US Army Corps of Engineers ®
Seattle District

Pierce County – Washington

Anderson-Ketron PSDDA Disposal Site Fate and Transport Modeling

Design Memorandum

September 2014

Table of Contents

1 Introduction 3
1.1 Purpose and Scope 3
1.2 Project Description: Background and Present Condition 3
1.3 Modeling Approach 3
2 Hydrodynamic Modeling 4
2.1 Model background 4
2.2 Model verification 5
3 Fate and Transport Modeling 9
3.1 Model Background 9
3.2 MPFATE Model Inputs 9
3.3 MPFATE Model Calibration 10
3.4 MPFATE Model Results 12
3.5 Particle Tracking Model (PTM) 12
3.6 Suspended Sediment Particle Pathways 13
4 Conclusions and Recommendations 14
5 Relationship with Nisqually Delta 15
6 References 15

1 Introduction

1.1 Purpose and Scope

Seattle District's Coastal Engineering Unit was tasked with answering three questions that had been raised over the continued use of the Anderson-Ketron dredged material disposal site: 1) are tidal currents at the site strong enough to carry significant quantities of dredged material off site? 2) if dredged material is carried off site, is it transported to shallower water, such as the Nisqually delta, where biological resources are more abundant than at the disposal site? 3) Do the hydrodynamics that are responsible for creating sand waves in the Nisqually delta have any effect on dredged material placed at the disposal site?

This report describes the results of a modeling study to determine the fate and transport of dredged material placed at the Anderson-Ketron disposal site. It also describes the relationship of the disposal site with the hydrodynamics of the Nisqually delta.

1.2 Project Description: Background and Present Condition

The Anderson-Ketron dredged material disposal site is located midway between Anderson Island and Ketron Island in south Puget Sound (Figure 1). The water depth at the site ranges from 360-460 ft (110-140m); the depth at the center of the site is 428 ft (130 m). Currents at the site are oriented primarily in the along-channel (approximately north-south) directions. The site is located within the Nisqually Reach Aquatic Reserve and dredged material disposal at the site is identified as an approved use within the reserve contingent on the oversight of the DMMP agencies (WADNR, 2011). Stakeholder concerns related to the impacts of dredged material placement on aquatic resources in the vicinity of the site, including the Nisqually River delta, prompted an investigation into the fate and transport of dredged material placed at the site.

1.3 Modeling Approach

Three numerical models are combined to accurately simulate the disposal and fate of dredged material placed at the Anderson-Ketron site. The results of an existing hydrodynamic model (CMS-FLOW, Sánchez et al. 2014) are used in conjunction with the results from a dredged material placement model (MPFATE, as described in Hayter et al. 2012) to force a particle tracking model (PTM, Demirbilek 2008) to simulate fate and transport of dredged material disposed at the site. The CMS-FLOW (Coastal Modeling System Flow) model simulates the tidal currents in the vicinity of the site. The MPFATE (Multiple Placement Fate of Dredged Material) model simulates the initial release and convective descent of dredged material to the bottom. The MPFATE model provides an estimation of the volume of material which will accumulate in the placement area as well as the amount of material which remains in suspension in the water column after the initial mass of material encounters the bottom. The suspended sediment concentrations calculated by the MPFATE model are then used as the initial conditions for the PTM model which simulates the transport and fate of the suspended sediment.

