Nearshore Confined Disposal in a Tidally-Influenced Environment—Design and Operation Experience in Puget Sound

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ABSTRACT

Port of Seattle studies of nearshore contaminated dredged material disposal sites have revealed many of the factors controlling contaminant loss. The information gathered and the knowledge gained have proven valuable not only for the design of nearshore confined disposal sites, but for understanding other sites where contamination from an upland source is entering marine surface water through tidally influenced ground water. In this paper we present some highlights and insights from our technical and regulatory experience over the past twelve years.

INTRODUCTION

For over a decade, the Port of Seattle has been engaged in research and monitoring of nearshore and nearshore/upland dredged material disposal sites. These studies have been prompted by state and federal regulatory agency concerns over the environmental consequences of our actions, and progress in understanding contaminated dredged material disposal. This progression of Port of Seattle studies constitutes the most thorough accumulation of knowledge we have found available on the major processes and driving forces influencing the design and operation of dredge material disposal sites in the saturated nearshore environment.

BACKGROUND

In Puget Sound, as elsewhere around the world, using dredged material as fill in Port developments is not a new concept. Specifics of construction vary depending on the site and need. The types of sites studied by the Port are primarily the deep

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nearshore fills, where berms are constructed and dredged material is placed inside and covered with structural fill cap, and secondarily nearshore/upland fills, where shoreside land is excavated to below the groundwater, dredged material placed inside, and the excavated material used as the cap. In both of these situations, the dredged material is kept within the saturated zone. In Puget Sound, these types of fills have been shown to be environmentally protective.

From the early 70's to the mid 80's, increasing and regulatory concern followed on the heals of increasing scientific and environmental awareness that you can have contaminated sediments while still complying with water quality criteria. It became generally known that many common contaminants become physically and/or chemically attached to and concentrated on sediment particles. In this climate, there was regulatory pressure to dispose of more contaminated sediments in confined disposal sites. There was also increasing agency concern over long-term contaminant retention in the confined disposal sites. At the time this concern was fostered by agency management experience being limited primarily to upland disposal of hazardous and solid waste.

PORT OF SEATTLE EXPERIENCE

In the last 12 years, the Port has studied three projects in succession that have increased our understanding of deep nearshore fills. All of these projects deal with clam shell dredged material.

Terminal 105

In 1982, the Port constructed a nearshore/upland pit for containment of contaminated dredged material. This site was monitored for loss of leachate through the ground water to the nearby estuarine waterway (Figure 1). The contaminants of concern were PCBs, metals, and PAHs. This early program found some losses from the site during the initial de-watering phase, but nothing that was of concern to the nearby surface water. Arsenic was the only contaminant showing a clear and continuing influence from the dredged material disposal, although of no environmental concern since it was over 20 times below Marine criteria.

Terminal 91 Nearshore Disposal Facility

Several years later in 1984, the Port proposed the Terminal 91 Nearshore fill. By then, there was increased regulatory awareness and concern regarding contaminated fills. There was also increased knowledge gained from Terminal 105, Waterways Experiment Station studies, and other published reports that gave the Port confidence that this was an environmentally reasonable approach. It appeared that if the dredged materials remained in their original saturated and anaerobic state, the contaminants would remain associated with the sediments particles and be retained within the fill.

The majority of the dredged material for the fill would come from the Port's Terminal 30 project which redeveloped an old petroleum handling and storage facility into a container terminal. The sediments contained moderate levels of the standard urban harbor contaminants, with maximum concentrations in the tens of ppm for total PAHs, in the hundreds for metals and up to 6 ppm for PCBs.

The Port's proposal was for a deep nearshore fill to be built by constructing two long berms spaced about 120 meters (400 feet) apart extending across the slip between the solid fill Piers 90 and 91. Each berm contained clean structural fill with sandy gravel cores covered with rip rap. Approximately 100,000 m^3 (130,000 cubic yards) of contaminated dredged materials would be clamshelled, barged into the site through a gap in one of berms which was kept closed with a surface to bottom silt curtain, and bottom dumped. The dredged material would be entirely contained below the saturated zone, and capped with uncontaminated sand and gravel and paved with asphalt. A stormwater drainage system would be installed to handle rainwater and runoff and a system of monitoring wells installed as part of the design to collect data and analyze how the facility would perform over time (Figure 1). There would be would be no liners, low permeability barriers, or leachate control systems. The design would retain the sediments, but the initial dewatering and regional groundwater could move through the dredged material and berms.

