WORK PLAN FOR GROUNDWATER MODEL DEVELOPMENT FOR KAISER MEAD NPL SITE

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1.0 INTRODUCTION

This Work Plan has been prepared to comply with one of the tasks listed in the request by the Washington Department of Ecology (Ecology, 2014) to Mead Custodial Trust dated December 8, 2014, to proceed with certain actions as a continuation of the Supplemental Feasibility Study (SFS) for the Kaiser Mead NPL site (Kaiser Mead). The purpose of the SFS is to develop and evaluate cleanup action alternatives for the contaminated groundwater at Kaiser Mead and to recommend a remedial alternative to be implemented to achieve compliance with cleanup requirements established for this site. The purpose of the activities described in this work plan is to provide sufficient information to support the selection of a preferred remedy in the SFS.

1.1 BACKGROUND

In 2013 Hydrometrics conducted field and laboratory studies in an effort to develop and evaluate additional remedial alternatives for the Site. Based on the completed work alternatives were developed that included (Hydrometrics, 2014):

- Alternative A, no additional actions
- Alternative B, implementation of a grout curtain to divert A-zone groundwater around the potential secondary sources;
- Alternative C, implementation of a in situ treatment zone to treat contaminated groundwater;
- Alternative D, ex situ treatment technologies to treat contaminated groundwater; and
- Alternative E, implementation (in a phased approach) the grout curtain (alternative B) and ex situ treatment technologies.

Alternative E was selected as the most cost effective remedial alternative. The Department of Ecology subsequently requested the Trust to increase the level of detail in the evaluation process further by conducting the following:

- Develop a groundwater model to estimate the response of groundwater conditions to installation of cutoff wall;
- Install a pilot test cutoff wall to test installation technique, assist in design and develop cost estimates for full scale implementation, and provide additional data that may be implemented into subsequent model simulations;
- Perform additional field activities, including aquifer tests and soil borings (with geochemical analysis) to support development of the groundwater model and refine estimates on the extent of potential secondary contaminant sources away from the SPL pile;
- Perform pilot scale tests of ex situ treatment technology for cyanide forms and of ex situ fluoride treatment; and
- Perform additional laboratory tests of in situ groundwater treatment reagents for both cyanide forms and fluoride.

1.2 WORK PLAN OVERVIEW

This work plan is specific to the development of a numerical groundwater flow model. The model will be used to evaluate remedial measures aimed at achieving compliance with the established cleanup goals and assist in any preliminary design alternatives. This will be accomplished by evaluating changes in the groundwater flow system and advective transport for different remedial designs. Groundwater modeling is an appropriate tool for this site because a model can simulate and evaluate a variety of potential actions and provide detailed estimates of impacts of the various remedial options. This work plan focuses on a groundwater flow model with evaluations of advective transport using particle tracking. However, if needed the model may be used in subsequent modeling efforts to simulate the fate and transport of constituents in the groundwater system. The modeling team will develop the structure of the groundwater flow model with an understanding of the geochemical stresses (e.g. greater discretization of cells in areas of high concentration gradients) in the system so the model can be used for future fate and transport development if needed. It should be noted that any fate and transport modeling results will have high degree of uncertainty as there is not sufficient transient data to calibrate plume movement.

The site's complex hydrogeology will be simulated by varying the hydrological properties within a range of values appropriate to the representative geologic materials during the calibration process. The calibrated flow model will then be used to assess stresses including installation of a cutoff wall and pumping of capture wells. The model will also be re-evaluated as new information is obtained from proposed additional wells and from a pilot cutoff wall test section.

