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New England District

Contract No. DACW33-01-D-0004
Delivery Order No. 01
June 15, 2004

Final Work Plan

Centredale Manor Sediment Stability Study

Centredale Manor Restoration Project Superfund Site North Providence, Rhode Island

SDMS DocID 206726

FINAL WORK PLAN

Centredale Manor Sediment Stability Study
Centredale Manor Restoration Project Superfund Site
North Providence, Rhode Island

Submitted to

Department of the Army
U.S. Army Corps of Engineers
North Atlantic Division
New England District

CONTRACT NUMBER: DACW33-01-D-0004
DELIVERY ORDER NO. 01

June 15, 2004

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ABBREVIATIONS AND ACRONYMS

Acoustic Doppler Current Profiler	ADCP
cfs	cubic feet per second
COC	Chemical-of-concern
CSM	Conceptual site model
EFDC	Environmental Fluid Dynamics Code
FEMA	Federal Emergency Management Agency
FIS	Flood Insurance Study
FS	Feasibility Study
QEA	Quantitative Environmental Analysis, LLC
RI	Remedial Investigation
TEQ	Toxic Equivalency Quotient
USACE	United States Army Corps of Engineers
USEPA	United States Environmental Protection Agency

1.0 INTRODUCTION

The U.S. Environmental Protection Agency (USEPA) Region I and U.S. Army Corps of Engineers (USACE) New England District are conducting a Remedial Investigation and Feasibility Study (RI/FS) for the Centredale Manor Restoration Project Site (i.e., the site), located in North Providence, Rhode Island. As part of the RI/FS, a sediment stability study will be conducted at the site. This work plan describes an approach for conducting the sediment stability study.

A sediment stability evaluation is used to assess the impacts of sediment erosion, transport, and deposition processes on surficial sediment bed and water column concentrations of a chemical-of-concern (COC) within a river channel. Thus, a general understanding of sediment transport processes is important when conducting a sediment stability study. Stability evaluations consider both the hydrodynamic forces that induce sediment resuspension and properties of the sediment bed that influence erosion rates. Erosion from a sediment bed occurs through two modes of transport: 1) bed load transport, which is the near-bed transport of sand and gravel; and 2) suspended load transport, which is resuspension of clay, silt and fine sand into the water column. The eroded sediment particles eventually deposit, or return to the sediment bed, at a different location.

The assessment of the efficacy of remedial alternatives for contaminated sediment deposits generally includes a sediment stability analysis. Determining whether a sediment deposit is stable or unstable typically involves evaluating the impact of sediment transport processes on COC concentrations in the bioavailable layer and the associated effects of remedial alternatives on mitigating those impacts. Erosion potential of the overlying portion of the sediment bed will determine whether or not the elevated COC concentrations become bioavailable at some point in the future. Re-exposure of the elevated concentrations to the bioavailable layer may occur due to bed elevation changes occurring over two time scales: 1) net erosion during a high-energy event, e.g., flood in a river; and 2) long-term bed degradation, e.g., changes on decadal time scales. Another process that must be considered is natural recovery, which is the burial of high-concentration COC deposits by subsequent deposition of low-concentration COC (i.e., cleaner) sediment. Erosion, transport, and deposition, and therefore natural recovery, are generally both temporally and spatially variable within a contaminated sediment site.

Erosion is caused by physical forces on the sediment bed. These forces are typically generated by two hydrodynamic processes: current velocity and surface waves. These processes induce erosion by applying a shear stress (i.e., force per unit area) on the sediment bed that exceeds the critical value for the bed to remain in place (i.e., critical shear stress). The sediment bed resists erosion through a combination of gravitational force on particles, physical structure of the bed, and cohesive forces holding the bed together. These cohesive forces depend on various sediment physical properties, including: bulk density, mineralogy, grain size distribution, gas content, and organic content.

1.1 Objective and Scope

Sediment stability is an important issue when considering the efficacy of various remedial alternatives at the site. While this study will consider site-specific issues or questions, the primary issues that this study focuses on, with respect to remedial alternative evaluation, are:

- Potential of short- and long-term erosive processes to re-expose relatively high bed concentrations currently buried below the surface layer.

- Potential for short- and long-term sediment transport processes to re-distribute bed contaminants within Allendale and Lyman Mill Ponds and downstream of Lyman Mill Dam (the amount of

sediment transported over Lyman Mill Dam may be estimated if existing data are sufficient to support the analysis).

- The impact of sediment transport processes on the natural recovery rate of bed concentrations in the surface layer.