The Terminal 91 site had existing sediment contamination from past and present sources. The area was a naval facility for 30 years and has been a bulk petroleum facility since the 1920's with major storm drains and sewer overflows in close proximity. Even if it were possible to do so, these present and historic contaminant sources have made the existing sediments too contaminated to observe losses from the facility by studying sediment recontamination.

When the Terminal 91 project was first proposed, the regulatory agencies believed that the Port lacked sufficient field data on long-term contaminant mobility from tidally-influenced nearshore disposal sites to fully evaluate the project and recommended totally enclosing the site with a slurry wall. The agency concerns were twofold: 1) what was the immediate impact of any leachate loss on the water quality and sediments; and 2) what was the longterm loss. A series of meetings and discussions between the Port and the agencies ensued during which ideas and approaches to resolving the issue and filling data gaps were debated. Major agency input during these discussions came from EPA Region 10, the Washington State Department of Ecology, and the U.S. Army Corps of Engineers.

The solution which surfaced during these discussions was to reasonably predict, monitor, and potentially remedy (to the agencies satisfaction), the performance of the disposal site. As a first step, the Port needed to assure the agencies that the containment system would provide adequate environmental protection based on existing water quality criteria. In order to evaluate the potential level of environmental protection the facility would provide, the agencies requested

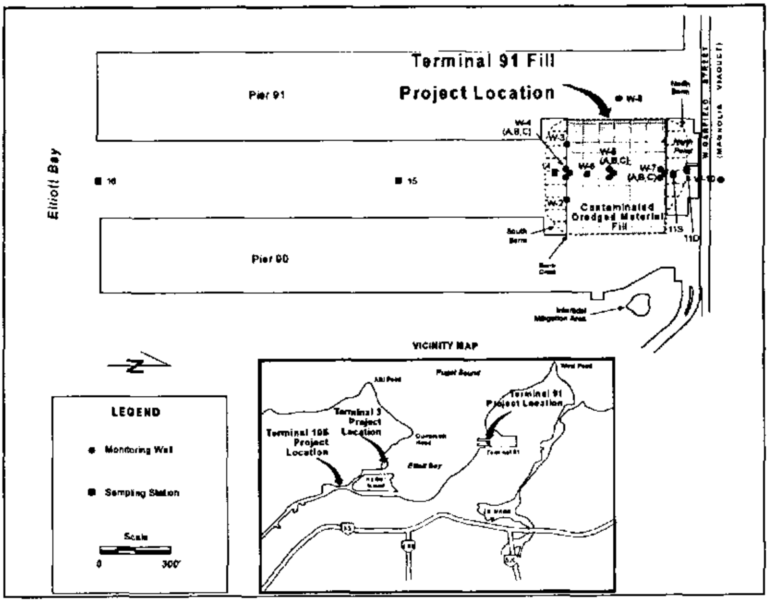

Figure 1. Terminal 105, Terminal 3 and Terminal 91 Sites

a reasonable prediction of the percent loss of the total amount of contaminants in the fill over time, and the potential impact on the water quality of the surrounding marine waters.

To evaluate the projected performance of the facility, the Port proposed a modeling approach to predict the long-term contaminant mobility from the facility. The first approach used a simplified steady state analytical model and could not accommodate the dynamic effects of tidal action. The regulatory agencies thought that the leaching could be exacerbated by the hydraulic pumping action of the tides indicating that a more complex analysis would be needed. A more sophisticated modeling approach was then developed.

In this second approach, leachate predictions were made using a numerical hydraulic model run separately from an analytical solute transport model employing conservatively estimated data and a conceptual model for the facility. The hydraulic model was run over a number of tidal cycles to simulate tidal pumping within the system. The tidal velocities were then used to estimate a tidal dispersion coefficient which was used as input to the analytical transport model. Steady-state hydraulic simulations were used to determine the long-term advective velocity through the fill. The tidal dispersion coefficient accounted for the accelerated transport due to tidal pumping. Both metals and organic contaminants were modeled.

