WATER QUALITY IMPACT EVALUATION

Ground Disposal of Effluent from WSDOT Preparatory Bridge Washing

Prepared for

Washington State Department of Transportation

January 2008

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Ground Disposal of Effluent from WSDOT Preparatory Bridge Washing

Prepared for

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Introduction

One of the responsibilities of the Washington State Department of Transportation (WSDOT) is to maintain and preserve steel bridges and marine transfer spans that are part of the state's transportation infrastructure. Activities associated with the maintenance and preservation of these structures include periodic washing that is conducted both for routine maintenance and in preparation for painting. The resulting wastewater from this washing can contain pollutants such as suspended solids, heavy metals from paint particles, and bacteria from bird feces. Because this contaminated wastewater could potentially contribute to the impairment of water quality in the adjacent receiving water body, the Washington State Department of Ecology (Ecology) required WSDOT to conduct an engineering feasibility study to evaluate various measures for protecting water quality during washing activities for bridges and marine transfer spans. The feasibility study (Herrera 2003a) identified a preferred treatment alternative out of a range of potential options that conforms with the definition of AKART (all known, available, and reasonable technology) as described in the Washington Administrative Code (WAC 173-201A). The results of this study indicated that the AKART treatment technology for washing bridges and marine transfer in preparation for painting is filter tarpaulins (tarps) that are suspended beneath the structures during active washing operations.

In compliance with federal regulations (40 CFR 122.44), WSDOT analyzed the preferred AKART treatment alternative to determine whether its use would be associated with a "reasonable potential" for water quality standards to be violated as a result of the discharge of the effluent generated. The results of the analysis (Herrera 2003b) indicated a potential for violating water quality standards when washing activities occur over those receiving waters (e.g., marine waters, lakes, wetlands, or streams) having little or no dilution potential (i.e., receiving waters exhibiting very low flows).

Based on the engineering feasibility study and the analysis of reasonable potential, Ecology subsequently issued an NPDES permit (WA-0039039) that authorizes the discharge of bridge washing effluent subject to certain limitations, including the implementation of several studies to obtain additional data on the potential for water quality impacts due to the discharge of bridge washing effluent. Specifically, Section S6.B of the NPDES permit includes the following text related to bridge washing activities performed over dry land: "

> *An evaluation of the impacts of discharge to ground is required. This evaluation is due one year after three pressure wash projects using #100 filter tarp have been completed and evaluated. The report shall use the effluent analysis required elsewhere in this permit and evaluate the potential of this discharge for violation of groundwater standards (WAC 173-200).*

This condition of the permit was specifically imposed to determine if discharge to nearby ground surfaces is a viable option for disposal of washwater effluent when full containment may be required for bridge washing over sensitive water bodies.

As a first step in complying with this permit obligation, WSDOT requested that Herrera Environmental Consultants (Herrera) perform a literature review to identify issues related to the transport and attenuation of heavy metals within unsaturated soils, or the vadose zone, that would require consideration in this evaluation. Based on the information obtained from this review, Herrera subsequently developed a conceptual approach for performing the groundwater impact evaluations specified under Section S6.B of the NPDES permit. This conceptual approach was described in a technical memorandum (Herrera 2007) that was submitted to Ecology for review and comment. After addressing Ecology's comments on the conceptual approach (Lenth 2007), Herrera performed the associated evaluations with the goal of answering the following specific questions related to the ground disposal of washwater effluent:

- Is there a risk of groundwater contamination from bridge washing effluent with high levels of chromium, copper, lead, and zinc given differing groundwater depths and upland soil types that may be present at specific bridge sites?

- Is there a risk that bridge washing effluent will reach nearby surface waters via overland flow given differing upland soil types and topography (i.e., ground slope) that may be present at specific bridge sites?

This report summarizes the results from separate evaluations that were performed to address these questions. It is organized to present the methods and results from these evaluations under the following major headings:

- Groundwater Impact Evaluation
- Surface Water Impact Evaluation

Conclusions and recommendations related to each of these evaluations are then summarized collectively at the end of this report.

Groundwater Impact Evaluation

Methods and results from the evaluation performed to assess the risk of groundwater contamination from bridge washing effluent are summarized herein. Conclusions and recommendations related to this evaluation are also provided under separate major section headings at the end of this report.

Methods

As described in Herrera (2007), the behavior of metals in soils is complex and a number of site-specific variables influence their attenuation and transport through the vadose zone. Because of the complexity of these interactions and the various soil types and hydrogeology that are likely to be encountered at bridge washing sites throughout the state, a modeling approach was used to evaluate potential impacts to groundwater quality from the ground disposal of bridge washing effluent. Based on a previous evaluation of commercially available vadose zone models (Herrera 2007), the Variably Saturated 2D Flow and Transport (VS2DT) model was chosen for this evaluation due to its widespread acceptance for use in simulating processes that influence metals transport in the vadose zone. Developed by the U.S. Geological Survey, the VS2DT model is a finite difference numerical model that simulates advection, hydrodynamic dispersion, decay, and adsorption of pollutants within the vadose zone. However, it should be noted that the VS2DT model does not simulate metal complexation, which is a process known to slow the transport of metals (McLean and Bledsoe 1992) through binding with suitable compounds (or ligands).

In this evaluation, the VS2DT model was specifically used to evaluate the potential risk of groundwater contamination from chromium, copper, lead, and zinc assuming all of the effluent from a typical bridge washing project was discharged to the ground surface at a single location. Input parameters for the model were varied across multiple model runs in order to evaluate this risk for twelve representative soil types and a range of depths to groundwater that might be encountered during specific bridge washing operations. Furthermore, each model run examined the potential for metals migration within the soil profile over a 10-year time period extending from the initial bridge washing event. The following output was subsequently compiled from each model run:

- Maximum metals concentration at different depths to groundwater over the 10-year time period extending from the initial bridge washing event.
- Metals concentration at different depths to groundwater at the end of the 10-year period extending from the initial bridge washing event.

To assess the potential for groundwater contamination from the ground disposal of bridge washing effluent, the modeled concentrations for each metal and soil type were subsequently compared to applicable groundwater quality criteria identified in WAC 173-200.

Throughout this evaluation, input parameters used in the model runs were generally derived based on worse-case assumptions in order to provide a more conservative assessment of the potential for groundwater contamination. Because the VS2DT model does not simulate metal complexation in soil, the model results likely overestimate the distance a given metal species will travel through the soil profile. Key input parameters that were used in the VS2DT model for this evaluation are discussed in more detail below.

Model Input Parameters

Major inputs to the VS2DT model are described herein under separate subsections for soil parameters, transport parameters, and model boundary conditions. Major inputs to the model are also summarized collectively in the sample output file that is presented in Appendix A.

Soil Parameters

For this evaluation, the VS2DT model was run for twelve (12) different types of soil texture that generally represent the full range of conditions that are likely to be encountered at specific bridge washing sites in Washington (see Table 1). To run the VS2DT model, inputs are required for specific parameters that are associated with each of these soil textures (e.g., saturated hydraulic conductivity, specific storage, porosity, and residual moisture content). The model comes with default inputs for each soil texture that are derived based on literature values; however, user defined values can also be entered. In this evaluation, the default values from the VS2DT model were used for all soil parameters except for soil porosity and saturated hydraulic conductivity. Inputs for these parameters were derived based on default values that were obtained from the Hydrologic Evaluation of Landfill Performance (HELP) model. Following recommendations provided in the instructional documentation for the VS2DT, the HELP model was used to estimate the infiltration of water into the soil surface for the upper boundary condition of the VS2DT model and is described in detail in the next section. The default values from the HELP model were used in this analysis in order to maintain consistency between the HELP model predictions for infiltration and the VS2DT model predictions for the upper boundary condition. These default values are provided in Table 1 for the twelve soil textures that were evaluated in connection with this effort. Values for all other soil parameter inputs are also presented in Appendix A.

Transport Parameters

Transport parameter inputs for the VS2DT model are pollutant-specific physical and chemical properties that influence a pollutant’s persistence and mobility within the soil (e.g., decay constant, density, and equilibrium partition coefficient). The primary transport parameter input in the VS2DT model that influences the mobility of metals is the equilibrium partition coefficient. This value is defined as the ratio of a metal’s concentration in the sorbed phase to the concentration in the liquid phase. For this evaluation, equilibrium partition coefficients for the targeted metals were obtained from a report prepared by the U.S. Environmental Protection Agency (2005) that summarizes these values for various pollutants in a soil-soil water system based on data derived from an extensive literature review. Table 2 presents summary statistics from this report for the metals of interest in this evaluation. Lower values in this table correspond to a water liquid phase concentration and subsequently a greater travel distance within the soil for each metal. Therefore, minimum values in Table 2 for each metal were used as input for the VS2DT model in order to represent worst-case conditions.