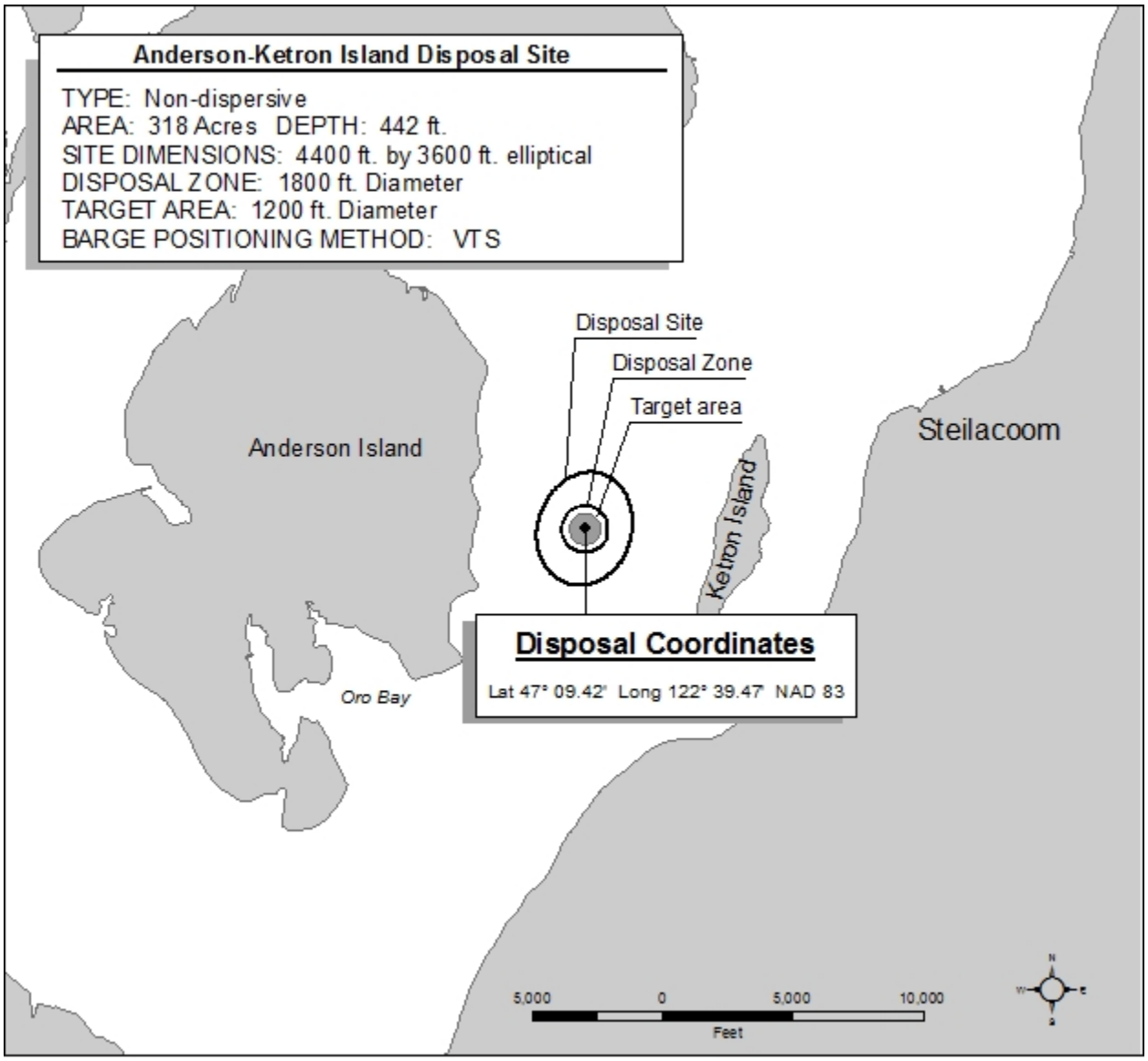

Figure 1: Anderson-Ketron Disposal Site Location and Description

2 Hydrodynamic Modeling

2.1 Model Background

CMS-FLOW solves the two-dimensional, depth-integrated continuity and momentum equations by applying a finite-volume method (Militello et al. 2004). These equations are solved numerically using an implicit finite differencing method. The model is forced with a water surface elevation at the offshore boundary generated from tidal constituents. An existing CMS-FLOW model developed for analysis of PSDDA dispersive disposal sites was utilized for this analysis. Details of the model development, calibration and validation can be found in USACE (2012)

2.2 Model Verification

2.2.1 Tides and Water Levels

In order to validate model results in the vicinity of the Anderson-Ketron site, they were compared to observed data at the nearest tide gauge location, in this case Tacoma, WA. Tides were analyzed using the T_Tide (Pawlowicz et al., 2002) harmonic analysis Matlab script. Figure 2 shows the modeled and measured water surface elevations at the tide gauge location are in good agreement, with a root mean square error (RMSE) of 0.32 m. Figures 3 and 4 plot the measured and predicted amplitude and phase for the 3 major tidal constituents at the Tacoma tide gauge. The model shows generally good agreement with maximum model errors for constituent amplitude and phase on the order of 10%.

