, South Park Marina, offsite upland sources and upstream sediments will not recontaminate the site at concentrations that exceed the sediment goals. In addition, most surrounding businesses were investigated and discounted as pollution sources after it was demonstrated that appropriate pollution managing measures/mechanisms were in place or proposed.

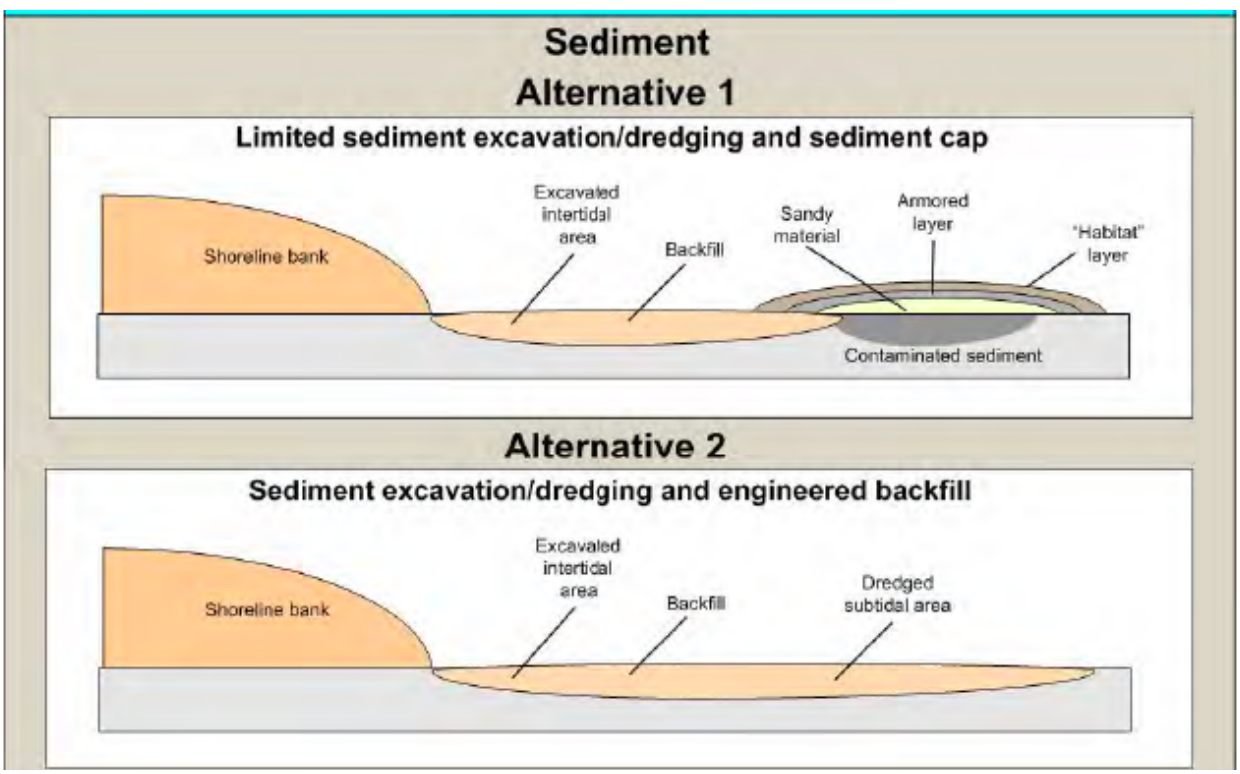
Also, monitoring in 2005 (Aecom et al. 2010) showed City stormwater is within allowable limits for pollution sources and therefore has been discounted as a source to the T-117 site. Monitoring of stormwater solids, groundwater and sediments will still be conducted after removal actions have concluded. It was determined that upland soils at the T-117 site will have no plausible source of contaminants and therefore will not be monitored (Interview - Peterson, 2013). Assessing other possible pollution sources demonstrates a commitment by project managers to address, to the extent practicable, each source to ensure recontamination prevention.

The EE/CA discusses various types of removal actions such as soil extraction, dredging in water sediments, sediment capping and treatment and disposal methods. When choosing a remediation action, the agencies focus on methods that have been used and have worked in the past at other sites. Technology types were assessed in consideration of site size, site-specific conditions, availability for implementation, and feasibility of implementation within the planned removal action timeframe (Aecom, 2013).

T-117 2010 EE/CA Recommended Alternatives.

The *Lower Duwamish Waterway Superfund Site Terminal 117 Early Action Area Revised Engineering Evaluation/ Cost Analysis (EE/CA)* report published in June 2010 has a brief analysis of removal action alternatives including a “no action” Alternative and 2 comparable alternatives (Aecom, 2010). The "no action" Alternative is not considered acceptable since it does not meet the removal action goals. Alternative 1 was upland soil and sediment removal with sediment capping. Upland and intertidal areas where soil has been removed would be backfilled with clean materials. Subtidal areas would not receive excavation but would be covered with a sediment cap. Avoiding subtidal sediment dredging has benefits and downsides. One benefit is cost savings and reducing the short-term likelihood of resuspending contaminated sediments; the downside is that leaving contaminated sediments in place may increase the risk of long-term failure. Alternative 2 would dredge all contaminated sediment within the sediment removal area. All T117 dredged areas would be backfilled with clean material to re-establish existing grades; no engineered sediment cap is proposed under Alternative 2.

Figure 5. Comparison of Alternatives 1 and 2 for remediation of the T-117 site.



Source: Aecom et al. 2010. Lower Duwamish Waterway Superfund Site Terminal 117 Early Action Area. Prepared for: The Port of Seattle and The City of Seattle. June 3, 2010. Seattle, Washington.

The EE/CA concludes both Alternatives 1 and 2 achieve the objectives set for T-117. However, Alternative 1, while less expensive, depends on the integrity of the sediment cap to provide long-term contamination containment. The EE/CA report notes, when considering meeting goals, objectives, compliance with toxicity levels, effectiveness and implementability, Alternatives 1 and 2 only differ in their possible effectiveness. The document also considers and compares materials and cost. Differences in effectiveness are summarized in the table below.

Table 4. The Effectiveness of T-117 Site Remediation Alternatives 1 and 2.