Boundary Conditions

In order to run the VS2DT model, upper and lower boundaries must be defined within the soil profile of the system being modeled. The upper boundary is always set at the soil profile surface while the lower boundary may be specified at any point within the soil profile, including points below the groundwater surface. Two sets of input parameters must be defined in the model for the soil profiles associated with the upper and lower boundaries: flow conditions and transport conditions. Inputs for flow conditions in the upper boundary control the interactions between the soil profile and the atmosphere in the upper soil layers. Inputs for flow conditions in the lower boundary control the interactions between the soil profile and the surrounding soil. Input parameters for transport conditions within both the upper and lower boundary are used to specify concentrations or the mass flux of pollutants within each associated soil profile. The key inputs to the VS2DT model that were used to define flow and transport conditions within the upper and lower boundaries are discussed below. All inputs related to these components of the model are also presented in Appendix A.

Transport Conditions in Upper Boundary

For transport conditions in the upper boundary soil profile, an initial pollutant concentration is required as input to the VS2DT model. This initial concentration will then influence how far a pollutant will migrate into the soil profile. For this evaluation, the input concentrations for chromium, copper, lead, and zinc were derived based on worst-case effluent concentrations that were used in previous evaluations of bridge washing effluent (Herrera 2003b). These worst-case effluent concentrations (Table 3) were calculated based on procedures identified in Ecology (2002) from monitoring data compiled through previous studies of bridge washing effluent (WSDOT 2001, 2002a, 2002b, 2003), and represent the 95^{th} percentile pollutant concentrations for the target metals in this evaluation. For reference, Table 3 also identifies the applicable groundwater criteria for each metal.

The VS2DT model was set up to simulate the application of bridge washing effluent to the soil surface at these concentrations over a period of 56.7 days. This time period was determined based on the anticipated length of time (170 days) that is required to wash a relatively large bridge assuming washing occurs for 8 hours each day. (This schedule was derived based on information obtained from WSDOT bridge maintenance personnel from an ongoing washing project on the Lewis and Clark Bridge in Longview, Washington [Reck 2007]). Since this time period was derived from a relatively large bridge, the time period of pollutant application is maximized, and therefore the model is generally simulating worst-case conditions.

Flow Conditions in Upper Boundary

Flow conditions in the upper boundary were defined based on an input to the VS2DT model for the amount of water that infiltrates into the soil surface on an annual basis. Following recommendations provided in the instructional documentation for the VS2DT model, this value was determined using the HELP model identified previously. The HELP model is commonly used to compute estimates of water balances for municipal landfills. It uses a built-in synthetic weather generator with coefficients for numerous cities in the United States to simulate daily, monthly, and yearly statistics for precipitation and evapotranspiration. From these inputs, the model can be used to calculate an average infiltration rate by difference (infiltration = precipitation – runoff – evapotranspiration).

For this evaluation, a synthetic weather generator for Seattle, Washington within the HELP model was used to estimate annual runoff and evapotranspiration rates based on user-defined values for average monthly temperature and precipitation. The values for average monthly temperature and precipitation (Table 4) were derived based on historic data (1948-2006) from Seattle-Tacoma Airport that were obtained from the Western Regional Climate Center website (http://www.wrcc.dri.edu/).

Evapotranspiration and runoff are calculated within the HELP model as a function of specific soil properties (i.e., hydraulic conductivity and soil porosity) for different soil textures. For this evaluation, default values from the HELP model (see Table 1) were used as input for the twelve targeted soil texture types. (As noted above, these same values were used as input for the VS2DT model to maintain consistency between the two models.)

The HELP model also uses a runoff curve number to calculate runoff. The runoff curve number is calculated as a function of soil slope, length of slope, soil type, and vegetation cover. In order to represent worst-case conditions in this evaluation, the following soil attributes were assumed:

- Bare ground to minimize evapotranspiration
- A 1 percent slope to minimize runoff
- A relatively long length of slope (1,000 feet) to minimize runoff.

Under these conditions, the HELP model will predict higher infiltration rates that will tend to carry pollutants deeper into the soil profile.

With the parameters described above as input, separate 10-year simulations were performed with the HELP model for each of the twelve soil texture types identified in Table 1. Average values for precipitation, runoff, and evapotranspiration were then extracted from each simulation (Table 5) and used to calculate average annual infiltration rates. These values (see Table 5) were then used as input in the VS2DT model to define flow conditions in the upper boundary soil profile.

Transport Conditions in Lower Boundary

Transport conditions for the lower boundary can be defined to simulate the introduction of a pollutant at lower depths within the soil profile. However, for this evaluation, it was assumed that the only source of pollutants to the entire soil profile was the application of bridge washing effluent to the ground surface and no inflow of pollutant (metals) occurred at the bottom of the soil profile. Therefore, the transport condition for the lower boundary was set to 0.0 mg/L for each metal over the 10-year period of the simulation.

Transport Conditions in Lower Boundary

The transport condition for the lower boundary was varied across multiple model runs to simulate a stable groundwater level at depths ranging from 0.15 to 100 feet within the soil profile. This relatively wide range was selected in an effort to capture the full range of conditions that might be encountered at actual bridge washing sites in Washington. The depth to groundwater was established in each model run by setting a constant pressure head at the lower flow boundary condition to a value equal to the total soil profile depth minus the depth to groundwater. For example, for a 100 feet deep soil profile with a groundwater depth of 10 feet, the lower boundary condition is set to a constant pressure head of 90 feet.

Results

VS2DT model results for the twelve soil texture types identified in Table 1 are summarized in Tables 6 through 17, respectively. Each table shows the modeled maximum concentrations for chromium, copper, lead, and zinc at different depths to groundwater over the 10-year time period simulated by the model. These tables also show the final modeled concentration for each metal at different depths to groundwater at the end of this 10-year time period. Finally, the data presented in Tables 6 through 17 for chromium, copper, lead and zinc are also summarized graphically in Figures 1, 2, 3 and 4, respectively.

To assess the risk of groundwater contamination from bridge washing effluent, the modeled concentrations for each metal in Tables 6 through 17 were compared to applicable groundwater criteria from WAC 173-200 (see Table 3). Results from this comparison indicated that modeled maximum concentrations for all four metals exceeded these criteria at one or more depths in all twelve of the soil texture types. However, in all cases, these exceedances were only observed at relatively shallow depths (i.e., < 1.35 feet). Specific exceedances of the applicable groundwater criteria are detailed under separate subsections below for each of the four metals. A complete summary of all groundwater criteria exceedances, including the duration of each exceedance over the 10-year simulation period, is also provided in Appendix B.

Chromium

Modeled concentrations of chromium exceeded the applicable groundwater criterion (0.05 mg/L) at all groundwater depths shallower than 0.48 feet (5.8 inches) for the following eight soil texture types: silt, silt loam, clay loam, loam, silty clay loam, sandy clay, silty clay, and clay (see Tables 10 through 17; Figure 1). Concentrations of chromium also exceeded the criterion at all depths shallower than 0.88 feet (10.6 inches) for the remaining four soil texture types: sand, loamy sand, sandy loam, sandy clay loam (see Tables 6 through 9; Figure 1). The highest chromium concentration (0.258 mg/L) was observed at a groundwater depth of 0.15 feet in sand (see Table 6). At groundwater depths of 0.88 feet and above, modeled chromium concentrations were all below 0.022 mg/L.

Copper

Modeled concentrations of copper exceeded the applicable groundwater criterion (1.0 mg/L) at all groundwater depths shallower than 0.48 feet (5.8 inches) for all twelve soil texture types (see Tables 6 through 17; Figure 2). The highest copper concentration (2.70 mg/L) was observed at a groundwater depth of 0.15 feet in sand (see Table 6). At depths greater that 0.48 feet, modeled copper concentrations were all below 0.817 mg/L.

Lead

Modeled concentrations of lead exceeded the applicable groundwater criterion (0.05 mg/L) at all groundwater depths shallower than 0.88 feet (10.6 inches) for the following six soil texture types: clay loam, loam, silty clay loam, sandy clay, silty clay, and clay (see Tables 12 through 17; Figure 3). Concentrations of lead also exceeded the criterion at all depths shallower than 1.35 feet (16.2 inches) for the remaining six soil texture types: sand, loamy sand, sandy loam, sandy clay loam, silt, and silt loam (see Tables 6 through 11; Figure 3). The highest lead concentration (1.95 mg/L) was observed at a groundwater depth of 0.15 feet in sand (see Table 6). At groundwater depths of 1.35 feet and above, modeled lead concentrations were all below 0.036 mg/L.

Zinc

Modeled concentrations of zinc exceeded the applicable groundwater criterion (5.0 mg/L) at all groundwater depths shallower than 0.48 feet (5.8 inches) for the following six soil texture types: clay loam, loam, silty clay loam, sandy clay, silty clay, and clay (see Tables 12 through 17; Figure 4). Concentrations of zinc also exceeded the criterion at all depths shallower than 0.88 feet (10.6 inches) for the remaining six soil texture types: sand, loamy sand, sandy loam, sandy clay loam, silt, and silt loam (see Tables 6 through 11; Figure 4). The highest zinc concentration (1.95 mg/L) was observed at a groundwater depth of 0.15 feet in sand (see Table 6). At groundwater depths of 0.88 feet and above, modeled zinc concentrations were all below 4.37 mg/L.