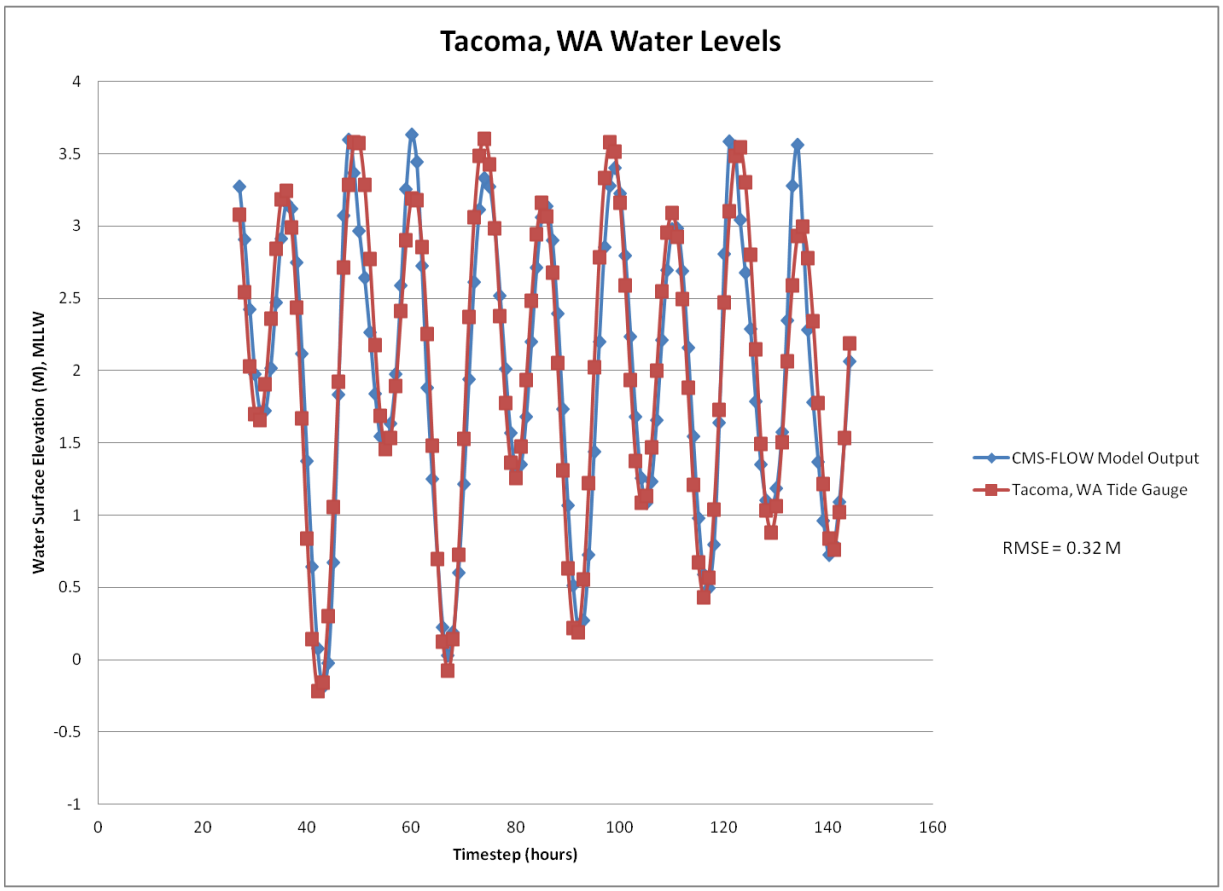

Figure 2: Measured and Modeled Water Surface Elevations at Tacoma, WA Tide Gauge

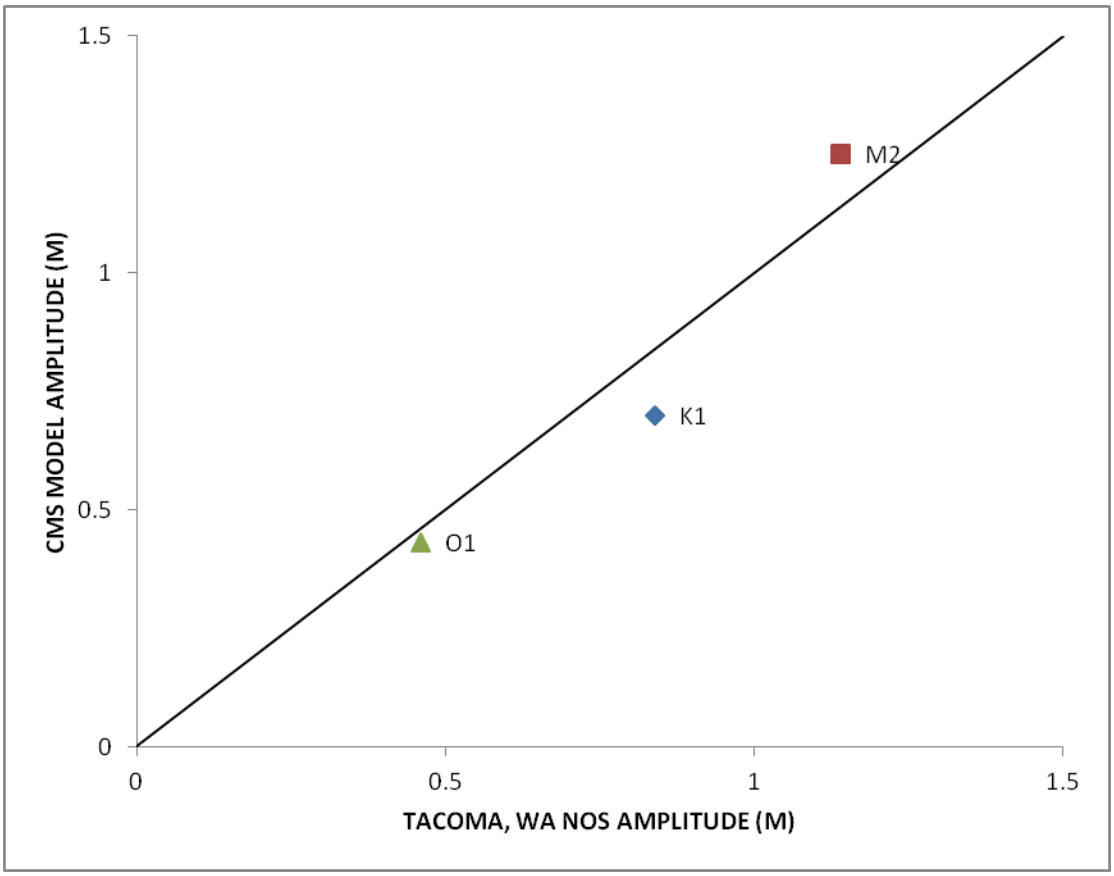

Figure 3: Tidal Constituent Comparison at Tacoma, WA Tide Station

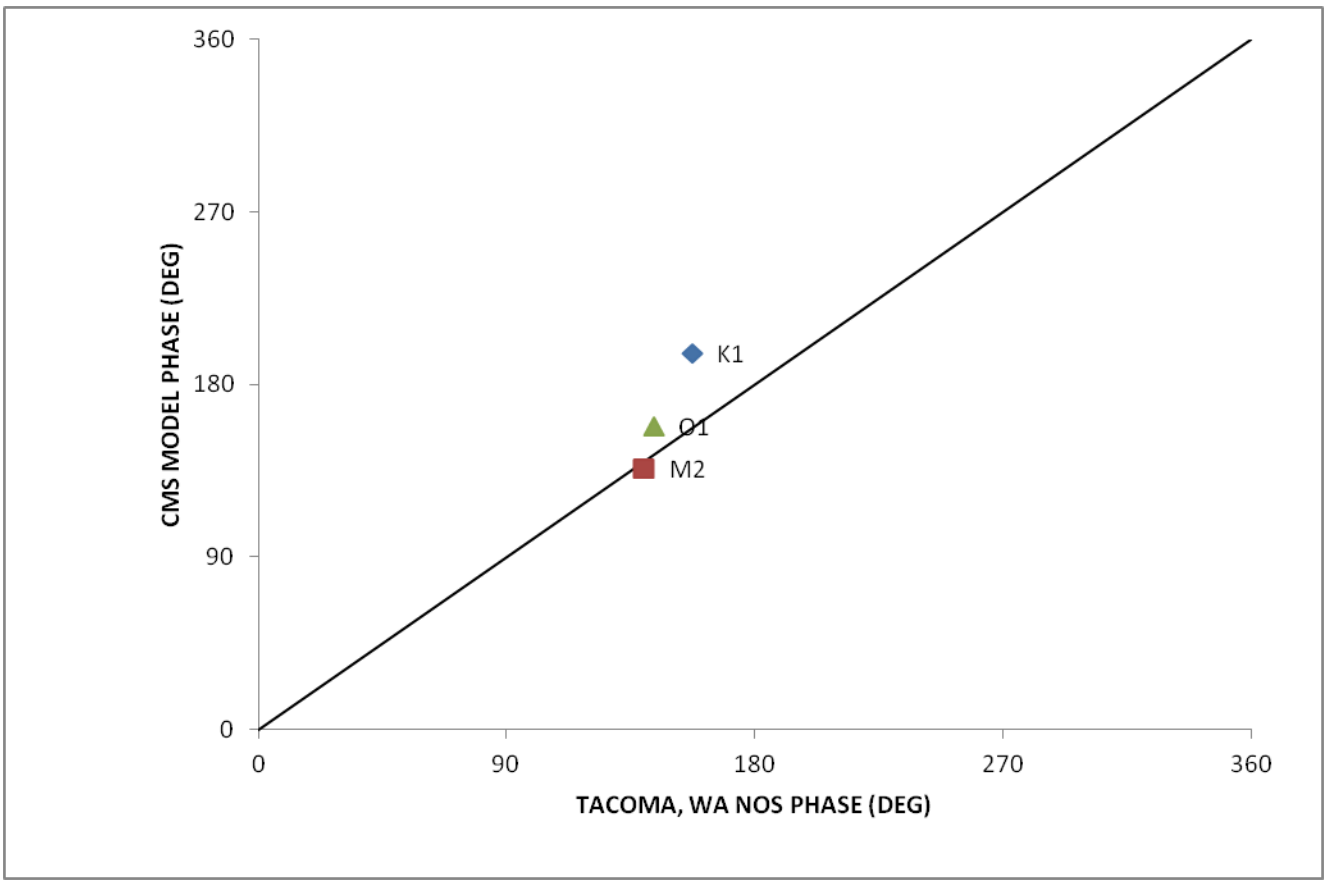

Figure 4: Water Surface Elevation at Tacoma, WA Station vs. CMS-FLOW Model

2.2.2 Currents

The current velocities at the site are also validated against measurements taken during the original siting of the disposal site. Figure 5 shows the locations (Gauges 66 and 70) of current measurements used for the original site modeling as well as the primary channel axis direction. The currents were measured at two depths at each of the measurement sites. Table 1 lists the measured and modeled velocities at the site. The average measured velocity varied between 9.4 and 17 cm/s while the maximum measured currents exceeded 30 cm/s at all of the sites. The CMS-FLOW model velocities are lower than the measured values, which can be partially attributed to the