Effectiveness	Alternative 1	Alternative 2
Long-term Effectiveness and permanence	Achieves long-term effectiveness and permanence through dredging and placement of a sediment cap that will require long-term monitoring and maintenance.	Achieves long-term effectiveness and permanence through dredging.
Short-term effectiveness	Achieved short-term effectiveness and involved less dredging than does Alternative 2. The Potential period of short-term impacts to water quality would be of slightly shorter duration than that for Alternative 2.	Achieved short-term effectiveness but involves more dredging than does Alternative 1. The Potential period of short-term impacts to water quality would be of slightly longer duration than that for Alternative 1.

Source: Aecom et al. 2010. Lower Duwamish Waterway Superfund Site Terminal 117 Early Action Area.

Ecology chose Alternative 2 as the recommended alternative for the T-117 EAA determining that Alternative 2 provides the greatest likelihood of long-term effectiveness and permanence. Alternative 2 also has the ability to accommodate a variety of final site uses, which are selected with input from the South Park community. The EE/CA provided timelines for progress on the T-117 site; currently progress is only about a year behind the 2010 projected schedule as remedial actions are currently proposed to begin in June 2013.

5.4 Following the 2002 Guidance Principles at the T-117 Site

It is clear through reviewing T-117 annual source control documents that the project managers made strong efforts to follow the 11 principles published in EPA's 2002 guidance document. There was identification, assessment, and when possible control of pollution sources, as is recommended under principle one. The community, state, local Government, tribes and natural resource trustees have all been involved prior to final decision-making in compliance with principles two and three.

There is evidence that both principles four and five were followed at the T-117 site; however, when looking at the entire listed waterway there are some weaknesses that can be observed in regards to both these principles. Principle four focuses on developing a conceptual site model early on to identify potential contamination source areas and incorporating new information as it arises. The conceptual source models for the LDW grouped stormwater outfalls, thus modeling fewer outfalls than exist and therefore only represented a fraction of incoming hydrologic sources to simplify the model (Interview -NOAA representative, 2013), which likely reduces its accuracy. Principle five proposes, "testing of hypotheses and conclusions and foster re-evaluation of site assumptions as new information is gathered". While principle five was likely employed to some degree, examples were identified where new information did not foster re-evaluation. As an example, it was determined that the original 24 sub-basin source control areas do not accurately depict the pollution source basins. However, the same 24 sub-basins are still being utilized (interview – WA DOE Representative, 2013). In addition, the sediment transport model, while presenting important information does not seem to have significantly affected remediation plans. While there are opportunities to adapt to change or new information, adapting may require significant time, effort and resources, which are not always readily available.

Principle six concerning assumptions and principle seven, stating cleanup approaches should be tailored towards the needs of the site, were both followed as carefully demonstrated in the EE/CA. Sediment cleanup levels were based on risk management goals and post-construction monitoring will require fish tissue sampling in compliance with principle eight. Principle nine, recommends using institutional controls to minimize risk, such as fish and recreation advisory signs which are used on a LDW site-wide scale. The T-117 site proposal closely adheres to principle ten, which recommends designing remedies to minimize short-term risks while achieving long-term protection. However, there will be further controls necessary in the field during construction to ensure risks are minimized. Short-term risks can be greatly minimized or exaggerated by the actions of the cleanup contractor in regards to how much care is taken in containing removed contaminated sediments. Number eleven, which considers monitoring, stating "a physical, chemical, and/or biological monitoring program should be established for sediment sites to order to determine if short-term and long-term health and ecological risks are being adequately mitigated at the site and to evaluate how well all remedial action objectives are being met" (USEPA, 2002) will also depend on future actions.

5.5 Following the 2005 Guidance Principles at the T-117 Site

The 2005 document focuses on considering sediment transport mechanisms and reviews the pros and cons of various cleanup actions including natural recovery. As discussed above, the EE/CA did consider several alternatives and decided on the one with the greatest likelihood of long-term permanence. However, when reviewing adherence to the 2005 guidance at T-117 one shortfall was identified; in-channel sediment and upstream sediment assessment was very limited. The 2005 document focuses on considering sediment transport mechanisms. The National Marine Fisheries Service (NMFS) has looked at sediment dynamics within the LDW and provided recommendations regarding sediment dynamics and cleanup actions. Due to tidal fluctuations, the salt wedge and typical characteristics of estuarine environment sediments in this area are highly mobile and should be considered as a potential pollution source. Correspondence with Ecology staff indicated sources at the T-117 site are assumed to be primarily limited to existing onsite contaminants and therefore upstream sources were not thoroughly considered as a risk of recontamination. Correspondence with NMFS staff indicated that there are remaining questions of whether or not sediment transport findings were incorporated into source control and remediation actions decisions.

The source control strategy published in 2012 by Ecology states that for the entire LDW it is unclear whether upstream (Green River) sources and sediments should undergo LDW-specific source control activities (Thomas et al., 2012). Ecology and King County are conducting an assessment of potential upstream sediment contamination sources in the Green River; interview correspondence indicated upstream sources are well above sediment standard goals (Interview - WA DOE Representative, 2013 (Cargill); Interview - Port of Tacoma Representative, 2013). After the assessments are complete, agencies will determine whether to include upstream areas in source control efforts (Thomas et al., 2012), which would greatly expand the source control area.

When considering sediments immediately adjacent to a cleanup site hydrodynamics, vessel traffic, dredging, and other waterway activities influence sediment transport. If post-construction monitoring shows a certain area has high concentrations of COCs a clean layer of sand can be applied to that location to lower the site's average contamination (Peterson, 2013).

5.6 T-117 Site Source Control Summary and Conclusion

Sections of the Lower Duwamish Source Control Documents (WA DOE 2007, 2008a, 2008b, 2009 and 2011) as well as the EE/CA (Aecom, 2010) and interviews with professionals working on the LDW Superfund project indicate that project managers and others involved with cleanup actions do in fact take into account guidance (EPA, 1998, EPA, 2002, and EPA, 2005) regarding sediment recontamination prevention and attempted to use the recommendations presented in the guidance. However, despite adherence to guidance, recontamination is still a potential event as explained in the following chapter.

Section 6: Will Source Control Efforts Prevent Recontamination?