2.0 DEVELOPMENT OF MODEL

2.1 MODEL OBJECTIVES

Development of a local numerical groundwater flow model will be necessary to test the effectiveness and assist in design of treatment alternatives B and D, the grout curtain and ex situ treatment alternatives respectively. The model used for the initial assessment of Alternative B is an analytical element model that was calibrated to the general flow direction and gradient, however it was not calibrated to specific heads in the A Zone aquifer. This model was an effective tool to understand at a screening level the feasibility of a grout curtain based on the general setting. A calibrated numerical flow model would allow for more detailed testing of the effectiveness of each treatment alternative and provide data that will be critical for final detailed design. Model results will also assist in finalizing the cost analysis for each alternative. The primary objectives of the numerical flow model are as follows:

- Support refinement of the site conceptual model with respect to groundwater flow;
- Estimate groundwater flow rates within the A and B Zone aquifers;
- Assess remedial alternatives effects on the groundwater flow system (Alt. B - reduction in flow through source area; Alt. D – optimize location and flow of extraction wells)
- Provide a tool that in conjunction with empirical data can assist in design of selected remedial alternatives (e.g. location, permeability and height of grout curtain or location and volume of capture wells), and;
- Provide predictive simulations of water level response to remedial alternatives that can be used to assess the effectiveness of alternatives after implementation (e.g. water level response to grout curtain or capture wells).

The flow model will allow for an initial assessment of the different remedial alternatives. Further analysis may be needed to fully evaluate the effectiveness of the remedial options on contaminant loading.

2.2 MODEL DEVELOPMENT APPROACH

Development of a numerical model needs to consider the complex hydrogeologic and geochemical characteristics of the site and aquifer system. Groundwater flow and transport of contaminants at the site are very complex and will require some flexibility in the development of the specific modeling approach until data collected through pilot testing and further investigations are fully analyzed. Although some details of the model development will evolve and be refined based on the results of the pilot tests and any additional field investigations, we have outlined an initial approach to model construction below. Modifications may need to be made based on future data collection.

2.2.1 Model Selection

The model will use MODFLOW 2000 to simulate the physical flow system. MODFLOW 2000 is an updated version of the U.S. Geological Survey's, modular 3D finite difference groundwater flow model, MODFLOW (McDonald and Harbaugh, 1988; Hill, 1992). Advective transport will be evaluated using MODPATH; which is a particle tracking code that can be used in conjunction with MODFLOW. MODPATH inputs particles into the model domain and then tracks the particles movement through advective transport. To facilitate model development and data processing the flow model will be implemented using the software program GMS (Groundwater Modeling System, version 10.0 or higher). These models were selected because of their comprehensive capabilities for simulating advective flow in groundwater flow systems under a wide range of hydrogeological conditions.

2.2.2 Model Domain/Grid

The model domain will encompass both the Zone A and Zone B aquifers. Determining the proper model domain is a critical step in any model development. This model will be a local model to allow for higher precision. The precision of the model must be balanced with ensuring there are no superfluous boundary effects. The horizontal extent of the model will be set so that boundary effects do not unrealistically alter/control the flow and/or contaminant transport. Evaluating potential stresses to the flow system through analytical models can assist in development of the model domain. Model development is, by necessity, a stepwise process where initial model parameters are tested and refined to best match empirical data.

A variable spaced grid will be developed for the model. Refinement points will be used to discretize the grid in areas where high potentiometric or geochemical gradients are present (SPL area), which will allow the model to more accurately simulate the flow in those areas. Refinement points will also be included in areas where potential remedial controls will be evaluated, and in downgradient areas of the plume where sharp geochemical gradients require higher model resolution.

2.2.3 Boundary Conditions

Boundary conditions will be used to simulate hydrogeologic conditions at the extents of the model domain. Proper use of boundary conditions is a central part of model construction especially when developing local models as effects from boundary conditions are more of a concern in small local models. It is anticipated that general head boundaries (GHB) will be used for the upgradient and downgradient portions of the model to minimize unwarranted boundary condition effects. A GHB uses an assigned head value and a conductance to calculate groundwater flux at the model boundary based on fixed conditions at a more distant hydrologic boundary. This allows for the boundary condition to be close to applied stresses in the model with limited effects on the results due to the boundary.

Initially, no-flow boundaries will be used where the flow pattern is parallel to the flow direction or in locations where there are natural no-flow boundaries. If hydrologic changes occur near the no-flow boundaries it may be necessary to adjust the location of the boundary or use an alternative boundary condition during simulations of treatment alternatives. Other boundaries that may be used are specified head or specified flow. These boundary conditions are more susceptible to causing boundary effects in local models; therefore it is not anticipated that these boundaries will be used.