1.2 Work Plan Organization

This work plan consists of four sections, as follows:

Section 1: Introduction
Section 2: Description of Work Plan Tasks
Section 3: Project Schedule and Deliverables
Section 4: References

2.0 DESCRIPTION OF WORK PLAN TASKS

2.1 Description of Study Area

The sediment stability study area consists of that portion of the Woonasquatucket River extending from Centredale Manor (upstream extent) to Lyman Mill Dam (downstream extent). The primary focus of the study will be the fine-grained sediment deposits located in Allendale and Lyman Mill Ponds. The free-flowing portions of the river channel that are located upstream of the dam backwaters (i.e., ponds) have sediment beds that are primarily composed of coarse sand, gravel and cobbles. These coarse sediment deposits have relatively low contaminant concentrations. Thus, the coarse channel deposits are a minor concern when evaluating sediment stability at the site.

Allendale and Lyman Mill Dams have an impact on the stability of sediment deposits within the ponds behind the dams. Removal of a dam, or lowering of the water level behind the dam, could have significant impacts on sediment stability in the area upstream of the dam. For this study, it is assumed that the two dams will not be removed in the foreseeable future.

2.2 Phase 1 Tasks

The first task of the study will be to determine the objectives of the sediment stability analysis. Typically, a list of site-specific questions concerning sediment stability is developed and the study focuses on using a weight-of-evidence approach to develop answers to these questions. Based on the outcome of a Work Plan review meeting held on June 3, 2004, the questions to be addressed in the sediment stability evaluation are as follows:

- What is the impact of floods of various magnitudes on surficial dioxin TEQ concentrations in Allendale and Lyman Mill Ponds?
    - What scour depth will be caused by floods of various magnitudes?
    - Where is scour likely to occur within the ponds?
- What effect will different remedial alternatives have on mitigating the impacts of a rare (i.e., 100-year) flood?

The study objectives were developed as a collaborative effort between USEPA, USACE, Battelle and Quantitative Environmental Analysis, LLC (QEA) personnel.

A number of studies have already been conducted to obtain and analyze site data. These past studies and data collection efforts include: 1) geomorphology and stratigraphy (USACE); 2) geophysics (Lockheed Martin); 3) geochronology (USACE); and 4) bed concentration data (various sources). Information and data from these studies, and other relevant studies, will be compiled, analyzed and synthesized. The objective of the data-synthesis task is to use the existing data- and knowledge-bases for the site to develop a coherent understanding of sediment transport in the study area.

In addition to gaining insights about sediment transport processes in the two ponds, which will be used to develop a better understanding of sediment stability, the results of the data- synthesis task will be used to develop a Conceptual Site Model (CSM) for sediment transport. A CSM is an important component of a sediment stability analysis because consistency must be maintained between the CSM and the results of quantitative and qualitative sediment stability analyses. A sediment transport CSM is different from a CSM that is typically developed for risk assessment at a contaminated sediment site. The type of CSM that is developed for sediment transport is a qualitative description of the processes (e.g., deposition and erosion) and system characteristics (e.g., upstream and tributary sediment loads, spatial distribution of bed properties) that control sediment dynamics within the study area.

2.3 Phase 2 Tasks

The sediment beds in Allendale and Lyman Mill Ponds are primarily composed of fine-grained, cohesive sediments, which contain varying mixtures of clay, silt, sand and organic matter. Two primary factors affect erosion of a cohesive sediment bed in a river: 1) bottom shear stress due to currents and 2) erosion properties of the bed. At the present time, data on the erosion properties of cohesive sediment in the study area have not been collected. However, information on bottom shear stresses in the two ponds for varying flow conditions can be obtained from the development and application of a hydrodynamic model. This type of model is used to predict water depth (or stage height) and current velocity at different locations in a river system. Predicted current velocity is used to calculate bottom shear stress. By comparing estimated bottom shear stress during a particular flood flow (e.g., 100-year flood) to critical shear stress for erosion, the potential impacts of a rare flood on bed stability in the two ponds can be estimated.

The hydrodynamic model that will be used in this study is an enhanced version of the Environmental Fluid Dynamics Code (EFDC). This model (EFDC) is an EPA-approved model which QEA has modified so as to make the model easier to use; the QEA version of EFDC is non-proprietary. EFDC is a sophisticated three-dimensional, time-dependent, boundary-fitted hydrodynamic model capable of simulating density-driven circulation in rivers, reservoirs, lakes, estuaries and coastal waters. The model has been extensively tested and applied to a wide range of aquatic systems. For this study, the model will be used in two-dimensional, vertically-averaged mode, which is a valid approximation for the shallow, unstratified flow conditions that exist in the two ponds during flood conditions; a two-dimensional model will yield results that are sufficiently accurate for this study.