As assessed is chapter 5 the federal guidance on source control and recontamination prevention seems to have been followed at the T-117 site. While the EE/CA states that recontamination is not likely to occur because the primary sources causing soil contamination will be removed (Aecom et al. 2010) other informational sources indicate that recontamination is inevitable (Flint and Thomas, 2013; Interview – Peterson, 2013) due to unidentified pollution sources and technological limitations as expressed by EPA below.

> "Even with this comprehensive and aggressive effort, there is likely to be some recontamination of LDW sediments after cleanup due to the ongoing and unidentified sources, the impacts of atmospheric pollutant deposition on stormwater quality, the current limits of control technologies, and the availability of resources. EPA and Ecology anticipate that recontamination will be localized, have different contaminant signatures from pre-cleanup conditions, and that concentrations of risk driver chemicals of concern (COCs) will be lower than those seen before cleanup" (Flint and Thomas, 2013).

In addition, current policy gaps such as a lack of regulatory authority regarding atmospheric deposition of PCBs (described in Chapter two) make it impossible to control all pollution sources. Due to constraints built into the bureaucratic processing of wastes sites this policy will not likely be addressed for at least several years if not a decade or more.

Review of source control efforts at the T-117 site indicated that while CERCLA regulations require a site to be cleaned up they do not provide sufficient guidance and mechanisms to conduct source control and prevent recontamination. CERCLA regulatory decentralization and a lack of national guidance on specific methodologies and tools to implement source control and recontamination prevention has led policy implementers to rely on other regulations such as the CWA and TOSA to enforce source control.

Further, the strict cleanup standards required at the T-117 site under MTCA are most likely unattainable due to the environmental complexity at the LDW and T-117 site, technological limitations, permitted discharges and typical urban anthropogenic sources of the same contaminants (Flint and Thomas, 2013). There is still a lot to learn when it comes to source control. In addition, there is a hope that better technologies will develop over the next several decades to help agencies achieve the contaminant cleanup standards that will be set for the LDW (Interview – Peterson, 2013).

Getting off the Superfund NPL list

As stated above, most agency representatives interviewed for this study indicated that recontamination would occur to some level at the river-wide LDW site. The interview perceptions on recontamination at the T-117 site were more mixed, with the reference that sources have been controlled but that recontamination from in-channel sediments is always a possibility. If recontamination from in-channel sediments is a concern this begs the question of *is it logical to cleanup an EAA like T-117 before cleaning up the rest of the LDW?*

Early Action Areas can be designated when an area poses a significant risk to human or environmental health due to high levels of toxic chemicals. This method is thought to be helpful in complex Superfund sites (2005 Guidance) where source control and planning can take decades before cleanup actions on the entire site are undertaken. It makes sense to designate and cleanup an EAA in upland areas or even in relatively immobile sites such as a lake, pond et cetera. However, a river system, where sediment transport occurs at a high rate and concentrated pollution areas occur throughout the system, may not represent the kind of site the guidance was intended for rendering the guidance regarding EAAs unrealistic (EPA, 2005 and 2002) and compromise meeting cleanup completion goals or may mean that strict cleanup goals are unrealistic. That said, removing contaminants at the EAAs in the LDW will remove an estimated fifty percent or more of the contaminants from the LDW Superfund Site (Interview - Peterson, 2013).

Several interviewees indicated that instead of reaching applicable or relevant and appropriate requirements (ARARs) to get off the NPL list, a technical impracticability waiver will likely be used at the LDW site. A technical impracticability waiver under Section 121 (b) of CERCLA is a means of waiving the site's designated ARARs and thereby facilitating it legally being removed from the NPL list. In the waiver it must be demonstrated that all methods have been attempted to meet the standards that were set for the site and that the standards are unachievable

(EPA, 2012). So while recontamination of the proposed standards is likely, it will not necessarily prevent the site from being removed from the NPL list.

Section 7: Recommendations

The status quo of bureaucratic governance, command-and-control regulations, and decentralization under Superfund, while not perfect, is a necessary basis of implementing projects; these policy frameworks provide the drive and the backbone to accomplish or at least make progress towards cleanup goals. Combining instruments can be complementary, repetitive, or counterproductive (Gunningham, 1998). The policy processes involved in Superfund are primarily complementary, such as one of the main source control mechanisms the CWA, which makes discharges illegal unless covered under a NPDES permit.

7.1 Prescriptive Regulations

Addressing the issue of aquatic site recontamination may need a distinct set of prescriptive source control regulations or at least guidance in the form of methodologies from EPA or Congress. Regulations can be designed as highly prescriptive in telling regulated entities and individuals what to do and how to do it. "Regulatory enforcement for prescriptive regulation emphasizes adherence to the prescribed rules and standards, which in turn is presumed to provide acceptable outcomes in meeting regulatory goals" (Koontz and Thomas, 2006). Not only Superfund but all regulations used for source control on the LDW lack prescriptive regulations with regard to managing source control and recontamination prevention. Aquatic Superfund site sediment recontamination occurs on a national scale, but regional offices are left to the extremely difficult task of trying to come up with source control strategies. A national, overarching set of prescriptive regulatory guidelines for how to manage these issues and conduct source control could improve pollution source control and help reduce recontamination events.

7.2 Knowledge Sharing for Recontamination Prevention

It is very difficult to account for all the environmental variables and pollution sources that may influence site recontamination, such as groundwater, surface water, stormwater, atmospheric deposition and sediment transport dynamics. A more comprehensive process for cross-region organizational learning than currently exists at EPA should be developed and implemented in a way that reaches greater numbers of employees than do present efforts. A comprehensive process could foster learning from the successes and failures of recontamination prevention strategies.

Currently there are several avenues for knowledge sharing within EPA including an annual national meeting through the National Association of Remedial Project Managers Annual Training Program and the Contaminated Sediments Technical Advisory Group (CSTAG). However these separate forums are not conducive to educating all Superfund project managers equally. Moreover, they are restricted to primarily federal Agency staff even though PRPs and local agency staff play a significant role in source control. In addition, there is no mandatory training or attendance for Program Managers (Nadeau, 2013).

EPA should create an informational session for all aquatic Superfund project staff and primary responsible parties on recontamination issues and prevention to disseminate knowledge gained from previous source control and recontamination prevention efforts. Industry has a separate educational and support group regarding Superfund sediment remediation issues known as the Sediment Management Work Group (SWMG), which produces scientific research papers and comments regularly on proposed projects and regulations concerning sediment management and cleanups (Nadeau, 2013; Brown et al, 2013).