Surface Water Impact Evaluation

Methods and results from the evaluation performed to assess the risk that bridge washing effluent will reach nearby surface waters via overland flow are summarized herein. Conclusions and recommendations related to this evaluation are also provided under separate major section headings at the end of this report.

Methods

In order to assess the risk that bridge washing effluent will enter and contaminate nearby surface waters via overland flow, a simple runoff model was used to determine the distance that effluent from a bridge washing project will likely travel on the ground surface before it infiltrates completely. This model was run multiple times to calculate this distance for ground surfaces with slopes ranging from 0.01 to 1.0 feet/feet and the following representative soil types: sand, loamy sand, sandy loam, loam, and sand clay loam. (Note that soils with extremely low-permeability [e.g., clays] were not evaluated because it was assumed they would not be suitable effluent disposal sites.)

In general, water can move across the ground surface as sheet flow, shallow concentrated flow, open channel flow, or a combination of these types of flow. For this analysis, it was assumed that bridge washing effluent initially moves across the ground surface as sheet flow. However, based on guidance presented in USDA (1986), it was assumed that this effluent begins moving as shallow concentrated flow after traveling a distance of 300 feet as sheet flow. It was further assumed that this effluent is continuously infiltrating into the ground as it moves as either sheet flow or shallow concentrated flow.

In order to model these processes, an initial effective flow depth for the bridge washing effluent was calculated based on information obtained from past and ongoing bridge washing projects. With this effective flow depth as an input, a spreadsheet model was used to determine the distance the bridge washing effluent travels across the ground surface at 1-minute time steps. Separate equations within the spreadsheet model were used to determine these distances for sheet flow and shallow concentrated flow. At each 1-minute time step, the amount of bridge washing effluent that infiltrates into the soil was also calculated based on representative infiltration rates obtained from the literature (Ecology 2005; Dunne and Leopold 1978) for the soil types identified above. The time required for all the bridge washing effluent to infiltrate (in minutes) was then calculated. The distances the effluent traveled at each minute over this period were then summed in order to determine the total distance the effluent traveled for a given slope and soil type combination. The following subsections provide more detailed information regarding the following components of this spreadsheet model:

- Equation for predicting sheet flow
- Equation for predicting shallow concentrated flow
- Initial affective flow depth for bridge washing effluent.

A sample of the output from the spreadsheet model is also provided in Appendix C.

Equation for Predicting Sheet Flow

Sheet flow is water flowing over the ground surface as a thin, irregular film. Its occurrence in any particular location is primarily governed by rainfall amounts and the slope and roughness of the ground surface. For sheet flow of less than 300 feet, travel time of sheet flow is typically defined using Manning's kinematic solution as (USDA 1986):

$$Tt = \frac{0.42(n_s L)^{0.8}}{(P_2)^{0.527}(So)^{0.4}}$$

Where:

Tt = travel time (hours, or minutes)
n= Manning's roughness coefficient
L=flow length (ft)
P_2= 2-year, 24-hour rainfall (in),
So=slope of hydraulic grade line (land slope, ft/ft).

The roughness coefficient (n) in the Manning's kinematic solution is a dimensionless coefficient that describes the resistance of water flowing over a given surface. Various roughness coefficients have been experimentally determined for different surfaces (Dunne and Leopold 1978). For this analysis, a roughness coefficient for cultivated soils with less than 20 percent residue cover (USDA 1986) was used as the input value in the Manning's kinematic solution. This value (0.06) was selected because these conditions are generally representative of the ground surface below a typical bridge (i.e., predominately bare ground with some areas of sparse vegetation).

Use of the Manning's kinematic solution requires an estimate of the excess rainfall intensity that is available for producing runoff. This quantity is approximated based on the precipitation total from the 2-year, 24-hour storm event (P_2). For this analysis, a value of 1.68 inches was used as input for the Manning's kinematic solution. This value was derived from the 2-year, 24-hour storm event for the Seattle vicinity (Seattle 2000) and is generally considered representative for western Washington.

The value for slope (So) in the Manning's kinematic solution was varied across multiple model runs to determine the distance bridge washing effluent will travel on ground surfaces with slopes ranging from 0.01 to 1.0 feet/feet. This relatively wide range was selected in an effort to capture the full range of conditions that might be encountered at actual bridge washing sites in Washington.

In order to determine the distance that bridge washing effluent will travel as sheet flow at 1-minute time steps, the value for flow length (L) in the Manning's kinematic solution was determined based on the inputs described above and an assumed travel time (Tt) of 1-minute. This process was used until the bridge washing effluent traveled a sufficient length of time to cover a distance of 300 feet. At the point, the equation described in the following subsection was used to determine the distance the bridge washing effluent traveled as shallow concentrated flow.

Equation for Predicting Shallow Concentrated Flow

After traveling 300 feet, runoff moving as sheet flow usually transitions to shallow concentrated flow (USDA 1986). The average velocity of water moving as shallow concentrated flow can be estimated as a function of slope using the following equation:

$$V=968.07s^{0.5}$$

Where

V=average surface velocity (feet/minute)
s=slope of hydraulic grade line (land slope, ft/ft).

The value for slope (s) in this equation was varied across multiple model runs to determine the distance bridge washing effluent will travel on ground surfaces with slopes ranging from 0.01 to 1.0 feet/feet. For each model run, the equation was used to determine the distance the bridge washing traveled as shallow concentrated flow after it travelled an initial 300 feet as sheet flow (see previous subsection).

Initial Affective Flow Depth for Bridge Washing Effluent

In order to determine the rate at which bridge washing effluent infiltrates into the soil, an initial effective flow depth for the effluent was required for input in the spreadsheet model developed for this evaluation. This value was calculated based on a worst-case effluent discharge rate that was used in previous evaluations of bridge washing effluent (Herrera 2003b). Specifically, this initial affective flow depth was generated based on the assumption that 6 power washers are operating simultaneously with an individual discharge rate of 3 gallons per minute (gpm) and with a collective discharge rate of 18 gpm. The footprint of the bridge washing platform was assumed to be 4,200 square feet (Reck 2007). Furthermore, it was assumed that the actual bridge washing effluent was discharged over an area of approximately 1,000 square feet after concentrating in the filter tarp. This area was estimated based on visual observations made during a large, ongoing washing project on the Lewis and Clark Bridge in Longview, Washington. Specifically, field personnel noted that approximately 25 percent of the soil under the footprint for the bridge washing platform was receiving effluent (Catarra 2007).

From this information, an initial effective flow depth for bridge washing effluent was calculated by dividing the collective discharge rate for the power washers (18 gpm) by the area that received the associated effluent (1,000 square feet). After the appropriate unit conversions, the resultant value (0.03 inches) was used as an input in the spreadsheet model to represent the initial depth of bridge washing effluent before it moves along the ground and subsequently infiltrates into the soil. This value was subsequently decreased at 1-minute time steps within the spreadsheet model by an amount determined by the soil’s infiltration rate (see Table 18) until it reached zero. The total time (in minutes) required for this number to reach zero was then used to calculate the total distances the effluent traveled over this period.

Results

Results from the surface water impact evaluation are summarized in Table 19 and Figure 5. This table and figure present travel distances for bridge washing effluent given different combinations of ground slope and soil type based on the output from the spreadsheet model described previously. As expected, travel distances for bridge washing effluent were positively correlated with ground slope across all the soil types. (In general, model runs with progressively higher slope values were halted for a given soil type once the distance required to achieve full infiltration of bridge washing effluent exceeded 0.5 miles [2,640 feet]) For example, as shown in Table 19, effluent travel distances for sand and loamy sand increased by a factor of 10 going from a slope of 0.01 to 1.0. This trend was even more pronounced for sandy loam, loam, and sandy clay loam. For example, the effluent travel distance for sandy loam at a slope of 0.75 was fifty times higher than the comparable travel distance at a slope of 0.01.

Effluent travel distances (Table 19) were also negatively correlated with infiltration rates for the five targeted soil types (see Table 18). Accordingly, for any given ground slope value, effluent travel distances showed the following increasing trend by soil type: sand < loamy sand < sandy loam < loam < sandy clay loam. At the low end of this continuum, effluent travel distances for sand ranged from 6.9 to 69.4 feet for ground slopes of 0.01 and 1.0, respectively. At the high end of the continuum, effluent travel distances for sandy clay loam ranged from 395 to 4,744 feet for ground slopes of 0.01 and 0.04, respectively. If it is assumed that the ground surface beneath a typical highway bridge has a slope of approximately 0.3, the expected travel distances for bridge washing effluent are as follows for sand, loamy sand, sandy loam, loam, and sandy clay loam, respectively: 38, 152, 266, >2,671, and >4,744 feet.