Estimated data were used in this effort as the facility had not been built. The estimates were based on published chemical analyses from similar yet fairly contaminated dredge materials from the Duwamish Waterway, and physical testing of materials similar to those expected to be used for the berms. Modeling assumptions used were consistently conservative in a direction which would produce worst-case results.

The model predictions showed that no water quality violations would be observed at the berm-seawater interface and that only a very small fraction of the contaminants would be removed in 100 years. To verify the predictions demonstrated in the model, and to develop a remedial action plan if it did not function as predicted, the Port prepared the Criteria, Threshold, Monitoring and Remedial Action Plan. This plan established basic performance criteria and a monitoring program for measuring performance of the facility. The plan: set threshold levels for initiation of remedial actions; established a remedial action agenda; and provided research and monitoring data that would also be applicable to other dredge disposal projects.

Performance criteria for the plan were established in cooperation with the lead regulatory agencies: the U.S. Army Corps of Engineers, U.S. EPA Region 10 and the Washington State Department of Ecology. The existing 1985 EPA chronic marine water quality criteria were used. If no EPA accepted criteria existed for a contaminant, the criterion used was ten times the level found in the background seawater in Elliott Bay. The plan was submitted as a consent agreement as part of the Water Quality Certification for the 404 dredge and fill permit which allowed the Port to obtain a water quality certification and proceed with the project.

Results from the computer modeling studies were used to determine locations and sampling depths of the monitoring wells to be used in a five-year monitoring program which would start in 1986. Well locations were chosen to best monitor the performance of the system in terms of hydraulic flow and contaminant concentrations. Wells were placed in the berms, in the contaminated dredge fill, in the cap material and near the Magnolia Viaduct (see Figure 1) which would be in an upgradient groundwater flow direction from the facility.

The established performance criteria for contaminants of either the 1985 EPA chronic marine water quality criteria, or ten times background seawater, would be applied to the long term average, or chronic concentrations in the monitoring wells.

A follow-up modeling study was conducted in 1990 after the facility had been monitored for four years. This study updated the earlier model using actual as-built measurements and the measured monitoring results. The modeling assumptions for the tidal dispersion coefficient were upheld and the updated predicted leach rates and concentrations were lower than originally predicted. However, the percentage of the total amount of contaminants in the fill which would be leached during the first 100 years of operation were predicted to be higher in than previously modeled, although generally less than one percent of the total. This higher percentage leached resulted primarily from greater estimated flow rates through the facility due to the way in which the facility was constructed.

The monitoring data demonstrated that the facility met all regulatory requirements and performance criteria established by the consent agreement with the agencies. While some levels for a few metals including nickel were elevated in the south berm wells, it was shown that these metals came from the clean structural fill in the berm itself and not from the contaminated dredged material. This was one of the important observations extracted from the monitoring data during the project. Two other important observations made regarding major processes and functioning of the facility are listed below.

- The majority of tidal flow within the berm occurs in the intertidal zone with the maximum flow out of the berm occurring at the end of the lower-low ebb tide.

The effects of this can be seen in Figure 2 which shows concentrations of

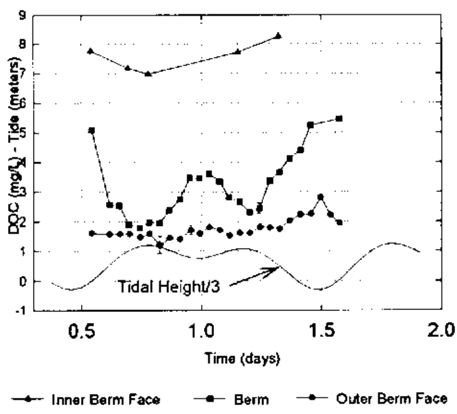

Figure 2. DOC Concentration from Tidal Survey

total dissolved organic carbon (DOC) over a tidal cycle at three locations within the facility. The inner berm face data is from well W-6 which was completed partially in the fill and partially in the berm at the inner berm face; the berm data is from well W-4B located in the center of the berm; and the outer berm face data is from Station 14 (see Figure 1.). The two wells are at the same elevation of about one meter below mean lower-low water. The outer berm face and berm time series shows rising DOC concentrations associated with falling tides with a spike at the outer berm face at the end of the lower-low ebb. Rising tides produce lower DOC concentrations within the berm as fresh seawater advances into the berm. DOC was demonstrated to be quasi-conservative given its residence time within the berm and to be an adequate tracer of tidal mixing.