The first step in developing a hydrodynamic model is to create a numerical grid that discretizes the geometry and bathymetry (water depth) of the study area. For this project, the area to be modeled will extend from Centredale Manor (upstream boundary) to Lyman Mill Dam (downstream boundary). Only the river channel and backwater areas of the two ponds will be included in the model; floodplain areas and tributaries will not be incorporated into the model. It is envisioned that square grid cells, with a size of approximately 10 meters, will be used for the numerical grid. This level of grid resolution should be adequate for resolving spatial gradients in water depth and current velocity. The practicality of using a finer grid resolution, e.g., 5-meter grid cell, will be investigated during the initial development of the numerical grid. Bathymetry data collected during the geophysics study will be used to specify model inputs for water depth.

Boundary conditions for the model are: 1) dam stage height at the downstream boundary and 2) inflow rate at the upstream boundary. Stage height, as a function of flow rate, at each dam will be estimated using a standard broad-crested weir formula. Historical flow rate data for the Woonasquatucket River are available for the USGS gaging station at Centredale (drainage area of 38.3 mi^2). Based on a Flood Insurance Study (FIS) conducted by FEMA, the 100-year flood ranges between 2,170 and 2,600 cfs in the vicinity of the two ponds. A flood frequency analysis was conducted by USACE during a previous study (M. Corcoran, personal communication, June 3, 2004). Results of the USACE analysis will be used to specify flood flow rates over a range of recurrence frequencies.

Site-specific hydrodynamic data, e.g., current velocity and stage height data, are not presently available for the two ponds. USEPA is considering the installation of one or more acoustic Doppler current profilers (ADCPs) in Allendale and Lyman Mill Ponds during the early stages of this project. The ADCPs will measure current velocity and stage height over a range of flow rates. The locations of the ADCPs in the ponds will be determined during discussions between USEPA, USACE, Battelle and QEA personnel. It is anticipated that the ADCP locations will be guided by preliminary model results. If

collected, the stage height and velocity data obtained from these devices will be used to calibrate the hydrodynamic model. Otherwise, model calibration will be accomplished by adjusting the effective bottom roughness (a model input parameter denoted as Z_o) such that agreement between observed and predicted current velocity and stage height is optimized.

Model accuracy is primarily determined by: 1) bathymetry and geometry data used for model input; 2) flow rates specified for river inflows (i.e., upstream boundary condition); 3) stage height as a function of flow rate at the dams (i.e., downstream boundary condition); and 4) effective bottom roughness that represents the hydrodynamic drag generated by the sediment bed. Information and data exist for sufficiently accurate specification of bathymetry/geometry, river inflow, and stage height at the dams. The effective bottom roughness is a calibration parameter that cannot be specified *a priori* using site-specific data. Thus, the accuracy of the model is primarily dependent on the reliability of data used to calibrate the model (i.e., adjustment of effective bottom roughness to achieve optimum agreement between observed and predicted stage height and current velocity).

The hydrodynamic model will be used to evaluate the potential impacts of a range of floods on bed stability. Impacts of floods with 5-, 10-, 25-, 50- and 100-year return periods will be investigated. For each flood simulation, two methods will be used to analyze the potential impacts on bed stability: 1) comparison of bottom shear stress and current velocity to critical values of those parameters and 2) estimation of scour depth.

First, the predicted current velocities will be used to calculate bottom shear stresses (τ), which will be compared to a critical shear stress for erosion (τ_{cr}). Areas where the bottom shear stress is greater than the critical value (i.e., $\tau > \tau_{cr}$) correspond to areas that are subject to scour during a flood. Critical shear stress for cohesive sediment is variable and depends on the site-specific erosion properties of surficial sediments; τ_{cr} typically ranges from about 0.1 to 0.5 Pa. Because uncertainty exists in the value of τ_{cr}, bounding estimates of critical shear stress will be determined from a literature search. Areas of potential bed scour will be determined using upper ($\tau_{cr,up}$) and lower ($\tau_{cr,low}$) bounds of critical shear stress. In addition, areas where the bottom shear stress is less than the critical shear stress for erosion are conducive to deposition. The potential amount of deposition cannot be determined without application of a sediment transport model, but a qualitative assessment of potential depositional areas during this rare flood can be accomplished. For each flood simulation, maps will be developed to indicate the locations of potential scour and deposition areas for $\tau_{cr,up}$ and $\tau_{cr,low}$. In addition to the graphical presentations, the surficial areas of potential scour in each pond will be quantified and tabulated.

While the critical shear stress analysis provides information on areas of potential scour, comparing current velocity to a critical velocity may be used to identify areas of potentially significant scour (i.e., scour depth greater than ~1-2 cm). Sediment stability work on the Grasse River suggested that significant scour of a cohesive bed may occur in locations where the current velocity exceeds 2 ft/s (Alcoa 2002). This criterion will be used to delineate areas where predicted current velocities are greater than 2 ft/s for each flood simulation. Maps will be prepared showing areas of potentially significant scour in each pond for a particular flood. Surficial areas of significant scour in each pond will be quantified and tabulated.