Conclusions

In general, results from this evaluation indicate the risk of groundwater contamination from the ground disposal of bridge washing effluent is relatively low because the associated metals generally are rapidly sequestered at shallow depths within the soil profile. For all metals, modeling results from this evaluation indicate that exceedances of the applicable groundwater criteria would potentially only occur at depths below 1.35 feet. These results are generally consistent with other studies that have shown metals to migrate small distances even during long-term releases. For example, soils subjected to 25 years of scrap metal waste showed that migration of metals below a soil depth of 15.75 inches (40 cm) was minimal so long as the pH was above 6.5 (Jensen et al. 2000). In another study (Kim et al. 2007), chromium and copper from chromate copper arsenate treated wood structures moved less than 0.4 inches (1 cm) into the soil column over a one-year period. Based on these considerations, movement of metals into groundwater from the ground surface may be considered to be minimal as long as the retention capacity of the soil is not exceeded (McLean and Bledsoe 1992). The discharge of bridge washing effluent to the ground is also not likely to be a concern in this regard due to the short-term and intermittent nature of bridge washing projects.

Modeling performed for this evaluation indicates there is some risk that bridge washing effluent will reach and potentially contaminate nearby surface waters via overland flow if the effluent is applied on certain combinations of soil and ground slope. For example, bridge washing effluent may travel in excess of 0.5 miles if applied to loam and sandy clay loam soils on typical ground slopes (e.g., 0.3) beneath highway bridges. However, for high infiltration soils (e.g., sands, loamy sands, and sandy loam), bridge washing effluent will infiltrate into the ground from 40 to within several hundred feet of its point of deposition on the ground surface.

Recommendations

Based on the conclusions presented above, the following recommendations are provided to prevent the potential contamination of groundwater and surface water from the ground disposal of bridge washing effluent:

- To protect groundwater quality, ground disposal of bridge washing effluent should not occur in areas where the depth to ground water is expected to be shallower than 1.5 feet.

- Ground disposal of bridge washing effluent should be permitted on soils with relatively high infiltration rates (e.g., sand, loamy sand, and sandy loam); however, appropriate set-back requirements from nearby receiving waters should be developed based on the data presented in Table 19 to protect surface water quality. Where inadequate space is available at a particular bridge site to meet the set-back requirements, appropriate containment systems should be used to prevent the overland flow of bridge washing effluent. This could include the use of approved drainage and runoff controls that are identified in the Regional Road Maintenance Endangered Species Act (ESA) Program Guidelines (Regional Road Maintenance Technical Group 2002).

- Ground disposal of bridge washing effluent on soils with relatively low infiltration rates (e.g., loam, sandy clay loam) should also be permitted; however, appropriate containment systems (as described above) should be used to prevent the overland flow of bridge washing effluent. Ground disposal of bridge washing effluent should not occur on soils with extremely low infiltration rates (e.g., clay). Furthermore, ground disposal of bridge washing effluent should not occur in areas that have been armored using riprap or other impervious materials.

- Physical factors such as slope stability and scour at the point of discharge for the bridge washing effluent should also be considered whenever ground disposal is proposed for a particular bridge site.

- A project evaluation protocol should be developed for subsequent use by WSDOT's design and permitting teams to identify appropriate ground disposal locations for bridge washing effluent at specific bridge sites based on the criteria identified here.

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TABLES AND FIGURES

Table 1. VS2DT and HELP model inputs for porosity and saturated hydraulic conductivity by soil texture type.

Soil Texture Type	Total Porosity (vol/vol)	Saturated Hydraulic Conductivity (cm/sec)
Sand	0.437	5.80E-03
Loamy Sand	0.437	1.70E-03
Sandy Loam	0.453	7.20E-04
Sandy Clay Loam	0.398	1.20E-04
Silt	0.44	4.05E-04
Silt Loam	0.501	1.90E-04
Clay Loam	0.464	6.40E-05
Loam	0.463	3.70E-04
Silty Clay Loam	0.471	4.20E-05
Sandy Clay	0.43	3.30E-05
Silty Clay	0.479	2.50E-05
Clay	0.475	1.70E-05

Source: Default Values from Hydrologic Evaluation of Landfill Performance (HELP) model.
vol: volume
cm: centimeter
sec: second

Table 2. Representative partition coefficients (Kd) for chromium, copper, lead, and zinc from data compiled by the U.S. Environmental Protection Agency (2005).

	N	Min	Max	Median	Mean
Chromium	22	**10.00**	50,119	7,943	6,310
Copper	20	**1.26**	3,981	501	316
Lead	31	**5.01**	100,000	12,589	5,012
Zinc	21	**0.10**	100,000	1,259	501

Values in **bold** were used as the input for the VS2DT model

Table 3. Maximum expected dissolved metal concentrations that were used as input concentration in VS2DT compared to water quality criteria for ground water in Washington State.

Metal	Maximum Effluent Concentration [a] (mg/L)	Ground Water Criterion [b] (mg/L)
Chromium	3.76	0.05
Copper	6.13	1.0
Lead	14.7	0.05
Zinc	13.4	5.0

[a] Source: Worst-case effluent concentrations from Herrera (2003b). These values represent the 95th percentile pollutant concentrations from data compiled through previous studies of bridge washing effluent (WSDOT 2001, 2002a, 2002b, 2003).
[b] Source: WAC 173-200-050.
mg/L = milligrams per liter

Table 4. Average monthly temperature and precipitation from Seattle-Tacoma Airport from the period from 1948 to 2006 that were used as input within the HELP model.

Month	Temp (° Fahrenheit)	Precipitation (inches)
January	40.01	5.79
February	42.78	4.02
March	45.21	3.71
April	49.39	2.55
May	55.34	1.70
June	60.41	1.46
July	64.87	0.77
August	64.84	1.10
September	60.36	1.72
October	52.39	3.50
November	44.97	5.97
December	40.75	5.81

Source: Western Regional Climate Center Website (http://www.wrcc.dri.edu/)

Table 5. Average annual precipitation, runoff, and evapotranspiration rates from a 10-year simulation of the HELP model that were used to calculate soil infiltration rates for input in the VS2DT model.

Soil Texture	**Precipitation (inches/year)**	**Runoff (inches/year)**	**Evapotranspiration (inches/year)**	**Infiltration (inches/year)[a]**
Sand	38.19	0.13	14.9	23.1
Loamy Sand	38.19	0.21	15.4	22.5
Sandy Loam	38.19	0.56	15.9	21.8
Sandy Clay Loam	38.19	4.42	15.5	18.3
Silt	38.19	1.82	15.6	20.7
Silt Loam	38.19	2.65	16.1	19.5
Clay Loam	38.19	5.66	15.7	16.9
Loam	38.19	1.87	15.9	20.4
Silty Clay Loam	38.19	6.40	15.5	16.3
Sandy Clay	38.19	6.62	15.2	16.4
Silty Clay	38.19	10.00	15.0	13.2
Clay	38.19	11.68	14.9	11.6

[a] Infiltration = precipitation – runoff – evapotranspiration

Table 6. Groundwater concentrations for metals at increasing depths in sand based on output from VS2DT model runs.

	Chromium		Copper		Lead		Zinc	
GW Depth Feet	**Max mg/L**	**@ 10 yrs mg/L**	**Max mg/L**	**@ 10 yrs mg/L**	**Max mg/L**	**@ 10 yrs mg/L**	**Max mg/L**	**@ 10 yrs mg/L**
0.15	**0.258**	**0.164**	**2.70**	0.748	**1.95**	**0.943**	**20.77**	3.22
0.48	**0.065**	**0.065**	0.816	0.654	**0.578**	**0.578**	**6.83**	3.10
0.88	0.021	0.021	0.514	0.514	**0.196**	**0.196**	4.36	3.00
1.35	0.001	0.001	0.237	0.237	0.035	0.035	2.96	2.74
1.92	0.000	0.000	0.026	0.026	0.001	0.001	1.90	1.90
2.61	0.000	0.000	0.000	0.000	0.000	0.000	0.608	0.608
3.43	0.000	0.000	0.000	0.000	0.000	0.000	0.091	0.091
4.41	0.000	0.000	0.000	0.000	0.000	0.000	0.006	0.006
5.59	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
7.01	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
8.72	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
10.65	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
12.65	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Values in bold represent concentrations that exceed applicable groundwater criteria for chromium (0.05mg/L), copper (1.0mg/L), lead (0.05mg/L), and zinc (5.0mg/L) from WAC 173-200.
Modeled concentrations that were less than 10^{-4} mg/L were assigned a value of 0.0 in this table.
mg/L = milligrams per liter

Table 7. Groundwater concentrations for metals at increasing depths in loamy sand based on output from VS2DT model runs.