If significant boundary effects cannot be avoided in the local model it may be necessary to construct a coarse regional model to assess the hydrologic response near the boundaries of the local model to specific stress applied to the system. The data from the regional model would then be applied to the local model boundaries to reduce superfluous boundary effects.

2.2.4 Sources and Sinks

Sources and sinks included in the model will consist of areal recharge from precipitation for the steady state model and any infiltration from the ex-situ treatment alternative. Extraction wells will be used to assess the capture system in the ex-situ treatment option. Areal recharge will initially be applied based on a percentage of precipitation based on local and regional data; likely in the range of 8% to14%. Simulated extraction wells will be used to evaluate the capture system for ex-situ treatment.

2.2.5 Hydraulic Parameters

The hydraulic properties will be assigned based on the major hydrostratigraphic units defined by the conceptual model. One potential way to discretize the aquifer properties into the model layers is using the MODFLOW-2000 hydrogeologic-unit flow (HUF) package (Anderman and Hill, 2000). The HUF package allows the vertical stratigraphy of the hydrologic system to be defined independent from the model grid. Using the HUF package the user establishes multiple hydrogeologic units with different hydrogeologic properties (hydraulic conductivity, anisotropy, specific yield, and specific storage) in the model. The top elevation of the model is defined by the first HUF array. The underlying HUF arrays define the thickness of different hydrogeologic units. Hydrogeologic unit thicknesses are allowed to equal zero, making it possible to simulate complex heterogeneities, including pinched out units and embedded lenses. The HUF arrays (with multiple hydrogeologic units) are imposed on the model grid, the model then uses the units within a cell to calculate the effective hydraulic properties resulting in a cell-to-cell conductance value. Using the HUF package will provide a tool to simulate the complex heterogeneities and known low permeability/aquitard zones of groundwater system in the modeled area. Hydraulic parameters will be assigned to each unit based on data collected from site monitoring wells and established literature values. Table 2-1 summarizes the average and/or range of values for hydraulic parameters for each unit that will be used as a guide for model development.

TABLE 2-1. SUMMARY OF HYDRAULIC PARAMETERS TO GUIDE MODEL DEVELOPMENT

Hydrogeologic Unit	**Hydraulic Conductivity (ft/day)**		**Specific Yield**	**Specific Storage (l/ft)**
	Range	Avg.	Range	Range
Zone A Sand	180 - 640	300	0.15 – 0.25	$1x10^{-5} – 1x10^{-8}$
Zone B Sand	270 – 540	340	0.15 – 0.25	$1x10^{-5} – 1x10^{-8}$
Silty Sand	0.1 – 10	NA	0.05 – 0.2	$1x10^{-5} – 1x10^{-8}$
Silt/Clay	0.001 – 0.01	NA	0.02 – 0.05	$1x10^{-5} – 1x10^{-8}$

NA: Not available, will be evaluated in further field investigations

2.2.6 Calibration and Sensitivity Analysis

The groundwater flow model will first be calibrated to steady state conditions. The model will initially be calibrated to the May 2013 water level data, as it is the most comprehensive data set for the site. Calibration of the flow model will be evaluated on a qualitative and quantitative basis. Calibration of groundwater flow will be evaluated qualitatively by comparing observed and simulated potentiometric surfaces (gradient and direction) and quantitatively by using observation points to compare observed vs. simulated heads and groundwater flux through specified areas.

Calibration targets will be established for quantitative analysis based on observed data and standard targets used in the industry (e.g. simulated heads within 10% of change in head across model domain). Primary calibration targets will be applied to areas of interest as well as areas where sufficient data is available to achieve the targets. Where there is insufficient data for some parameters or data that has less precision it may be necessary to evaluate the calibration of these areas using secondary targets. The primary and secondary calibration targets will be determined prior to model development based on a review of data collected in previous investigations and that collected as part further investigations and pilot testing.

In addition to model calibration, sensitivity analyses will be conducted to quantify the uncertainty in the calibrated model caused by estimates of parameters used in the model.