fact that the circulation model and its output are depth averaged. While the average velocities are well below the 25 cm/s threshold identified for non-dispersive sites the peak measured velocities exceed this threshold. PSDDA (1989) acknowledges that the peak current velocities measured at the site are at or above the threshold for fine particle transport, with the caveats that the measurements were taken at various depths in the water column but not at the bottom where currents are expected to be lower and that the depositional analysis conducted at the time indicates that the site has a nondispersive character.

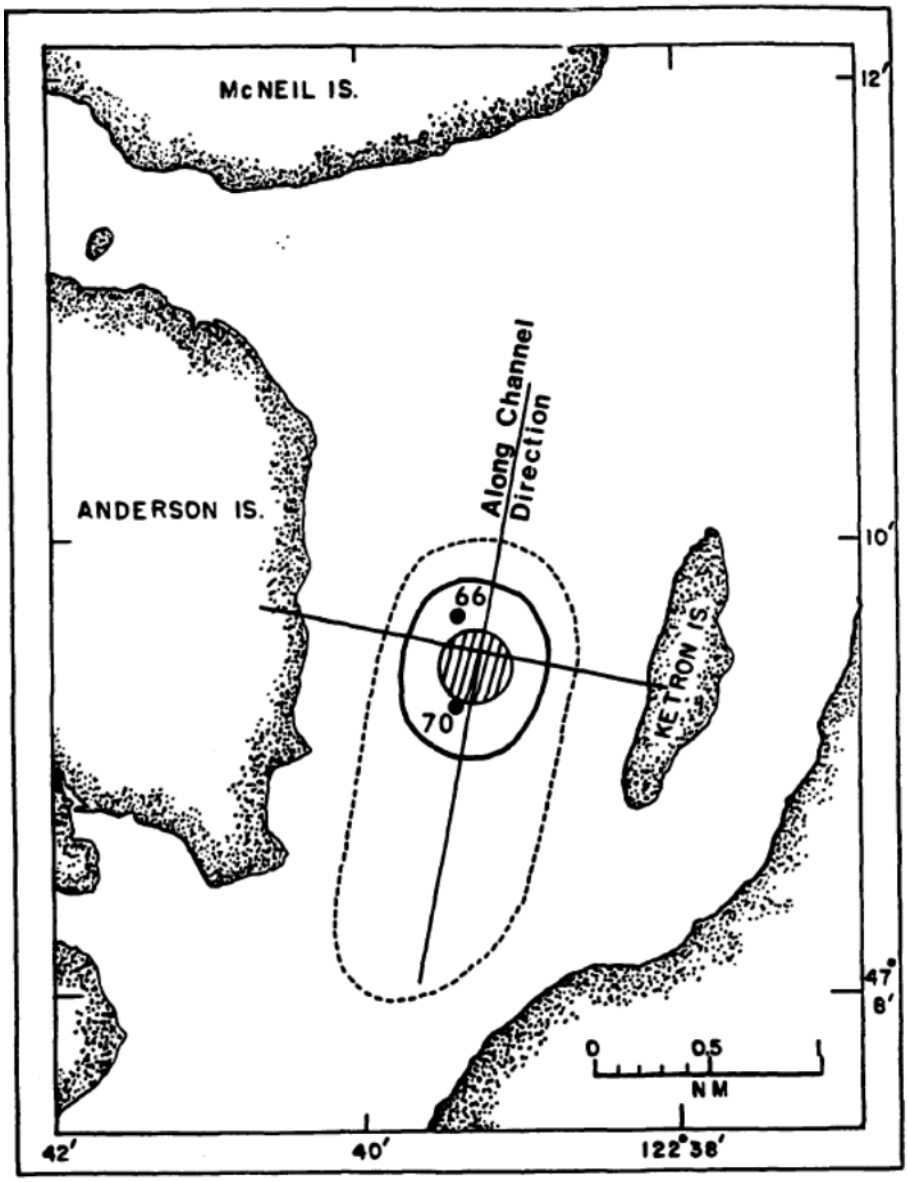

Figure 5: Primary Current Direction and Current Measurement Locations

Table 1: Measured and Modeled Current Velocities

Source	Approximate Bottom Depth (m)	Depth of Current Meter (m)	Current Velocity (cm/s)	
			Maximum	Average
CMS-FLOW	Varies	Depth-Averaged	22.1	9.2
Gauge 66	134	22	33.0	11.2
Gauge 66	134	119	35.4	15.7
Gauge 70	129	6	38.4	17.0
Gauge70	129	34	31.8	9.4