Informational instruments go well with almost any other instrument (Gunningham, 1998). A knowledge sharing policy should be both politically feasible and complementary to other forms of policy. When combining policy instruments it is also important to sequence them in the right way. Gunningham (1998) believes knowledge sharing should come first if combining processes. Superfund already has an extensive matrix of policy processes but a knowledge sharing policy would likely still further improve processes and outcomes.

7.3 Achieving Washington States Sediment Management Standards (SMS)

Due to perceptions of the Washington State SMS seeming unachievable, it has been suggested that remedy selection decisions be taken out of the hands of the region and transferred to the NRRB and CSTAG panel at the EPA headquarters. At the headquarters level, decisions would presumably be made more consistently and would be based on the best available science (interview - Nadeau, 2013).

While some Ecology programs and citizens may see further restricting the SMS as a step in the direction of a healthier environment, the SMWG determined that some of the requirements had not incorporated national policy or key scientific and technical advances, stating: “the proposed amendments are likely to have the unintended consequence of making progress at sediment sites in the State of Washington even more difficult to achieve" (Nadeau, 2012). The SMWG's concerns include analyzing chemical background levels at regional background level versus an area background level, preferring an active cleanup method over natural recovery when in some cases dredging has increased risk through contaminated sediment resuspension and movement through residential areas. In addition there was concern over the use of the term "regardless of cost". In the case of the Lockheed West Seattle Superfund cleanup, costs doubled when cleanup standards were adjusted from urban background levels down to natural background levels, which was not sustainable long term because the site simply recontaminated to urban background levels within a matter of years (Nadeau, 2012). Requiring these more stringent cleanup standards regardless of cost can make cleanup allocation at multi-party sites more difficult and time consuming which in turn increases the consumption of federal and state oversight resources without improving the long-term outcome.

Piper Peterson (Interview- Peterson. 2013), the EPA project manager on the T-117 site believes that the cleanup standards being applied at the LDW, despite their seeming unachievability, are still appropriate. Setting the sediment cleanup goals at the levels necessary to achieve human and environmental health will drive new innovation and rigorous standards create an incentive to develop technology to detect low levels of contaminants and potentially clean sediments to natural background levels. The sediment management standards are not too stringent because they are correlated with human health protection as well as forcing innovation.

An additional challenge agency representatives mentioned was a public misperception that the LDW Superfund site can be cleaned up to recreational use and human consumption levels.

While many public documents have been published stating that both Ecology and EPA expect levels of recontamination, several interviewees indicated that the general public does not seem to understand the extent of contamination nor do they understand the quantity of toxic chemicals in the environment or the complexity of trying to test and remove the chemicals from the system. While all parties involved in the T-117 Superfund cleanup project are working very hard towards meeting the goals they are assigned, divvying up Superfund tasks can potentially lead to a piecemeal project which is not able to meet the original goal: getting of the NPL list. Regulatory flexibility such as decentralization is necessary to allow project staff to cater actions to the individual environmental and social variables at a particular site. However, it is important to have the right mixture of structured guidance and flexibility. Mandating knowledge sharing for project managers, creating more effective federal guidance on source control methods, and reexamining the achievability of cleanup standards would likely reduce the occurrence of potential recontamination.

References

Aecom, Crete, Dalton Olmsted & Fuglevand Inc., Integral Consulting Inc. and Windward Envrionmental LLC. 2010. Lower Duwamish Waterway Superfund Site Terminal 117 Early Action Area. Prepared for: The Port of Seattle and The City of Seattle. June 3, 2010. Seattle, Washington.

Anchor Environmental LLC. May 2007. Duwamish/Diagonal Sediment Remediation Project 4-Acre Residuals Interim Action Closure Report. Seattle, Washington.

Arcadis. 2007**.** Existing Site Updates for the MCSS Sediment Sites Database: Lower Duwamish Waterway. Portland, Oregon.

B.J. Cummings, Duwamish River Cleanup Coalition. January 15, 2008. RE: Draft Lower Duwamish Waterway Remedial Investigation. Seattle, Washington.

Barnett, Harold. 1994. Toxic Debts and the Superfund Dilemma. Chapel Hill: University of North Carolina Press

Baur, D., Eichenberg, T., and Sutton, M. 2009. Ocean and Coastal Law and Policy. American Bar Association; 1st edition. Chicago, Illinois.

Blomberg, G; Simenstad, C. and Hickey, P., 1988. Changes in Duwamish River estuary habitat over the past 125 years. In: Procedures of the. First Annual Meeting on Puget Sound Research. Seattle, Washington: Puget Sound Water Quality Authority, pp. 437– 454.

Bridges, Todd S., Nadeau, Steven C., McCulloch, Megan C. 2010. Dredging Processes and Remedy Effectiveness: Relationship to the 4 Rs of Environmental Dredging. Integrated Environmental Assessment and Management. Vol 6 Number 4 pp. 619-630.

Bridges, Todd S., Nadeau, Steven C., McCulloch, Megan C. 2012. Accelerating Progress at Contaminated Sediment Sites: Moving from Guidance to Practice. Integrated Environmental Assessment and Management. Vol 8 Number 2 pp. 331-338.

Bromm, Susan 2005. Memorandum: Enforcement First at Superfund Sites: Negotiation and Enforcement Strategies for Remedial Investigation/ Feasibility Studies (RI/FS). August 9, 2005. OSWER 9355.2-21.

Brown, Steven S., McCulloch, Megan C., Dekker, Tim. 2013. Creative Solutions for Watershed-based Sustainable Sediment Management. Battelle's 7th International Conference on Remediation of Contaminated Sediments. February 7, 2013. Dallas, Texas.

Cargill, Dan. 2012. (Interview) Personal communication between Dan Cargill, Department of Ecology and Railin Peterson, School of Marine and Environmental Affairs Student.

Cargill, Dan. 2013. (Interview) Personal communication between Dan Cargill, Department of Ecology and Railin Peterson, School of Marine and Environmental Affairs Student.