	Chromium		Copper		Lead		Zinc	
GW Depth Feet	**Max mg/L**	**@ 10 yrs mg/L**	**Max mg/L**	**@ 10 yrs mg/L**	**Max mg/L**	**@ 10 yrs mg/L**	**Max mg/L**	**@ 10 yrs mg/L**
0.15	**0.251**	**0.163**	**2.63**	0.751	**1.90**	**0.944**	**20.36**	3.23
0.48	**0.062**	**0.062**	0.796	0.651	**0.560**	**0.560**	**6.65**	3.11
0.88	0.010	0.010	0.446	0.446	**0.172**	**0.172**	3.73	2.82
1.35	0.001	0.001	0.215	0.215	0.028	0.028	2.43	2.34
1.92	0.000	0.000	0.082	0.082	0.003	0.003	1.96	1.96
2.61	0.000	0.000	0.014	0.014	0.000	0.000	1.07	1.07
3.43	0.000	0.000	0.003	0.003	0.000	0.000	0.591	0.591
4.41	0.000	0.000	0.000	0.000	0.000	0.000	0.161	0.161
5.59	0.000	0.000	0.000	0.000	0.000	0.000	0.028	0.028
7.01	0.000	0.000	0.000	0.000	0.000	0.000	0.003	0.003
8.72	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
10.65	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
12.65	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Values in bold represent concentrations that exceed applicable groundwater criteria for chromium (0.05mg/L), copper (1.0mg/L), lead (0.05mg/L), and zinc (5.0mg/L) from WAC 173-200.
Modeled concentrations that were less than 10^{-4} mg/L were assigned a value of 0.0 in this table.
mg/L = milligrams per liter

Table 8. Groundwater concentrations for metals at increasing depths in sandy loam based on output from VS2DT model runs.

GW Depth Feet	Chromium Max mg/L	Chromium @ 10 yrs mg/L	Copper Max mg/L	Copper @ 10 yrs mg/L	Lead Max mg/L	Lead @ 10 yrs mg/L	Zinc Max mg/L	Zinc @ 10 yrs mg/L
0.15	**0.251**	**0.170**	**2.62**	0.795	**1.90**	**0.996**	**20.07**	3.39
0.48	**0.058**	**0.058**	0.793	0.674	**0.550**	**0.550**	**6.43**	3.25
0.88	0.008	0.008	0.434	0.434	**0.151**	**0.151**	3.61	2.90
1.35	0.001	0.001	0.193	0.193	0.021	0.021	2.37	2.33
1.92	0.000	0.000	0.053	0.053	0.002	0.002	1.59	1.59
2.61	0.000	0.000	0.009	0.009	0.000	0.000	0.879	0.879
3.43	0.000	0.000	0.001	0.001	0.000	0.000	0.402	0.402
4.41	0.000	0.000	0.000	0.000	0.000	0.000	0.185	0.185
5.59	0.000	0.000	0.000	0.000	0.000	0.000	0.049	0.049
7.01	0.000	0.000	0.000	0.000	0.000	0.000	0.009	0.009
8.72	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001
10.65	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
12.65	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Values in bold represent concentrations that exceed applicable groundwater criteria for chromium (0.05mg/L), copper (1.0mg/L), lead (0.05mg/L), and zinc (5.0mg/L) from WAC 173-200.
Modeled concentrations that were less than 10^{-4} mg/L were assigned a value of 0.0 in this table.
mg/L = milligrams per liter

Table 9. Groundwater concentrations for metals at increasing depths in sandy clay loam based on output from VS2DT model runs.

GW Depth Feet	Chromium Max mg/L	Chromium @ 10 yrs mg/L	Copper Max mg/L	Copper @ 10 yrs mg/L	Lead Max mg/L	Lead @ 10 yrs mg/L	Zinc Max mg/L	Zinc @ 10 yrs mg/L
0.15	**0.244**	**0.172**	**2.57**	0.829	**1.84**	**1.02**	**20.37**	3.67
0.48	**0.053**	**0.053**	0.786	0.688	**0.527**	**0.527**	**6.87**	3.47
0.88	0.007	0.007	0.433	0.433	**0.135**	**0.135**	3.87	3.08
1.35	0.001	0.001	0.180	0.180	0.019	0.019	2.54	2.49
1.92	0.000	0.000	0.052	0.052	0.002	0.002	1.75	1.75
2.61	0.000	0.000	0.010	0.010	0.000	0.000	1.04	1.04
3.43	0.000	0.000	0.001	0.001	0.000	0.000	0.392	0.392
4.41	0.000	0.000	0.000	0.000	0.000	0.000	0.158	0.158
5.59	0.000	0.000	0.000	0.000	0.000	0.000	0.053	0.053
7.01	0.000	0.000	0.000	0.000	0.000	0.000	0.016	0.016
8.72	0.000	0.000	0.000	0.000	0.000	0.000	0.004	0.004
10.65	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001
12.65	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Values in bold represent concentrations that exceed applicable groundwater criteria for chromium (0.05mg/L), copper (1.0mg/L), lead (0.05mg/L), and zinc (5.0mg/L) from WAC 173-200.
Modeled concentrations that were less than 10^{-4} mg/L were assigned a value of 0.0 in this table.
mg/L = milligrams per liter

Table 10. Groundwater concentrations for metals at increasing depths in silt based on output from VS2DT model runs.

GW Depth Feet	Chromium Max mg/L	Chromium @ 10 yrs mg/L	Copper Max mg/L	Copper @ 10 yrs mg/L	Lead Max mg/L	Lead @ 10 yrs mg/L	Zinc Max mg/L	Zinc @ 10 yrs mg/L
0.15	**0.231**	**0.166**	**2.51**	0.827	**1.75**	**0.992**	**19.13**	3.46
0.48	0.048	0.048	0.755	0.678	**0.486**	**0.486**	**5.92**	3.29
0.88	0.006	0.006	0.403	0.403	**0.113**	**0.113**	3.41	2.82
1.35	0.000	0.000	0.154	0.154	0.013	0.013	2.23	2.21
1.92	0.000	0.000	0.036	0.036	0.001	0.001	1.42	1.42
2.61	0.000	0.000	0.005	0.005	0.000	0.000	0.701	0.701
3.43	0.000	0.000	0.001	0.001	0.000	0.000	0.265	0.265
4.41	0.000	0.000	0.000	0.000	0.000	0.000	0.072	0.072
5.59	0.000	0.000	0.000	0.000	0.000	0.000	0.064	0.064
7.01	0.000	0.000	0.000	0.000	0.000	0.000	0.015	0.015
8.72	0.000	0.000	0.000	0.000	0.000	0.000	0.003	0.003
10.65	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
12.65	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Values in bold represent concentrations that exceed applicable groundwater criteria for chromium (0.05mg/L), copper (1.0mg/L), lead (0.05mg/L), and zinc (5.0mg/L) from WAC 173-200.
Modeled concentrations that were less than 10^{-4} mg/L were assigned a value of 0.0 in this table.
mg/L = milligrams per liter

Table 11. Groundwater concentrations for metals at increasing depths in silt loam based on output from VS2DT model runs.

GW Depth Feet	Chromium Max mg/L	Chromium @ 10 yrs mg/L	Copper Max mg/L	Copper @ 10 yrs mg/L	Lead Max mg/L	Lead @ 10 yrs mg/L	Zinc Max mg/L	Zinc @ 10 yrs mg/L
0.15	**0.217**	**0.156**	**2.24**	0.745	**1.63**	**0.928**	**16.41**	3.10
0.48	0.045	0.045	0.672	0.607	**0.454**	**0.454**	**5.07**	2.93
0.88	0.005	0.005	0.357	0.357	**0.105**	**0.105**	2.90	2.52
1.35	0.003	0.003	0.134	0.134	0.012	0.012	1.99	1.99
1.92	0.000	0.000	0.030	0.030	0.001	0.001	1.16	1.16
2.61	0.000	0.000	0.004	0.004	0.000	0.000	0.532	0.532
3.43	0.000	0.000	0.000	0.000	0.000	0.000	0.171	0.171
4.41	0.000	0.000	0.000	0.000	0.000	0.000	0.038	0.038
5.59	0.000	0.000	0.000	0.000	0.000	0.000	0.005	0.005
7.01	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001
8.72	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
10.65	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
12.65	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Values in bold represent concentrations that exceed applicable groundwater criteria for chromium (0.05mg/L), copper (1.0mg/L), lead (0.05mg/L), and zinc (5.0mg/L) from WAC 173-200.
Modeled concentrations that were less than 10^{-4} mg/L were assigned a value of 0.0 in this table.
mg/L = milligrams per liter

Table 12. Groundwater concentrations for metals at increasing depths in clay loam based on output from VS2DT model runs.

GW Depth Feet	Chromium Max mg/L	Chromium @ 10 yrs mg/L	Copper Max mg/L	Copper @ 10 yrs mg/L	Lead Max mg/L	Lead @ 10 yrs mg/L	Zinc Max mg/L	Zinc @ 10 yrs mg/L
0.15	**0.189**	**0.154**	**1.43**	0.963	**1.42**	**0.963**	**15.50**	3.51
0.48	0.027	0.027	0.331	0.331	**0.331**	**0.331**	4.76	3.21
0.88	0.002	0.002	0.049	0.049	0.049	0.049	2.67	2.66
1.35	0.000	0.000	0.004	0.004	0.004	0.004	1.67	1.67
1.92	0.000	0.000	0.000	0.000	0.000	0.000	0.813	0.813
2.61	0.000	0.000	0.000	0.000	0.000	0.000	0.279	0.279
3.43	0.000	0.000	0.000	0.000	0.000	0.000	0.064	0.064
4.41	0.000	0.000	0.000	0.000	0.000	0.000	0.011	0.011
5.59	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001
7.01	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
8.72	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
10.65	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
12.65	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Values in bold represent concentrations that exceed applicable groundwater criteria for chromium (0.05mg/L), copper (1.0mg/L), lead (0.05mg/L), and zinc (5.0mg/L) from WAC 173-200.
Modeled concentrations that were less than 10^{-4} mg/L were assigned a value of 0.0 in this table.
mg/L = milligrams per liter

Table 13. Groundwater concentrations for metals at increasing depths in loam based on output from VS2DT model runs.