3 Fate and Transport Modeling

3.1 Model Background

3.1.1 MPFATE

MPFATE is an updated version of MDFATE (Moritz 1995) which simulates multiple dredged-material placements to estimate the resulting bathymetry change within and around the placement site. This is accomplished by organizing and executing multiple simulations of the STFATE (Johnson et al. 1994) model. STFATE simulates short-term processes such as convective descent, dynamic collapse, and transport-diffusion during the disposal process. The MPFATE model improves on STFATE by including greater flexibility in specifying vertical velocity structure, provisions for time variant currents and the ability to run on larger grids.

3.1.2 PTM

The Particle Tracking Model (PTM) computes the fate and transport of sediments and other waterborne particulates in coastal engineering and dredging applications in a Lagrangian modeling framework (Demirbilek et al. 2008). The PTM uses the hydrodynamic results of the CMS-FLOW simulation to simulate sediment movement with the flow field, including erosion, transport, settling, and deposition.

3.2 MPFATE Model Inputs

The material typically placed at the Anderson-Ketron site is composed of medium to fine silty sands. Review of the sediment characterization and grain size distributions from dredging projects that have used the site in the past shows that sediment is approximately 60% sands, 25% silts and 15% clays. For modeling purposes it was assumed that approximately 10% of the silt and clay material form clumps which have a significantly greater fall velocity than individual particles. The percentage of clumps is based on the assumption that the material is low overburden material which has not significantly compacted as discussed in Hayter (2012). The volume of each placement was 1,000 cubic yards (CY) with 35% solids by volume, representing a typical barge placement in Puget Sound. The placement locations were varied randomly within the target area of the site. The barge direction was varied randomly and the barge velocity was varied randomly between 0 and 2 knots. The tidal currents were extracted from the CMS-FLOW model and vary in both velocity and direction. The MPFATE model sediment inputs are listed in Table 2.

Table 2: Material Characteristics for MPFATE Modeling

Material	Density (g/cc)	Concentration By Volume	Settling Velocity (ft/s)	Cohesive
Sand	2.65	0.20	0.020	N
Clay	2.60	0.05	0.001	Y
Silt	2.60	0.08	0.001	Y
Clumps	2.60	0.02	0.250	Y

3.3 MPFATE Model Calibration

Approximately 33,000 CY of material was placed at the Anderson-Ketron site between the baseline survey in 1989 and the first monitoring effort in 2005. That 2005 monitoring found dredged material at two stations located at the center of the disposal area with an average thickness of approximately 12 cm as shown in Figure 6. Figure 7 shows the MPFATE model results after simulating placement of 33,000 CY of material. The model results show both coverage and dredged material thickness in good agreement with the monitoring results, indicating that the model is accurately simulating the placement process.