Cho, Y., Ghosh, U., Kennedy, AJ., Grossman, A., Ray, G., Tomaszewski, JE., Smithenry, DW., and Luthy, RG. 2009. Field Application of Activated Carbon Amendment for In-Situ Stabilization of Polychlorinated Biphenyls in Marine Sediment. Environmental Science and Technology. Vol 43, 3815-3823.

Chittenden, Hiram Martin. 1907. Report of an Investigation by a Board of Engineers of the Means of Controlling Floods in the Duwamish-Puyallup Valleys and Their Tributaries in the State of Washington. Lowman, Seattle.

Clarke, Chuck. May 2008. South Park Streets Fact Sheet. Seattle Public Utilities. http://yosemite.epa.gov/r10/CLEANUP.NSF/LDW/Fact+Sheets/$FILE/South-Park-Street-FS.pdf. Visited site: May, 2013.

Crete Consulting Inc., Grette Associates, Jacobs Associated and Moffatt and Nochol. 2012. Final Design Phase 1: Sediment and Upland Cleanup Lower Duwamish Waterway Superfund Site Terminal 117 Early Action Area.

Daley, Dorothy M., and Layton, David F. 2004. Policy Implementation and the Environmental Protection Agency: What Factors Influence Remediation at Superfund Sites? Policy Studies Journal, August 2004. Vol. 32, Issue 3. pp. 375-392.

DOE, Toxics Control Program. 2004. *Lower Duwamish Waterway Source Control Strategy.* Publication No. 04-09-043. Bellevue, Washington.

DOE 2005. Toxics Cleanup Program. *Lower Duwamish Waterway Source Control Action Plan for the Terminal 117 Early Action Area*. Publication No. 05-09-1010. Bellevue, Washington.

DOE, 2007. Lower Duwamish Waterway Source Control Status Report – 2003 to 2007. Publication No. 07-09-064. July, 2007. Bellevue, Washington.

DOE, 2008a. Lower Duwamish Waterway Source Control Status Report – July 2007 to March 2008. Publication No. 08-09-063. May, 2008. Bellevue, Washington.

DOE, 2008b. Lower Duwamish Waterway Source Control Status Report – April 2008 through August 2008. Publication No.08-09-068. October, 2008. Bellevue, Washington.

DOE, 2009. Lower Duwamish Waterway Source Control Status Report – September 2008 through June 2009. Publication No. 09-09-183. September 2009. Bellevue, Washington.

DOE, 2011. Lower Duwamish Waterway Source Control Status Report – July 2009 through September 2008. Publication No. 11-09-169. September 2011. Bellevue, Washington.

DOE, Lower Duwamish Waterway Source Control Status Report - October 2010 to December 2011. Publication No. 12-09-131. July 2012. Bellevue, Washington.

Duwamish River Cleanup Coalition. 2008. Duwamish Valley Vision Map & Report. Seattle, Washington. http://duwamishcleanup.org/wp-content/uploads/2012/02/Duwamish-Valley-Vision-Report-2009.pdf

Duwamish River Cleanup Coalition (DRCC). January 15, 2008. Comment Memo: Draft Lower Duwamish Waterway Remedial Investigation.

EcoChem Inc. 2005. Duwamish/Diagonal CSO/SD Sediment Remediation Project Closure Report: Elliott Bay/Duwamish Restoration Program Panel. Panel Publication 39. July 2005. Seattle, Washington

Environmental Partners, Inc; Golder Associates Inc., 2009. Boeing Plant 2 Seattle/Tukwila, Washington. Uplands Corrective Measures Study Vol IXa: 2-10 Area: Data Gap Investigation Work Plan. Prepared for The Boeing Company. November 2009. Seattle, Washington.

EPA. 1998. EPA's Contaminated Sediment Management Strategy. Office of Water 4305. EPA-823-R-98-001. April 1998. Seattle, Washington.

Horinko, Marianne. 2002. Principles for Managing Contaminated Sediment Waste Sites. OSWER Directive 9285.6-08. February 12, 2002. Washington, D.C

EPA. 2011. Detailed Analysis. http://www.epa.gov/superfund/cleanup/analys.htm. Last updated August 9, 2011

EPA. 8/11/2011. Summary of the Comprehensive Environmental Response, Compensation, and Liability Act (Superfund). http://www.epa.gov/lawsregs/laws/cercla.html

EPA. 9/21/2011. Integrated Cleanup Initiative. http://www.epa.gov/oswer/integratedcleanup.htm

EPA. April 2010. Lower Duwamish Site. http://yosemite.epa.gov/r10/nplpad.nsf/epaid/wa0002329803

Federal Register Notice. September 1, 2001. NPL Site Narrative for Lower Duwamish Waterway.

Flint, Kris. 2012. It takes a Team. Source Control on Lower Duwamish Waterway and Lessons Over Time. Kris Flint, EPA Region 10. November 29, 2012. US EPA 22nd Annual NARPM Training Sediment Form. Seattle, Washington.

Formation Environmental. 2010. Final Sediment Recontamination Analysis Approach Terminal 4 Removal Action. Prepared for the Port of Portland. Boulder, Colorado.

Foster, Richard. 1945. Sources of Pollution in the Duwamish-Green River Drainage Area. Pollution Control Commission Survey. December 6, 1945.

Fuller, Rick. 2012. Interview - Personal communication between Rick Fuller – Retired City of Tacoma Environmental Manager and Railin Peterson School of Marine and Environmental Affairs student.

Frontline. 2009. How to clean up a Superfund site. April 21, 2009. WGBH Educational Foundation. http://www.pbs.org/wgbh/pages/frontline/poisonedwaters/themes/duwamish.html. Updated 2013.

Gibbs, Charles and Isaac, Gary. 1968. Seattle Metro's Duwamish Estuary Water Quality Program. Water Pollution Control Federation. Vol 40, No 3, Mar. 1968.

Giles, Cynthia 2011. Memorandum: "Enforcement First" for Removal Actions. August 4, 2011. Washington, DC.

Government Accountability Office (GAO). July 18, 2008. Superfund: Funding and Reported Costs of Enforcement and Administration Activities. http://www.gao.gov/new.items/d08841r.pdf

Government Accountability Office. May, 2010. SUPERFUND: EPA's Estimated Costs to Remediate Existing Sites Exceed Current Funding Levels, and More Sites Are Expected to Be Added to the National Priorities List. Washington, DC.