The second method will use the predicted bottom shear stresses to estimate scour depths in the two ponds. This approach will apply the Lick equation (Ziegler 2002), which is given by

$$\varepsilon = A\,(\tau/\tau_{cr} - 1)^n, \qquad \tau > \tau_{cr} \qquad (1)$$

where ε = resuspension potential (i.e., mass eroded per unit area); τ = bottom shear stress; τ_{cr} = critical bottom shear stress, assumed to be 0.1 Pa for this analysis (Ziegler 2002); A = site-specific constant; and

n = site-specific exponent. A field study would need to be conducted to determine site-specific values of A and n for the study area, but this work is beyond the scope of the current study. Results from studies carried out in other river systems provide sufficient data to make reasonable estimates of A and n for the Woonasquatucket River (Ziegler 2002). These approximate values (i.e., average values of A and n of 0.21 mg/cm^2 and 2.6, respectively) will produce order-of-magnitude estimates of scour depths during a flood. Uncertainty in the values of A and n exists, but 95 percent confidence intervals for these two parameters have been determined (Ziegler 2002). To account for this uncertainty, the 95 percent confidence interval information for A and n will be used to determine upper and lower bound of estimates of resuspension potential (i.e., ε_{up} and ε_{low}) for each flood simulation.

Scour depths are calculated using

$$T = \varepsilon / \rho \qquad (2)$$

where T = scour depth and ρ = dry density of sediment. The results of this analysis will be presented in the form of maps showing the spatial distribution of estimated scour depth in each pond. Due to uncertainty in ε, two scour depth plots will be produced for each flood: an upper-bound estimate (T_{up} corresponding to ε_{up}) and a lower-bound estimate (T_{low} corresponding to ε_{low}).

While the model will be calibrated using current velocity and stage height data, there will probably be uncertainty in the calibration parameter ($Z_{o.cal}$ or effective bottom roughness). To investigate the sensitivity of model results to Z_o, the 100-year flood simulation will be repeated using upper and lower bound estimates of Z_o, with $Z_{o.up} = 2\ Z_{o.cal}$ and $Z_{o.low} = 0.5\ Z_{o.cal}$. Model results for the sensitivity simulations will be evaluated similar to the other simulations (e.g., critical shear/velocity and scour depth maps).

The primary modeling assumptions for the study are:

- Allendale and Lyman Mill Dams are not removed in the foreseeable future.
- The Lick equation predicts the resuspension potential of a cohesive sediment bed with reasonable accuracy. Without making this assumption, scour depths in the pond could not be estimated during this study.
- Tributary inflow and direct runoff between the USGS gage at Centredale Manor and Lyman Mill Dam are negligible. This assumption is valid because uncertainty in river discharge is typically about 10 percent, which is greater than the potential increase in river flow due to tributaries and direct runoff.
- Stage height at the dams can be estimated using a weir equation. Due to a lack of site-specific data, this assumption is necessary for realistic hydrodynamic simulations.

2.4 Reporting

Weekly conference calls will be conducted to review project status and discuss technical progress throughout the duration of the sediment stability evaluation. Participants in the weekly calls will include personnel from USEPA, USACE, Battelle, and QEA. A Sediment Stability Technical Memorandum will be prepared that provides details about the technical analyses and model development, as well as results and conclusions about sediment stability in the study area. The primary focus of the memorandum will be to answer the site-specific questions posed at the beginning of the study and develop conclusions about sediment stability in Allendale and Lyman Mill Ponds. This objective will be accomplished by integrating the Phase 1 and 2 results and by using a weight-of-evidence approach to address the sediment stability questions.

3.0 PROJECT SCHEDULE AND DELIVERABLES

After the final version of this work plan is submitted to USEPA and USACE, the tasks described in Section 2 will be initiated. The project will be completed within 50 working days of submission of the final work plan, with QEA submitting a draft technical memorandum to Battelle. Battelle will distribute the draft memorandum to USEPA and USACE personnel for review and comment. The Final Sediment Stability Technical Memorandum will be submitted by QEA to Battelle within seven days of QEA receiving USACE and USEPA comments on the draft document.

4.0 REFERENCES

Alcoa, 2002. *Analysis of Alternatives Report. Grasse River Study Area. Massena, New York.* Alcoa report. June 12, 2002.

Ziegler, C.K., 2002. Evaluating sediment stability at sites with historic contamination. *Environmental Management*, 29(3):409-427.