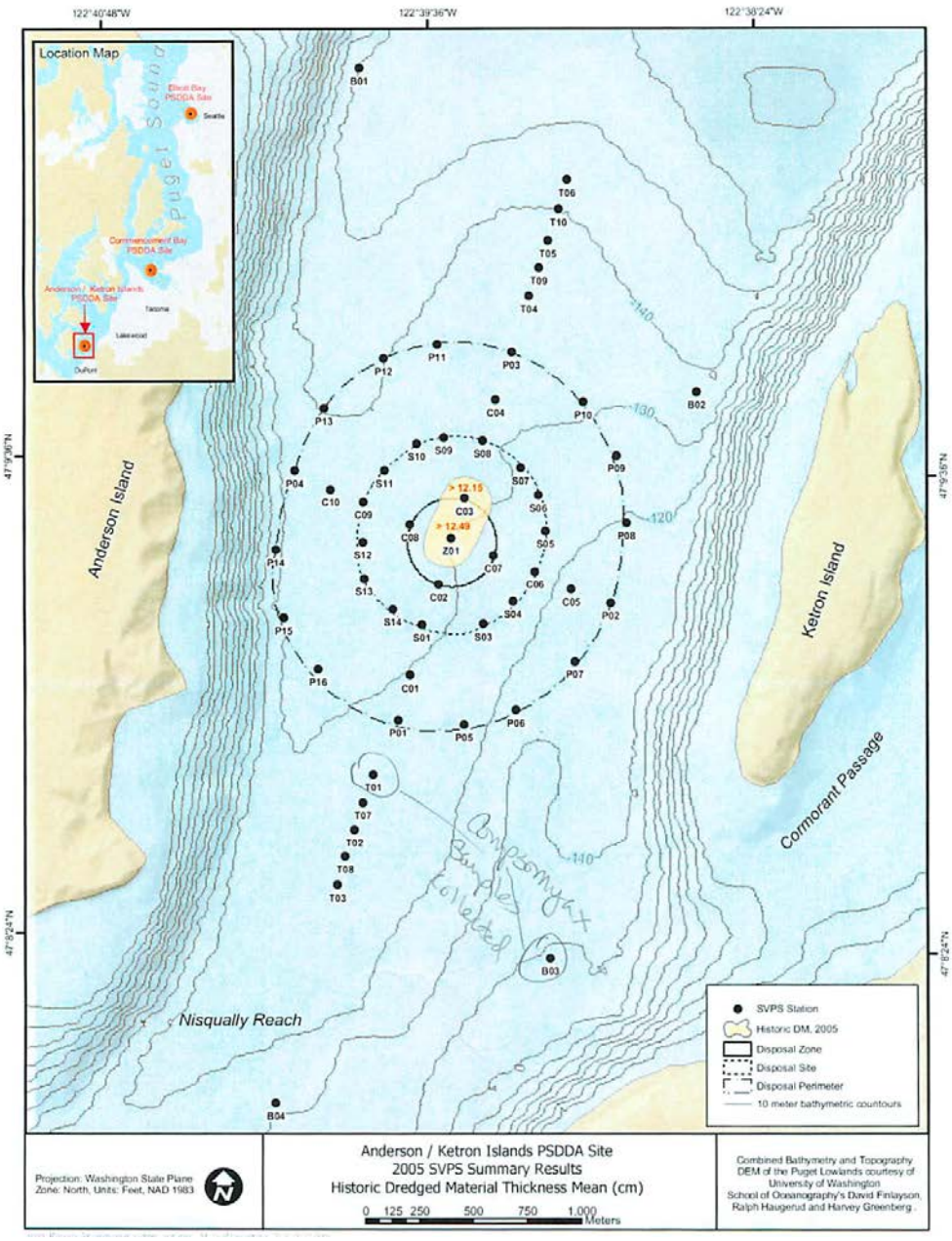

Figure 6: 2005 dredged material thickness monitoring results after placement of approximately 33,000 CY of material

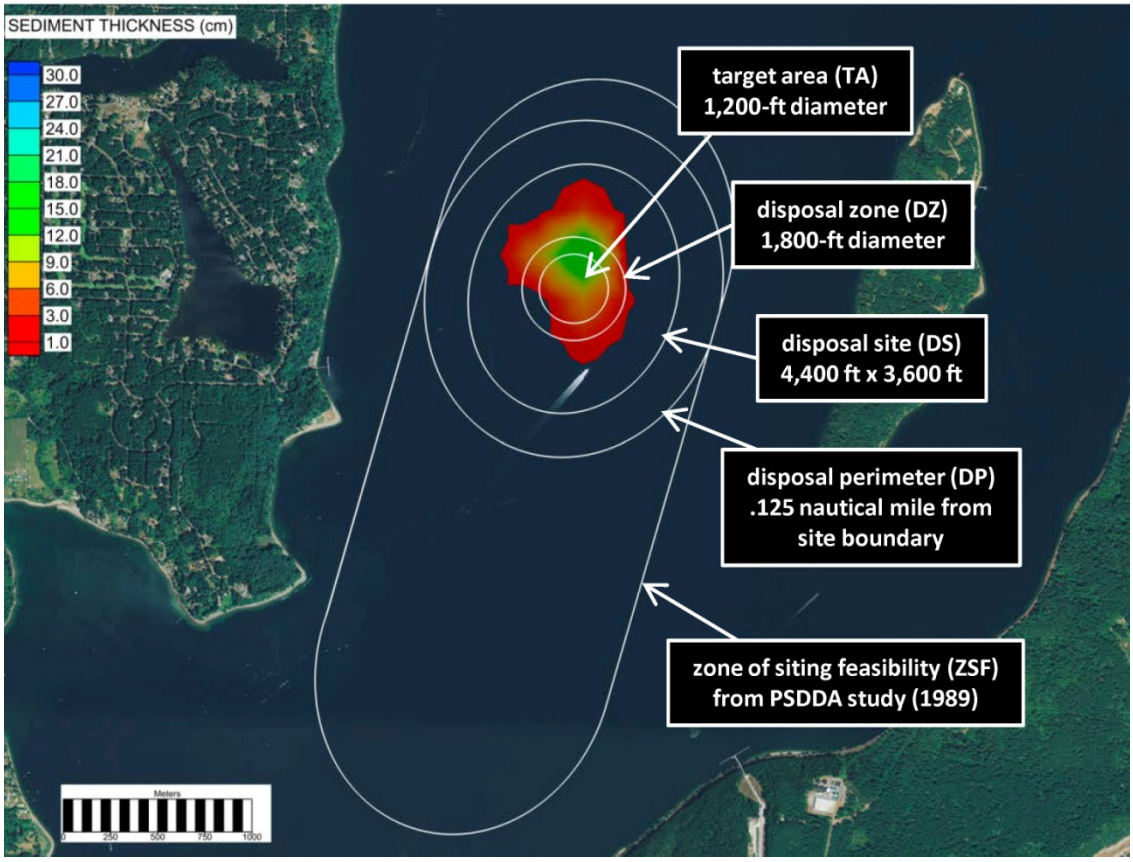

Figure 7: Sediment thickness output from MPFATE model after placement of 33,000 CY of material

3.4 MPFATE Model Results

Since 2005 an additional 127,000 CY of material has been placed at the site for a total of 160,000 CY. Figure 8 shows the dredged material footprint and thickness predicted by the MPFATE model after placement of 160,000 CY. The results show a maximum thickness of around 30 cm and that all of the material which settles to the bottom is deposited within the disposal site boundary. The MPFATE results indicate that approximately 95% of the material placed settles to the bottom within two hours of placement and is deposited within the disposal site boundary. This leaves approximately 5% of placed material which remains in suspension after the initial mass of dredged material encounters the bottom and settles out. The remaining suspended portion of material was used as the initial condition for the particle tracking model.