Gunningham, Sinclair, and Grabosky, "Instruments for Environmental Protection," in Smart Regulation, Oxford, 1998, pp. 37-91.

Hilary Sigman. 2000. The Pace of Progress at Superfund Sites: Policy Goals and Interest Group Influence. NBER Working Paper No. 7704

Huey, Richard. (2001) Cooperation vs. Coercion in the Negotiated Settlement for a Remedial Investigation/Feasibility Study of the Lower Duwamish Waterway Site (Seattle, Wa). Seattle, Washington.

Jankowski, Piotr. 2003. Collaborative Spatial Decision Making in Environmental Restoration Management: An Experiment Approach. Journal of Hydroinformatics. 02.3 pg 197.

King County. 2010. Norfolk CSO Sediment Remediation Project. http://www.kingcounty.gov/environment/wastewater/SedimentManagement/Projects/Norfolk.aspx. Last updated: March 13, 2012.

Koontz, T., Steelman, T., Carmin, J., Korfmacher, K., Moseley, C., and Thomas, C. 2004. Collaborative Environmental Management: What Roles for Government. Routledge, Taylor and Francis Group. New York, New York.

Koontz and Thomas. 2006. "What Do We Know and Need to Know about the Environmental Outcomes of Collaborative Management," Public Administration Review 66.

Kubasek, N., Silverman, G., 2010. Environmental Law. 7th Ed. Pearson Custom Business Resources.

Lower Duwamish Waterway Group (LDWG). 2003. Phase 1 Remedial Investigation Report Final. Seattle, Washington.

Lower Duwamish Waterway Group (LDWG). 2010. Lower Duwamish Waterway Remedial Investigation. Seattle, Washington. http://www.ldwg.org/assets/phase2_ri/final%20ri/Final_LDW_RI.pdf

Lower Duwamish Waterway Group, 2012. Lower Duwamish Waterway Superfund Site Conceptual Model Background Information for the Participants of the Carbon Amendment Workshop. January 16, 2012. Power point.

May. 2002. "Social Regulation," The Tools of Government, Oxford, pp.156-185.

Nadeau, S. and Skaggs, M. 2007. Analysis of Recontamination of Completed Sediment Remedial Projects. Fourth International Conference on Remediation of Contaminated Sediments. Battelle Press, Columbus, OH.

Nadeau, Steven. 2012. Re: Sediment Management Work Group's Comments on the Proposed Amendments to the Sediment Management Standards Rule, WAC 173-204, August 15, 2012 Review Version. Sediment Management Work Group. October 25, 2012.

Nadeau, Steven. 2013. Interview - Personal Communication between Railin Peterson and Steven Nadeau regarding Superfund recontamination issues. March 28, 2013.

Nakamura, R., and Church, T., 2003. Taming Regulation: Superfund and the challenge of regulatory reform, Brookings Institution Press. Washington, DC.

National Research Council. 2007. Sediment Dredging at Superfund Megasites Assessing the Effectiveness. National Academies Press. Washington, DC.

Palermo MR, Schroeder PR, Estes TJ, Francingues NR. 2008. United States Army Corps of Engineers. Engineer Research and Development Center. Technical guidelines for environmental dredging of contaminated sediments. September. ERDC/EL TR-08-29. Vicksburg, MS.

Peterson, Piper, 2013. Interview - Personal Communication between Railin Peterson and Steven Nadeau regarding Superfund recontamination issues.

Port of Seattle. 2009. Lower Duwamish River Habitat Restoration Plan An Inventory of Port of Seattle Properties. https://www.portseattle.org/downloads/community/environment/Final_DuwamishMP_20090716.pdf. Last referenced September 2012.

Probst, Katherine. 2001. Superfund's Future: What Will It Cost? Resources for the Future Press. Washington, DC.

Probst, Kate. 2009. Reinstating the Superfund Taxes: Good or Bad Policy? Resources for the Future Press. Washington, DC.

Ramseur, Jonathan and Reisch, Mark. 2006. CRS Report for Congress. Superfund Overview and Selected Issues. Library of Congress. Order Code RL 33426.

Romberg, Patrick G. Recontamination Sources At Three Sediment Caps In Seattle King Country, Department of Natural Resources and Parks. Proceedings of the 2005 Puget Sound Georgia Basin Research Conference. Seattle, Washington.

Sato, Mike. 1997. The Price of Taming a River: The Decline of Puget Sound's Duwamish/Green Waterway. Mountaineers Books. Seattle, Washington.

Scheberle, "Devolution," in Environmental Governance Reconsidered: Challenges, Choices, and Opprotunities. Ed 1. MIT Press, 2004, pp. 361-392. Cambridge, MA.

Sherman, D. 2004. Contamination, Collaboration, Remediation, and Restoration: Lessons on First- and Next-Generation Environmental Policy Approaches from the St. Paul Waterway Superfund Site in Tacoma, WA. Society & Natural Resources, 24:3, 303-311.

Simenstad, C., Tanner, C., Crandel, C., White, J., and Cordell, J. 2004. Challenges of Habitat Restoration in a Heavily Urbanized Estuary: Evaluating the Investment. Journal of Coastal Research. No. 40, pp. 6-23.

Starkes, Jim. 2001. Reconnaisance Assessment of the State of the Nearshore Ecosystem: Eastern Shore of Central Puget Sound, including Vashon and Maury Islands (WRIAS 8 AND 9). Executive Summary. Prepared for KCDNR. http://www.kingcounty.gov/environment/watersheds/central-puget-sound/nearshore-environments/reconnaissance-assessment.aspx. Last Visited: May, 2013.

Thomas, R., Bardy, L., Alam, M., McCrea, R. 2012. Lower Duwamish Waterway Source Control Strategy. Draft Final. Toxics Cleanup Program and Water Quality Program. Northwest Regional Office, Washington State Department of Ecology. Bellevue Washington 98008-5452.

Trim, Heather. 2004. Restoring our River; Protecting our Investment: Duwamish River Pollution Source Control. http://duwamishcleanup.org/superfund-info/drcctag-reports/ Last visited: May, 2013

USEPA. 2002. Principles for Managing Contaminated Sediment Risks at Hazardous Waste Sites. OSWER Directive 9285.6-08. February 12, 2002.