- The berm acts an active biogeochemical filter, tapping trace metals while enhancing biodegradation of organic contaminants.

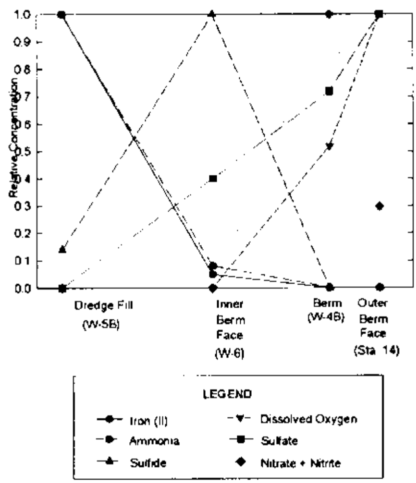

Figure 3. Inorganic Species in Terminal 91 Nearshore Confined Disposal Facility

Figure 3 illustrates the impact of the major biogeochemical processes occurring within the berm on the berm chemistry. It shows the concentrations of six reactive inorganic species at four locations within the facility normalized to their largest value for convenient display. The locations are the same inner and outer berm face and berm locations as in Figure 2 with the addition of a dredge fill location (well W-5B).

Figure 3 shows that oxygen, nitrate + nitrite and sulfate are introduced into the berm at the outer berm face through tidal action. Oxygen is consumed by the time it reaches the inner berm face. Sulfate is partially reduced near the inner berm face as the oxygen becomes depleted as evidenced by the large increase in sulfide. Nitrate + nitrite are produced in the outer portions of the berm and consumed in the inner berm where the oxygen becomes depleted. Iron (II) and ammonia are highest in the dredge fill and are rapidly depleted as they enter the berm.

This figure clearly shows that oxygen is being utilized within the berm. Most of oxygen in the inner portion of the berm is probably being consumed in iron (II) and sulfide oxidation and nitrification of the ammonia. In the outer berm, oxygen is primarily being consumed in aerobic respiration of organic carbon with a smaller amount used in nitrification to produce the peak of nitrate + nitrite concentrations. In the inner portions of the berm, organic matter is being oxidized by anaerobic bacterial respiration via sulfate reduction, nitrate reduction and denitrification.

In addition to the bacterial mediated organic matter oxidation, iron (II) oxidation to iron (III) also occurs within the berm. This is an important process because iron (III) is relatively insoluble and precipitates out of solution as ferric oxides and hydroxides (oxyhydroxides). The precipitating ferric oxyhydroxides are captured on the surface of the berm material and remain there. Although not shown in Figure 3, total unfiltered iron is undetected at < 0.01 mg/L in the berm dropping from over 11 mg/L in the fill indicating that the iron has been lost from solution. The precipitating ferric oxyhydroxides will simultaneously coprecipitate other metals along with the iron. Coprecipitation with ferric iron is a well known and highly efficient removal mechanism for trace metals from solution. Once formed, the precipitated metal oxyhydroxides also act as a highly efficient surface-active sorption substrate for capturing additional metals from solution over time.

Furthermore, the production of sulfide concentrations near the inner berm face which are ten times the concentration in the fill (see Figure 3) will enhance precipitation of the highly insoluble metal sulfides at or near the inner berm face. This should serve as an addition geochemical barrier to trace metal transport from the fill for those metals whose concentration is controlled by sulfide solubility.

The Terminal 91 project has shown that efficient containment is achieved through the combination of a high-permeability berm, low-permeability dredged material, and a shallow upland hydraulic gradient. The shallow gradient and low-permeability dredged material limits flow rates through the fill. Low flow rates help maintain the anaerobic conditions within the contaminated dredge material fill which in turn produces minimal release of most metals and organics. The high-permeability berm allows fresh oxygenated seawater to enter deep into the berm due to tidal action. This allows biogeochemical processes to occur deep within the berm which act to trap the trace metals and enhance aerobic and anaerobic biodegradation of organic contaminants throughout the berm.