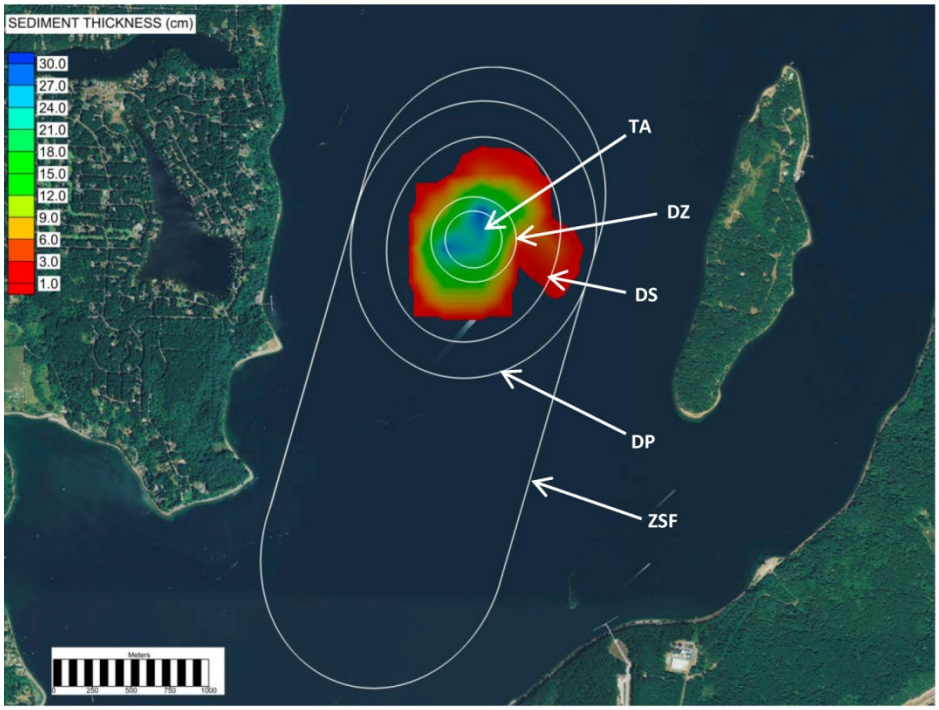

Figure 8: Sediment thickness output from MPFATE model after placement of 160,000 CY of material

3.5 Particle Tracking Model (PTM)

The particle tracking model was used to estimate the fate and transport of the fraction of dredged material which remains in suspension after the initial mass reaches the bottom. This fraction represents approximately 5% of the total volume of material placed at the site and is a result of finer sediments being stripped from the mass of dredged material during descent through the water column. In order to simulate the release of sediment throughout the water column particles are released at a depth of 50 m from the water surface and 1 m from the bottom. Table 3 lists the sediment properties used for the particle tracking model which were determined from the suspended sediment plume output in the MPFATE model.

Table 3: Sediment Grain Size for PTM Model

Sediment Type	D_{min} (mm)	D_{50} (mm)	D_{max} (mm)
Silts and Clays	0.002	0.015625	0.0625

3.6 Suspended Sediment Particle Pathways

Figure 9 shows the total excursion of the particles during the simulation. Approximately 50% of the suspended particles end up settling within the disposal site after 48 hours. The remaining material, representing approximately 2-3% of material placed, remains in suspension and is transported along with the tides in a cyclical manner. Some of this material is moved outside the disposal site boundary during this reciprocating transport; however all of the material remains

confined by bathymetric features into water great than 100 meters in depth where impacts to resources are expected to be minimal.