USEPA, 2005. Contaminated Sediment Remediation Guidance for Hazardous Waste Sites. EPA-540-R-05-012. OSWER 9355.0-85. December 2005.

USEPA. 2011a. Contaminated Sediments Technical Advisory Group (CSTAG) Website: http://www.epa.gov/superfund/health/conmedia/sediment/cstag.htm. Last Updated September 12, 2011

USEPA. 2011b. Basic Information (NRRB) Website: http://www.epa.gov/superfund/programs/nrrb/. Last Updated September 12, 2011

USEPA. 2011c. SARA Overview. Last Updated December 12, 2011. http://www.epa.gov/superfund/policy/sara.htm

USEPA. 2013a. Summary of the Clean Water Act. Last Updated February 24, 2013. http://www.epa.gov/lawsregs/laws/cwa.html

USEPA, 2013b. Proposed Plan Lower Duwamish Waterway Superfund Site. USEPA Region 10. February 28, 2013.

USEPA. 2011. Website: http://www.epa.gov/superfund/cleanup/. Cleanup Process. August 9, 2011.

USFWS. 2004. Elliott Bay/ Duwamish Restoration Program: Intertidal Habitat Projects Monitoring Report. 2001-2003 Final Report.

Wagner, Travis. 1994. The Complete Guide to the Hazardous Waste Regulations. Second Edition. A comprehensive Step-By-Step Guide to the Regulation of Hazardous Wastes under RCRA, TSCA, HMTA, OSHA and Superfund. Van Nostrand Reinhold An International Thompson Publishing Company. New York.

Warren, Bob. 2012. Interview - Personal communication between Bob Warren, Department of Ecology and Railin Peterson, School of Marine Affairs Student.

WA DOE, 2007. Model Toxics Control Act Statue and Regulations. Publication No. 94-06. Revised November 2007.

WA Department of Health (DOH). 2010. Letter Health Consultation: Rainier Commons LLC Polychlorinated Biphenyls (PCBs) Paint Contamination Seattle, King County, Washington. DOH 334-227 March 2010.

Washington State legislature. Washington Administrative Code. Chapter 173-204 Sediment management standards.

Weimer, D. and Vining, A. 2011. Policy Analysis. Ed 5. Prentice Hall.

Yin, Robert. 2008. Case Study Research: Design and Method. Sage Publications, Inc. 4th Ed.

Zahler, A., Marti, A., and Thomsen, G. 2009. Seattle's South Park. Images of America: Washington. Arcadia Publishing. Mount Pleasant, SC.

Appendix A. Technical Tables

Table A.1. Regulatory Authorities Applicable to Source Pathways

Levels of Gov't	Regulatory Authority	Applicable Permits/ Regulations	Pathways							
			Direct Discharges	Surface Runoff	Contaminated Groundwater	Contaminated Soil Erosion/ Leaching	Waterway Operations	Spills, Leaks & Inappropriate Management	Atmospheric Deposition	In-water Transport of Contaminated Sediments
State	State Water Pollution Control Law (RCW 90.48) and federally delegated NPDES program under CWA	Municipal stormwater permits	X	X				X		
		Industrial stormwater permits	X	X				X		
		Municipal wastewater and CSO permits	X	X				X		
		Industrial wastewater	X	X				X		
	State MTCA (RCW 70.105D)	Cleanup regulations	X [a]	X [a]	X	X			X [c]	X
	Hazardous Waste & Toxic Reduction (RCW 70.105)	Control and management of hazardous waste	X [a]	X [a]	X	X			X [c]	X
	State OHSSPR (RCW 90.56)	Surface water spill prevention regulations	X [b]	X [b]			X	X		
Federal	CWA 33 USC §§ et seq.	Point Source general permits (federal, e.g. vessel general permits)	X	X			X	X		
	TSCA 15 USC §§ 2601-2692	Regulates PCBs, asbestos, lead, radon, and other substances and mixtures	X	X	X	X		X		

Levels of Gov't	Regulatory Authority	Applicable Permits/ Regulations	Pathways							
			Direct Discharges	Surface Runoff	Contaminated Groundwater	Contaminated Soil Erosion/ Leaching	Waterway Operations	Spills, Leaks & Inappropriate Management	Atmospheric Deposition	In-water Transport of Contaminated Sediments
	RCRA 42 USC § 6901 et seq.	Sets standards for the treatment, storage, and disposal of hazardous waste in the U.S.	X[a]	X[a]	X	X				
	CWA 33 USC § 404 et seq.	Dredging, filling, work in navigable waters					X	X		
	CERCLA 42 USC § 6901 et seq.	Cleanup regulations/ National Contingency Plan	X[a]	X[a]	X	X			X[c]	
	OPA, 33 USC §§ 2701 et seq.	Surface water spill prevention regulations/ National Contingency Plan	X[b]	X[b]			X	X		
	CAA, 42 USC §§ 7401 et seq.	Air regulations							X	

Levels of Gov't	Regulatory Authority	Applicable Permits/ Regulations	Pathways							
			Direct Discharges	Surface Runoff	Contaminated Groundwater	Contaminated Soil Erosion/ Leaching	Waterway Operations	Spills, Leaks & Inappropriate Management	Atmospheric Deposition	In-water Transport of Contaminated Sediments
Regional & Local	Delegated state CAA (RCW 70.94) and federal CAA	PSCAA permits							X	
	King County Codes: Title 28 Metropolitan services and delegated pretreatment program; Title 9.04, 9.12; Title 16.82	King County industrial waste permits and discharge authorizations; sets requirements for stormwater detention/ treatment, source control, and maintenance	X	X				X		
	Seattle Municipal Codes: Stormwater Code (22.800-22.808) and Side Sewer Code (21.16)	Sets requirements for stormwater detention/ treatment, source control, and maintenance; side sewer construction and permitting	X	X				X		
	Tukwila Code Titles 6, 14, 21, and 22	Permits, licenses, orders, decrees, and notices	X	X				X		

Levels of Gov't	Regulatory Authority	Applicable Permits/ Regulations	Pathways							
			Direct Discharges	Surface Runoff	Contaminated Groundwater	Contaminated Soil Erosion/ Leaching	Waterway Operations	Spills, Leaks & Inappropriate Management	Atmospheric Deposition	In-water Transport of Contaminated Sediments

CAA = Clean Air Act
CERCLA = Comprehensive Environmental Response, Compensation, and Liability Act
CSO = combined sewer overflow
CWA = Clean Water Act
MTCA = Model Toxics Control Agency
NPDES = National Pollutant Discharge Elimination System
OHSSPR = Oil and Hazardous Substance Spill Prevention and Response
OPA = Oil Pollution Act of 1990
PSCAA = Puget Sound Clean Air Agency
RCRA = Resource Conservation and Recovery Act
RCW = Revised Code of Washington
TSCA = Toxic Substances Control Act
USC = United States Code

a. The character, nature, and extent of chemical contamination, affected media, and pathways at any given place may determine how these regulations apply. Each source may be uniquely regulated.

b. Spill response regulations apply to an immediate threat to human health and to the environment for oil and hazardous substances.

c. Cleanup regulations apply to other media contaminated by air sources.