GW Depth Feet	Chromium Max mg/L	Chromium @ 10 yrs mg/L	Copper Max mg/L	Copper @ 10 yrs mg/L	Lead Max mg/L	Lead @ 10 yrs mg/L	Zinc Max mg/L	Zinc @ 10 yrs mg/L
0.15	**0.228**	**0.184**	**2.47**	**1.02**	**1.72**	**1.16**	**18.14**	4.24
0.48	0.034	0.034	0.736	0.726	**0.399**	**0.399**	5.75	3.88
0.88	0.003	0.003	0.319	0.319	**0.059**	**0.059**	2.05	2.05
1.35	0.000	0.000	0.081	0.081	0.004	0.004	2.03	2.03
1.92	0.000	0.000	0.012	0.012	0.000	0.000	1.00	1.00
2.61	0.000	0.000	0.001	0.001	0.000	0.000	0.363	0.363
3.43	0.000	0.000	0.000	0.000	0.000	0.000	0.090	0.090
4.41	0.000	0.000	0.000	0.000	0.000	0.000	0.021	0.021
5.59	0.000	0.000	0.000	0.000	0.000	0.000	0.004	0.004
7.01	0.000	0.000	0.000	0.000	0.000	0.000	0.004	0.004
8.72	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001
10.65	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
12.65	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Values in bold represent concentrations that exceed applicable groundwater criteria for chromium (0.05mg/L), copper (1.0mg/L), lead (0.05mg/L), and zinc (5.0mg/L) from WAC 173-200.
Modeled concentrations that were less than 10^{-4} mg/L were assigned a value of 0.0 in this table.
mg/L = milligrams per liter

Table 14. Groundwater concentrations for metals at increasing depths in silty clay based on output from VS2DT model runs.

GW Depth Feet	Chromium Max mg/L	Chromium @ 10 yrs mg/L	Copper Max mg/L	Copper @ 10 yrs mg/L	Lead Max mg/L	Lead @ 10 yrs mg/L	Zinc Max mg/L	Zinc @ 10 yrs mg/L
0.15	**0.182**	**0.148**	**1.91**	0.784	**1.37**	**0.924**	**14.72**	3.35
0.48	0.027	0.027	0.570	0.562	**0.321**	**0.321**	4.54	3.06
0.88	0.002	0.002	0.249	0.249	0.048	0.048	2.55	2.45
1.35	0.000	0.000	0.064	0.064	0.004	0.004	1.60	1.60
1.92	0.000	0.000	0.010	0.010	0.000	0.000	0.799	0.799
2.61	0.000	0.000	0.001	0.001	0.000	0.000	0.296	0.296
3.43	0.000	0.000	0.000	0.000	0.000	0.000	0.075	0.075
4.41	0.000	0.000	0.000	0.000	0.000	0.000	0.018	0.018
5.59	0.000	0.000	0.000	0.000	0.000	0.000	0.004	0.004
7.01	0.000	0.000	0.000	0.000	0.000	0.000	0.003	0.003
8.72	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
10.65	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
12.65	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Values in bold represent concentrations that exceed applicable groundwater criteria for chromium (0.05mg/L), copper (1.0mg/L), lead (0.05mg/L), and zinc (5.0mg/L) from WAC 173-200.
Modeled concentrations that were less than 10^{-4} mg/L were assigned a value of 0.0 in this table.
mg/L = milligrams per liter

Table 15. Groundwater concentrations for metals at increasing depths in sandy clay based on output from VS2DT model runs.

GW Depth Feet	Chromium Max mg/L	Chromium @ 10 yrs mg/L	Copper Max mg/L	Copper @ 10 yrs mg/L	Lead Max mg/L	Lead @ 10 yrs mg/L	Zinc Max mg/L	Zinc @ 10 yrs mg/L
0.15	**0.184**	**0.156**	**1.96**	0.872	**1.39**	**0.991**	**16.96**	3.83
0.48	0.023	0.023	0.583	0.583	**0.295**	**0.295**	4.87	3.47
0.88	0.001	0.001	0.228	0.228	0.037	0.037	2.75	2.69
1.35	0.000	0.000	0.050	0.050	0.002	0.002	1.67	1.67
1.92	0.000	0.000	0.007	0.007	0.000	0.000	0.776	0.776
2.61	0.000	0.000	0.001	0.001	0.000	0.000	0.264	0.264
3.43	0.000	0.000	0.000	0.000	0.000	0.000	0.059	0.059
4.41	0.000	0.000	0.000	0.000	0.000	0.000	0.013	0.013
5.59	0.000	0.000	0.000	0.000	0.000	0.000	0.007	0.007
7.01	0.000	0.000	0.000	0.000	0.000	0.000	0.003	0.003
8.72	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001
10.65	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
12.65	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Values in bold represent concentrations that exceed applicable groundwater criteria for chromium (0.05mg/L), copper (1.0mg/L), lead (0.05mg/L), and zinc (5.0mg/L) from WAC 173-200.
Modeled concentrations that were less than 10^{-4} mg/L were assigned a value of 0.0 in this table.
mg/L = milligrams per liter

Table 16. Groundwater concentrations for metals at increasing depths in silty clay based on output from VS2DT model runs.

GW Depth Feet	Chromium Max mg/L	Chromium @ 10 yrs mg/L	Copper Max mg/L	Copper @ 10 yrs mg/L	Lead Max mg/L	Lead @ 10 yrs mg/L	Zinc Max mg/L	Zinc @ 10 yrs mg/L
0.15	**0.147**	**0.126**	**1.54**	0.718	**1.11**	**0.812**	**11.63**	3.07
0.48	0.017	0.017	0.460	0.460	**0.224**	**0.224**	3.64	2.73
0.88	0.001	0.001	0.167	0.167	0.026	0.026	2.04	2.03
1.35	0.000	0.000	0.034	0.034	0.002	0.002	1.18	1.18
1.92	0.000	0.000	0.004	0.004	0.000	0.000	0.496	0.496
2.61	0.000	0.000	0.000	0.000	0.000	0.000	0.155	0.155
3.43	0.000	0.000	0.000	0.000	0.000	0.000	0.032	0.032
4.41	0.000	0.000	0.000	0.000	0.000	0.000	0.116	0.116
5.59	0.000	0.000	0.000	0.000	0.000	0.000	0.013	0.013
7.01	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.002
8.72	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
10.65	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
12.65	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Values in bold represent concentrations that exceed applicable groundwater criteria for chromium (0.05mg/L), copper (1.0mg/L), lead (0.05mg/L), and zinc (5.0mg/L) from WAC 173-200.
Modeled concentrations that were less than 10^{-4} mg/L were assigned a value of 0.0 in this table.
mg/L = milligrams per liter

Table 17. Groundwater concentrations for metals at increasing depths in clay based on output from VS2DT model runs.

GW Depth Feet	Chromium Max mg/L	Chromium @ 10 yrs mg/L	Copper Max mg/L	Copper @ 10 yrs mg/L	Lead Max mg/L	Lead @ 10 yrs mg/L	Zinc Max mg/L	Zinc @ 10 yrs mg/L
0.15	**0.130**	**0.117**	**1.36**	0.753	**0.980**	**0.785**	**10.64**	3.29
0.48	0.012	0.012	0.394	0.394	**0.162**	**0.162**	3.22	2.68
0.88	0.001	0.001	0.122	0.122	0.020	0.020	1.82	1.82
1.35	0.000	0.000	0.025	0.025	0.001	0.001	1.01	1.01
1.92	0.000	0.000	0.004	0.004	0.000	0.000	0.464	0.464
2.61	0.000	0.000	0.001	0.001	0.000	0.000	0.201	0.201
3.43	0.000	0.000	0.000	0.000	0.000	0.000	0.013	0.013
4.41	0.000	0.000	0.000	0.000	0.000	0.000	0.004	0.004
5.59	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001
7.01	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
8.72	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
10.65	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
12.65	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Values in bold represent concentrations that exceed applicable groundwater criteria for chromium (0.05mg/L), copper (1.0mg/L), lead (0.05mg/L), and zinc (5.0mg/L) from WAC 173-200.
Modeled concentrations that were less than 10^{-4} mg/L were assigned a value of 0.0 in this table.
mg/L = milligrams per liter

Table 18. Infiltration rates for soil types in spreadsheet model for the surface water impact evaluation.