Calibrated parameters (e.g. hydraulic conductivities) will be changed within previously established possible ranges that are based on both empirical data and/or literature values. Model sensitivity will be measured by assessing the effect of a parameter change on the average measure of error. At a minimum, sensitivity will be measured based on head and possibly transport velocities. Additional parameters such as groundwater flux and plume geometry may also be evaluated in the sensitivity analysis.

2.3 PREDICTIVE SIMULATIONS

The model will be used for predictive simulations of the different remedial alternatives. The proposed predictive simulations and purpose of each is summarized below:

1. Transient simulation of grout curtain
    a. Assess the ability of the grout curtain to reroute water outside of the source area and estimate potentiometric response of curtain.
    b. Further evaluate the necessary reduction in permeability for the grout curtain to be effective.
    c. Assess uncertainties of grout curtain integrity (e.g. effects of areas where grout is not injected to anticipated radius of influence).
    d. Provide information on the hydrologic response to allow for proper placement of monitoring wells and a basis to evaluate the effectiveness of the treatment.
2. Simulate ex-situ treatment
    a. Assist in design of pump and treat system.
        i. Placement and pumping rate of extraction wells
        ii. Placement of infiltration pond for treated water
    b. Evaluate changes of flow field due to pump capture system.
3. Simulation of combination of grout curtain and ex-situ treatment alternatives
    a. Assess effectiveness of dual treatment
    b. Assist in proper placement of extraction wells
    c. Estimate reduction in pumping rate for ex-situ treatment with grout curtain in place.

The flow model results will be utilized to further evaluate and refine contaminant transport estimates under the various remedial alternatives. The need for a more detailed contaminant fate and transport model will be evaluated following a review of flow model results by Ecology. At this time there is insufficient data to build a contaminant transport model that would provide a useful level of precision/accuracy. Additional data would be needed to develop a numerical geochemical fate and transport model including defining the source terms for both cyanide and fluoride including loading rates, extent of source areas and leachability and attenuation capacity of the soils. Data on the source terms would be needed throughout the plume area including upgradient, within, and downgradient of the source area(s) to construct an effective fate and transport model. Since these data are limited, pursuing a fate and transport model option is not feasible at this time. The need and feasibility of a fate and transport model will be evaluated following the implementation of the tasks requested by DOE.

2.4 SCHEDULE

Initial development of the 3D finite difference ground-water flow model using MODFLOW as described above is expected to take 3 to 4 months. While model development would be facilitated by the additional aquifer data expected from the additional wells planned for the site, model results may provide important information useful in selecting test cutoff wall design parameters. Therefore, it may be advantageous to schedule the initial model development and preliminary testing of remedial design options in advance of installation of new wells, collecting additional field data or constructing a pilot test cutoff wall. The model would then become a working tool that would incorporate additional data from new wells and results of the cutoff wall pilot testing to further remedy selection and final design. Target completion date for the initial calibrated model and evaluation of potential cutoff wall configurations is 15 weeks after approval to proceed.

After initial model construction Hydrometrics will coordinate a call with the Trust and DOE to report on progress and discuss any issues that arise in model development. It is anticipated that this status call will occur approximately 8 weeks after project initiation. After model testing, calibration and initial runs another call or meeting will be held to describe initial results and discuss further use of the model as additional empirical data is obtained.

3.0 REPORTING

A Groundwater Model Report will be written to document the development of the groundwater model, coordination with Ecology on input to the model and calibrations of the model. Evaluations of the model results will be included in the Groundwater Model Report and their implications to the remedy selection.

The evaluation of the groundwater model results and all task results will be discussed in updated sections to the Supplemental Feasibility Study Report and the conclusions of the Supplemental Feasibility Study Report will be revised as appropriate.

4.0 REFERENCES

Ecology, 2014. Washington Department of Ecology. *Kaiser Mead Supplemental Feasibility Study Next Steps.* Letter to Mead Custodial Trust. December 8, 2014.

Hydrometrics, 2014. Supplemental Feasibility Study Report for the Kaiser Mead Facility. January 2014.

MODFLOW (McDonald and Harbaugh, 1988; Hill, 1992)

MODFLOW-2000 hydrogeologic-unit flow (HUF) package (Anderman and Hill, 2000)