Source: DOE, Toxics Control Program. 2004. *Lower Duwamish Waterway Source Control Strategy.* Publication No. 04-09-043. Bellevue, Washington.

Table A.2. T-117 Groundwater, Soils and Sediments RvALs

COC	Removal Action Level[1]		
	Soil	*Sediment*[2]	*Groundwater*
Total Petroleum Hydrocarbons (TPH; as diesel and heavy oil-range organics)	200 mg/kg dw (Diesel only; Upper 6 ft) 2,000 mg/kg dw	n/a	500 µg/L
Carcinogenic polycyclic aromatic hydrocarbons	140 µg TEQ/kg dw	90 µg TEQ/kg dw	0.15 µg TEQ/L
Dioxins/furans	11 ng TEQ/kg dw	13 ng TEQ/kg dw	n/a
Total PCBs	0.65 mg/kg dw (Upper 2 ft) 1 mg/kg dw (Below 2 ft)	12 mg/kg oc 130 µg/kg dw (Upper 10 cm) 500 µg/kg dw (Upper 45 cm)	0.01 µg/L
Arsenic	7.3 mg/kg dw[3]	12 mg/kg dw	5 µg/L
Silver	2 mg/kg dw (Upper 6 ft) 400 mg/kg dw	n/a	1.9 µg/L
COC	**Removal Action Level[1]**		
	(Below 6 ft)		
2-Methyl naphthalene	n/a	38 mg/kg oc	n/a
Acenaphthene	n/a	16 mg/kg oc	n/a
Anthracene	n/a	220 mg/kg oc	n/a
Dibenzofuran	n/a	15 mg/kg oc	n/a
Bis(2-ethylhexyl)phthalate	n/a	n/a	1.7 µg/L
Fluoranthene	n/a	160 mg/kg oc	n/a
Fluorene	n/a	23 mg/kg oc	n/a
Phenanthrene	n/a	100 mg/kg oc	n/a
Phenol	n/a	420 µg/kg dw	n/a

Source: Crete Consulting Inc., Grette Associates, Jacobs Associated and Moffatt and Nochol. 2012. Final Design Phase 1: Sediment and Upland Cleanup Lower Duwamish Waterway Superfund Site Terminal 117 Early Action Area.

Table A.3. Sediment Sites with Reported Contamination (2007).

Site	Response Measure(s)	Recontamination Information	References
Anacostia River, DC	2004 Cap	2006 Urban sources, upstream sources	USEPA 2006
Bloomington, IN (3 creeks)	1987 Sediment Removal	1992 All sources unclear – point source discharge included	ATSDR 1992
Bremerton Naval Complex, WA	2000 Dredge	2000 Losses from CAD placement	SPI 2002, DNO 2002
Convair Lagoon, CA	1998 Cap	2002 Public storm drain discharges	Zeng 2002, Carlisle 2002
Denny Way Site, WA	1990 Cap	1993 CSO point source discharges	Palermo 2002, NRC 2001, Romberg 2005, WDNR 2002
Duwamish Norfolk CSO, WA	1999 Dredge-Cap	2001 CSO point source discharges; unremediated adjacent contaminated sediment	WDE 2003, USEPA 2003
Duwamish River Diagonal, WA	2004 Dredge	2005 Sewage system discharges	SPI 2005
Eagle Harbor Site, WA	1994 Cap	1999 "Surface sources", "offsite sources"	USEPA 1999, Palermo 2002
Ford Outfall/River Raisin, MI	1997 Dredge	2001 Unremediated upstream sediments and/or upland sources; sediments sloughed from adjacent navigational channel	Cieniewski 2003, Bergeron 2000, Cleland 2000, Cleland 2001 Weston 2004
Fox River SMU 56/57, WI	2000 Dredge-cap	2005 1.2-1.5 m of new impacted sediment deposited in five years	AE 2006
Housatonic River, MA	2002 Dredge-Cap	2005 Upstream sediments, CSO and SSO point source discharges	BG 2005
Lauritzen Canal, CA	1996 Dredge-Cap	1998 Undetected point source(s); incomplete remediation near margins of site	USEPA 2001, Weston 2002, USEPA 2004a
Long Beach North Energy Island Borrow Pit (NEIBP), CA	2001 Cap	2004 "Deposition from the surrounding harbor"	USACE 2005
Pier 51 Ferry Terminal, WA	1989 Cap	1990 PAHs due to pile pulling; metals from "new sediment deposition"	HSRC
Pier 53-55, WA	1992 Cap	2002 Prop wash resuspension near edges; PAHs due to pile removal	Romberg 2005
Pier 64-65, WA	1994 Cap	2002 Piling repair work released creosote	Romberg 2005
Puget Sound Naval Shipyard Pier D, WA	1994 Dredge	1998 Suspected resuspension of sediments from outside response area	RETEC 2002
Sitcum Waterway/ Nearshore Tideflats, WA	1993 Dredge	2002 "Continued source input from recent sediment deposition or off-loading activities"	RETEC 2002
St. Clair Shores, MI	2002 Dredge	2003 Sewer pipe discharges	TMD 2006
Thea Foss Waterway, WA	2002 Dredge-Cap	2006 City storm drain discharges	TNT 2006a, TNT 2006b

Source: Nadeau, S. and Skaggs, M. 2007. Analysis of Recontamination of Completed Sediment Remedial Projects. Fourth International Conference on Remediation of Contaminated Sediments. Battelle Press, Columbus, OH.