Soil type	Infiltration Rate (inches/hour)	Source
Sand	2.0	Ecology (2005)
Loamy Sand	0.5	Ecology (2005)
Sandy Loam	0.25	Ecology (2005)
Loam	0.13	Ecology (2005)
Sandy Clay Loam	0.04	Dunne and Leopold (1978)

Table 19. Travel distance (feet) required for complete infiltration of bridge washing effluent based on output from spreadsheet model.

Slope (ft/ft)	Sand	Loamy Sand	Sandy Loam	Loam	Sandy Clay Loam
0.01	6.9	27.8	48.6	97.1	395
0.02	9.8	39.2	68.7	137	2211
0.03	12.0	48.1	84.1	168	3644
0.04	13.9	55.5	97.1	194	4744
0.05	15.5	62.1	109	214	NC
0.06	17.0	68.0	119	238	NC
0.07	18.4	73.4	129	257	NC
0.08	19.6	78.5	137	275	NC
0.09	20.8	83.3	146	291	NC
0.10	21.9	87.8	154	591	NC
0.11	23.0	92.0	161	620	NC
0.12	24.0	96.1	168	959	NC
0.13	25.0	100	175	1,322	NC
0.14	26.0	104	182	1,372	NC
0.15	26.9	108	188	1,420	NC
0.16	27.8	111	194	1,826	NC
0.17	28.6	114	200	1,883	NC
0.18	29.4	118	206	1,937	NC
0.19	30.2	121	212	2,382	NC
0.20	31.0	124	217	2,443	NC
0.21	31.8	127	223	2,504	NC
0.22	32.5	130	228	2,563	NC
0.23	33.3	133	233	2,671	NC
0.24	34.0	136	238	NC	NC
0.25	34.7	139	243	NC	NC
0.26	35.4	142	248	NC	NC
0.27	36.0	144	252	NC	NC
0.28	36.7	147	257	NC	NC
0.29	37.4	149	262	NC	NC
0.30	38.0	152	266	NC	NC
0.35	41.0	164	287	NC	NC
0.40	43.9	176	876	NC	NC
0.45	46.5	186	929	NC	NC
0.50	49.1	196	979	NC	NC
0.55	51.5	206	1,693	NC	NC
0.60	53.7	215	1,768	NC	NC
0.65	55.9	224	1,841	NC	NC
0.70	58.0	232	1,910	NC	NC
0.75	60.1	240	2,755	NC	NC
0.80	62.1	248	NC	NC	NC
0.85	64.0	256	NC	NC	NC
0.9	65.8	263	NC	NC	NC
0.95	67.6	271	NC	NC	NC
1.00	69.4	278	NC	NC	NC

NC= not calculated; model runs were stopped after travel distance was greater than 0.5 miles (2640 feet).

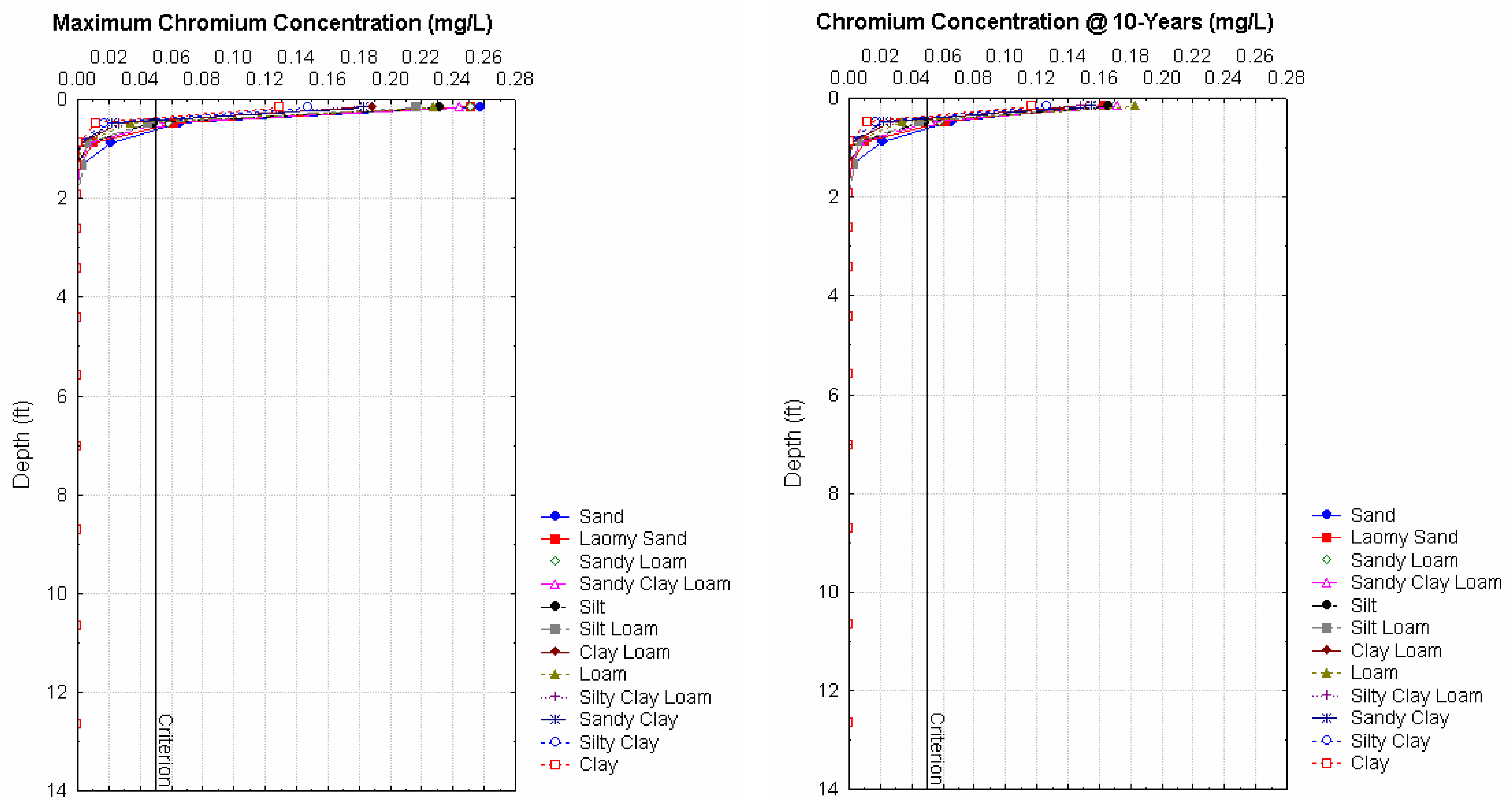


Figure 1. Groundwater concentrations for chromium at increasing depths based on output from VS2DT model runs.