<u>Terminal 3 Nearshore Confined Disposal Feasibility Study</u>

This project was initiated by the Port of Seattle in 1992 as a remedial alternatives feasibility study to develop cleanup alternatives for the contaminated sediments adjacent to Terminal 3. This was part of a remedial investigation/feasibility study and EIS for the redevelopment of the property as an expanded container shipping terminal. Two sediment cleanup alternatives were investigated: a nearshore confined disposal facility which would create new upland and which would also potentially serve as a multi-user confined disposal site for other contaminated sediment cleanups; and a much smaller confined aquatic cap placed just below the intertidal zone.

Since Terminal 3 could potentially serve as a multi-user site, it received extensive peer review throughout the project from EPA, USGS, US Army Corps of Engineers, and state agencies along with the Port. It was agreed that because site conditions affecting system performance would be different than in the Terminal 91 project, and because computer resources and more sophisticated models were available which could include other processes not included in the Terminal 91 model, a more sophisticated model would be used. A more sophisticated modeling approach would help differentiate between predictions of unacceptable concentrations resulting from overly conservative modeling assumptions, and predictions that more realistically represent actual system performance. This would allow for more control and flexibility in the design to maximize the use of the most contaminated sediments and make the best use of this valuable resource.

Based on our Terminal 91 experience, a number of selection criteria were established:

- Tidal Action: The model needs to account for varying thickness of saturated flow within the berm with time-varying flow and solute conditions at the outer berm face boundary.

- Density Dependent Flow: As the upland freshwater moves through the fill over time, the density difference between it and the saline dredged material may alter the flow paths and local discharge rate. The model will need to accommodate density dependent flow as a function of the changing salinity in the facility over time.

- Biogeochemical Processes: At a minimum then model must be able to handle equilibrium adsorption and first order biodegradation. As a plus the model should be able to include source/sink terms which could simulate other processes such as solubility limited dissolution/precipitation and changes in chemical mobility related to leaching and colloidal release in the transition from salt to freshwater.

The model chosen was a modified version of PORFLOW which could directly include variably saturated density-dependent flow and the tidal boundary conditions for both flow and solutes, as well as some of the biogeochemical processes.
Simulations were conducted using three inorganic contaminants (copper, lead, arsenic) and three polyaromatic hydrocarbons (naphthalene, fluoranthene, indeno(1,2,3-cd)pyrene) which were chosen based on their known level of contamination in sediments likely to be dredged, their toxicity, mobility and persistence. The major biogeochemical processes included were:

- First order biodegradation for the organics using anaerobic rate constants which are conservatively much less than aerobic rates,

- Adsorption constants for inorganic contaminants based on geochemical models using amorphous ferric oxides in the berm and cap and organic carbon equilibrium partitioning for the organics, and

- A salinity-dependent source term to simulate leaching and colloidal release from the dredged fill based on laboratory column and sequential batch leach tests using upland groundwater and modified USACOE Waterways Experiment Station protocols.

Major conclusions from the modeling are:

- The model shows that the flow is strongly influenced by the density difference along the freshwater/saltwater interface. Fresh upland groundwater flow is directed upward as it approaches the more dense saltwater. This enhances the outward flow in the intertidal zone where greater than 95% of flux of contaminants occurs.

- Flow paths through the fill are also influenced by the hydraulic conductivities of the surrounding upland soils and aquatic sediments.

- The model is much more sensitive to the inorganic K_ds in the berm, the salinity-dependent source term, and the biodegradation rates than to the hydraulic flow parameters.

- Concentrations derived from the fill at the berm or cap face did not pose a human health or environmental risk. The net mass loss from each of the alternatives was less one percent after a 100 year period.

<u>Summary</u>

Our experience has shown that nearshore confined fills in tidal environments can be designed to be environmentally protective and permitted at a reasonable cost. This is accomplished by understanding the site conditions and incorporating this information along with the major processes affecting contaminant fate and transport into a conceptual design model. Intelligent decisions can then be reached regarding berm and cap design as well as dredge fill placement and sequencing to minimize contaminant discharge to the environment. This knowledge is not restricted to nearshore fills and has also found to be very valuable in understanding other sites where contamination from an upland source is entering marine surface water through tidally influenced ground water.