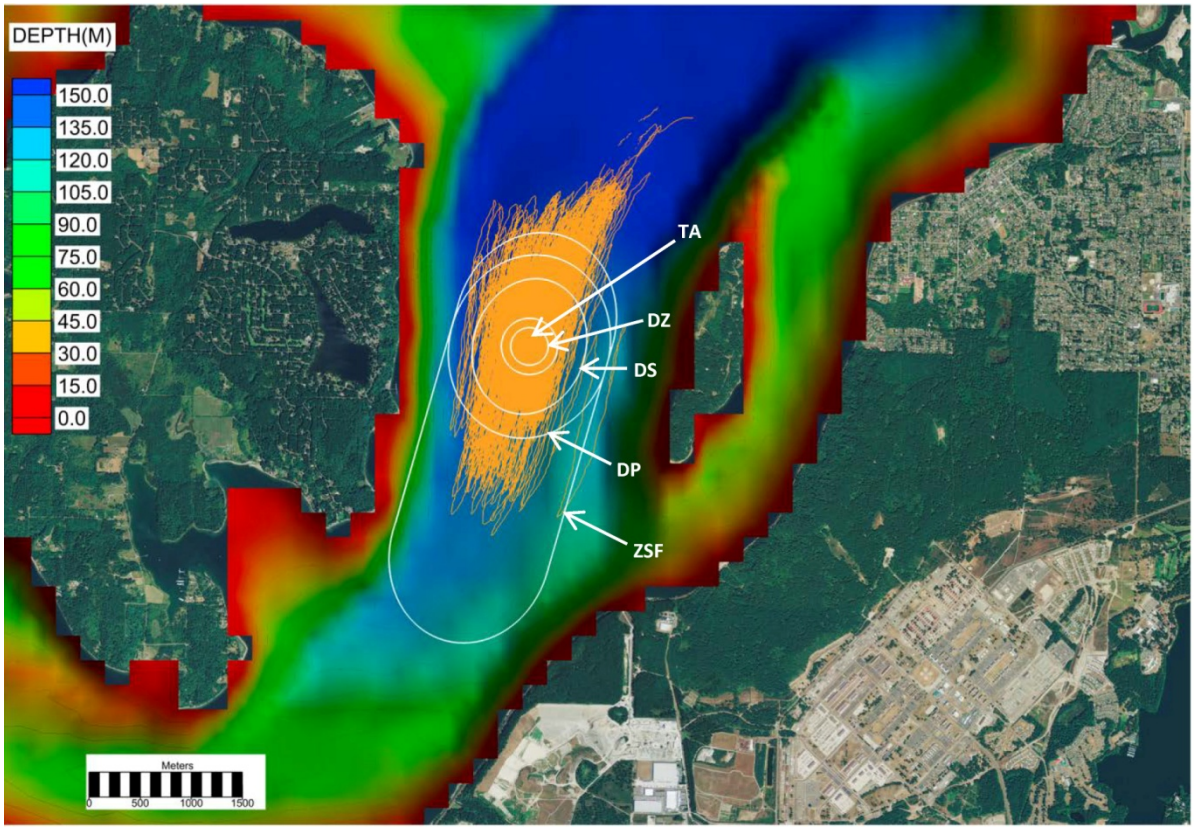

Figure 9: Sediment Particle Pathways (orange) showing limit of material movement

4 Modeling Conclusions and Recommendations

Based on the model results up to 5% of material placed at the Anderson-Ketron disposal site remains in suspension in the water column after the initial mass of sediment encounters the bottom. There is the potential for a fraction of this material to be transported outside of the disposal site boundary. The PTM results indicate that approximately one-half of the material in suspension eventually settles out within the disposal area boundary, leaving 2-3% of material placed in suspension with the potential to be transported outside of the site boundary. Although this fraction of material has the potential to move beyond the site boundaries the site is situated such that the material remains confined by the bathymetric features into water depths greater than 100 meters where impacts to resources are expected to be minimal. These model results confirm that the assumptions used during the original siting of the disposal site were accurate and that the site is acting as described in PSDDA (1989).

These conclusions come with the caveat that the CMS-FLOW tidal circulation model is limited to 2-D depth averaged currents. As a result the model peak velocities are lower than the measured peak velocities and the model is not capable of representing the variation of velocities with depth or the effects of vertical mixing due to freshwater input. Representing these processes would require a three-dimensional circulation model. Both of these processes could result in material transported further from the site than indicated in the model results.

5 Relationship with Nisqually Delta

The Nisqually River watershed includes drainage from Mount Rainer. The morphology of the Nisqually River delta has a strong correlation to debris flows (lahars triggered by volcanic activity) and co-seismic subsidence which adjusted the relative sea level at the delta and triggered erosion (Barnhardt and Sherrod 2006; Takesue and Swarzensk 2011. Recent investigations using high resolution multibeam hydrographic surveys of the Nisqually delta show two large sandy shoals on either side of the river mouth, a smaller ebb shoal to the east of the river and a larger flood shoal to the west. The flood tidal shoal to the west of the mouth is much larger in volume indicating a net sediment transport pathway in the flood tide direction. Over time strong tidal currents have developed sand wave bedforms east of the river mouth that dissipate at the 60 m depth contour. The Anderson-Ketron site is located in a deep basin with depths exceeding 100 m, suggesting no active conduit for bedload sediment transport between the two areas.

6 References

Barnhardt, W.A. and Sherrod, B.L., 2006. *Evolution of a Holocene Delta Driven by Episodic Sediment Delivery and Coseismic Deformation*, Puget Sound, Washington, USA. Sedimentology, 53: 1211–1228. doi: 10.1111/j.1365-3091.2006.00809.x

Demirbilek, Z., Connell, K.J., MacDonald, N.J. and Zundel, A.K., 2008. Particle *Tracking Model in the SMS 10: IV. Link to Coastal Modeling System, Coastal and Hydraulics Engineering Technical Note ERDC/CHL CHETN-IV-71*. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

Hayter, E., Smith, J., Michalsen, D., Demirbilek, Z and Lin, L., 2012 *Dredged Material Placement Site Capacity Analysis for Navigation Improvement Projects at Grays Harbor, WA*. Technical Report ERDC/CHL TR-12-18. U.S. Army Engineer Research and Development Center, Coastal and Hydraulic Laboratory, Vicksburg, MS.

Johnson, B.H., McComas, D.N., McVan, D.C. and Trawle, M.J., 1994. *Development and Verification of Numerical Models for Predicting the Initial Fate of Dredged Material Disposed in Open Water; Report 1, Physical Model Tests of Dredged Material Disposal from a Split-hull Barge and a Multiple Bin Vessel*. Draft Technical Report, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Militello, A., Reed, C.W., Zundel, A.K. and Kraus, N.C., 2004. *Two Dimensional Depth-averaged Circulation Model M2D: Version 2.0, Report 1: Technical Documentation and User's Guide*, Coastal and Hydraulics Laboratory Technical Report ERDC/CHL TR-04-2. U.S. Army Engineer Research and Development Center, Vicksburg, MS.

Moritz, H.R. and Randall, R.E. 1995. Simulating dredged material placement at open water disposal sites, *J. Waterway, Port, Coastal, and Ocean Engineering*, ASCE (121) 1.

Pawlowicz, R., Beardsley, B. and Lentz, S., 2002. *Classical Tidal Harmonic Analysis Including Error Estimates in MATLAB using T_TIDE*. Computers and Geosciences, 28, 929-937.

PSDDA, 1989. *Disposal Site Selection Technical Appendix – Phase II (North and South Puget Sound)*. Prepared by the Puget Sound Dredged Disposal Analysis Agencies.

Sánchez, A., Wu, W., Li, H., Brown, M., Reed, C., Rosati, J., and Demirbilek, Z. (2014). *Coastal Modeling System: Mathematical Formulations and Numerical Methods* ERDC/CHL TR-14-2, U.S. Army Engineer Research and Development Center, Coastal and Hydraulics Laboratory, Vicksburg, MS.

Takesue, R.K., and Swarzenski, P.W., 2011 *More than 100 Years of Background-Level Sedimentary Metals, Nisqually River Delta, South Puget Sound, Washington.* USGS Open-File Report 2010-1329, Reston, VA

USACE, 2012. *Dredged Material Management Program Dispersive Disposal Site Fate and Transport Analysis for Puget Sound, Washington*, U.S. Army Corps of Engineers – Seattle District.

WADNR, 2011. *Nisqually Reach Environmental, Scientific & Educational Aquatic Reserve Management Plan*, Washington State Department of Natural Resources.