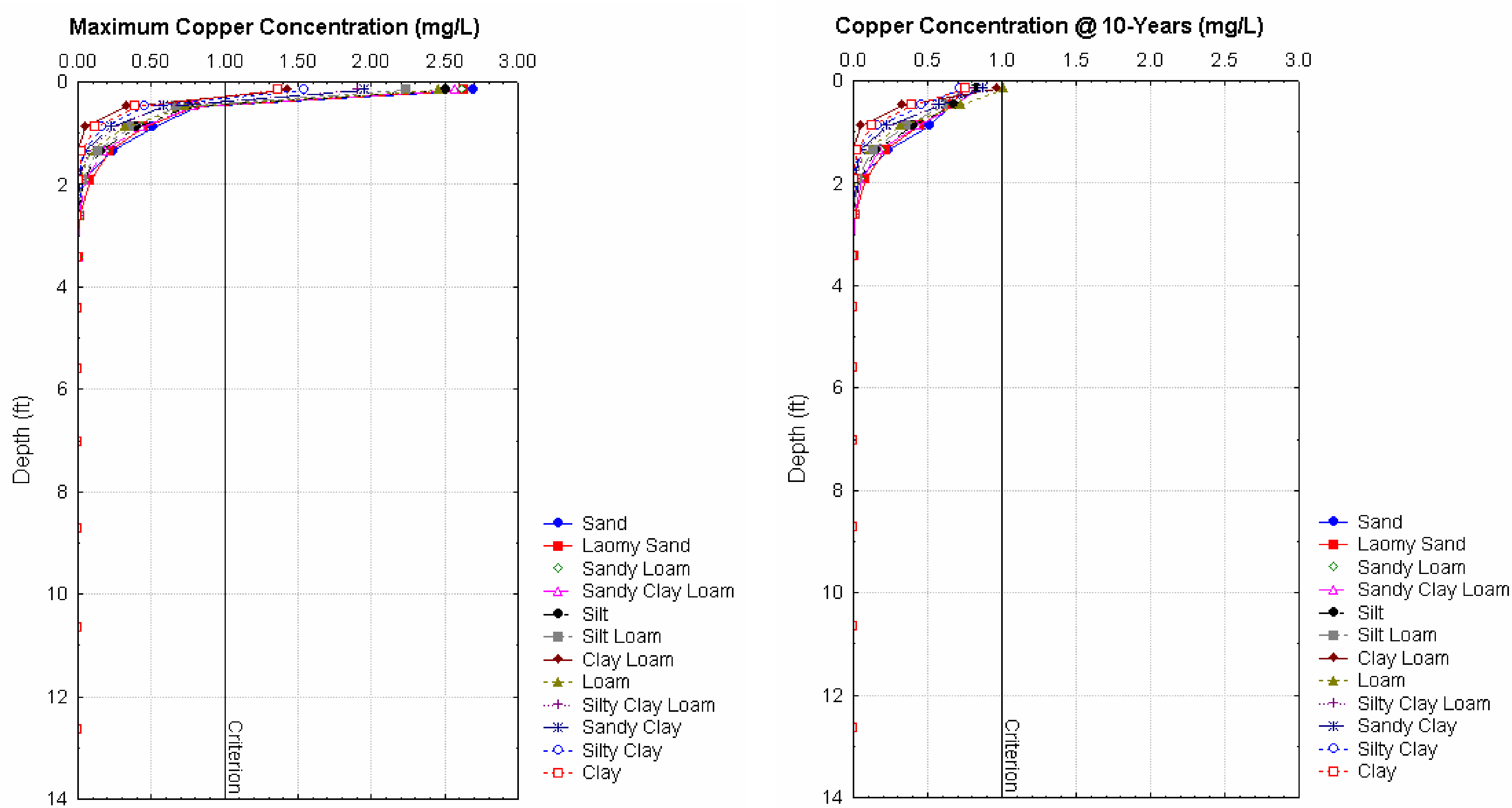


Figure 2. Groundwater concentrations for copper at increasing depths based on output from VS2DT model runs.

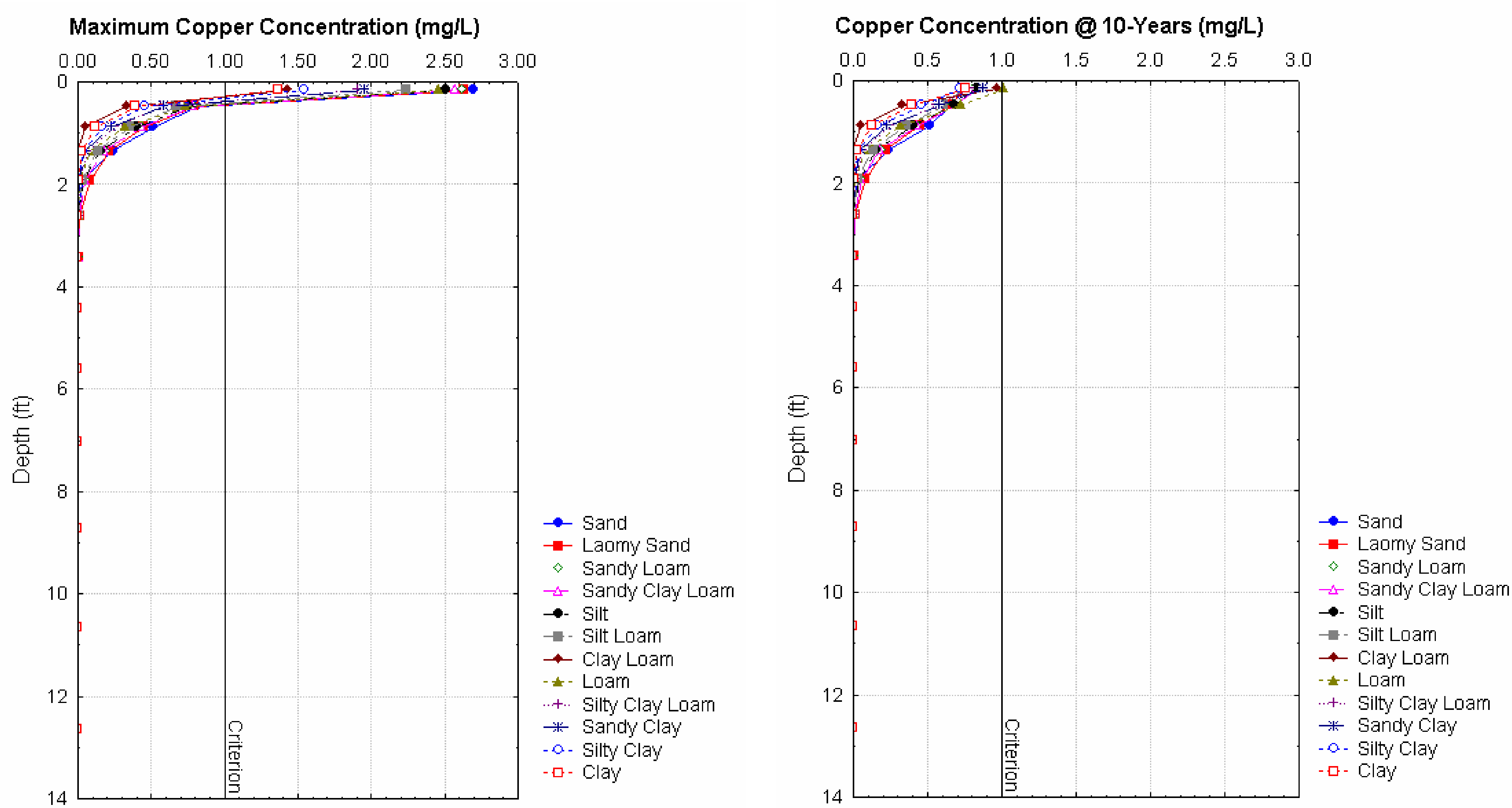
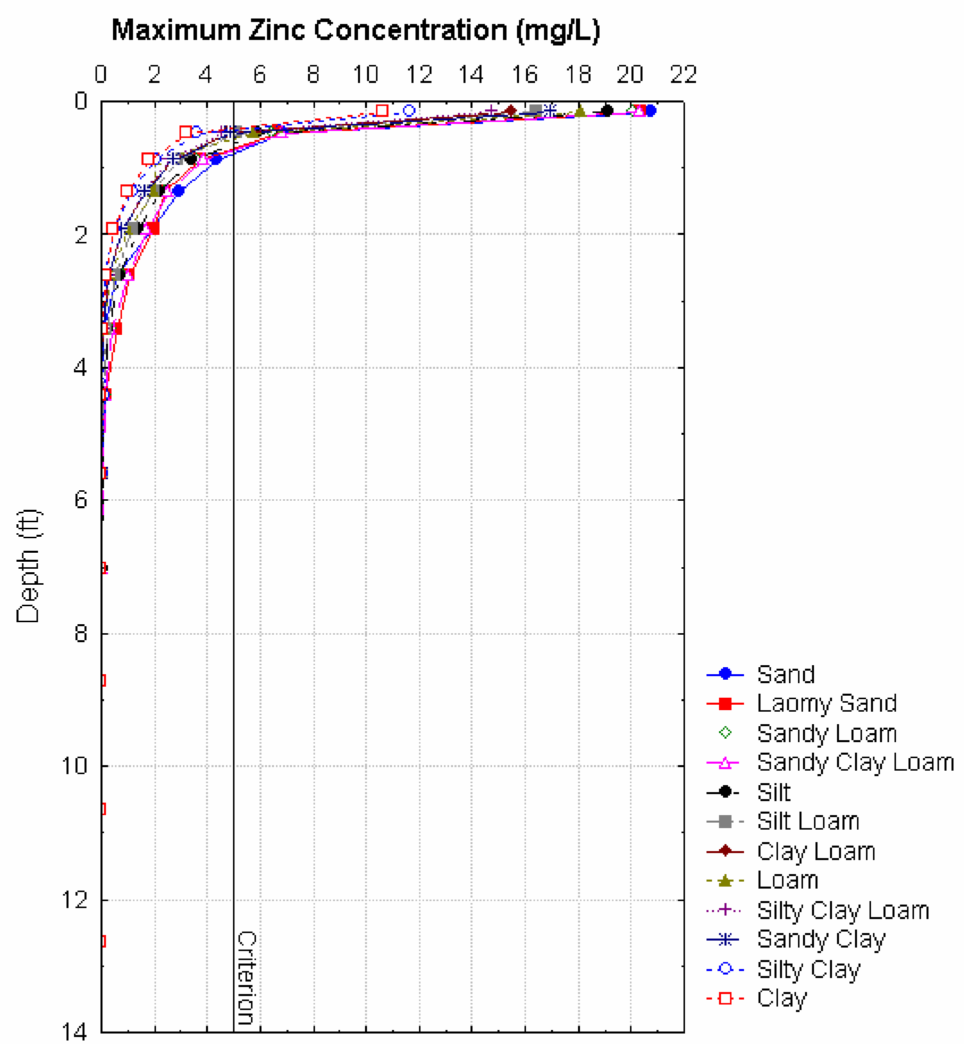


Figure 2. Groundwater concentrations for copper at increasing depths based on output from VS2DT model runs.



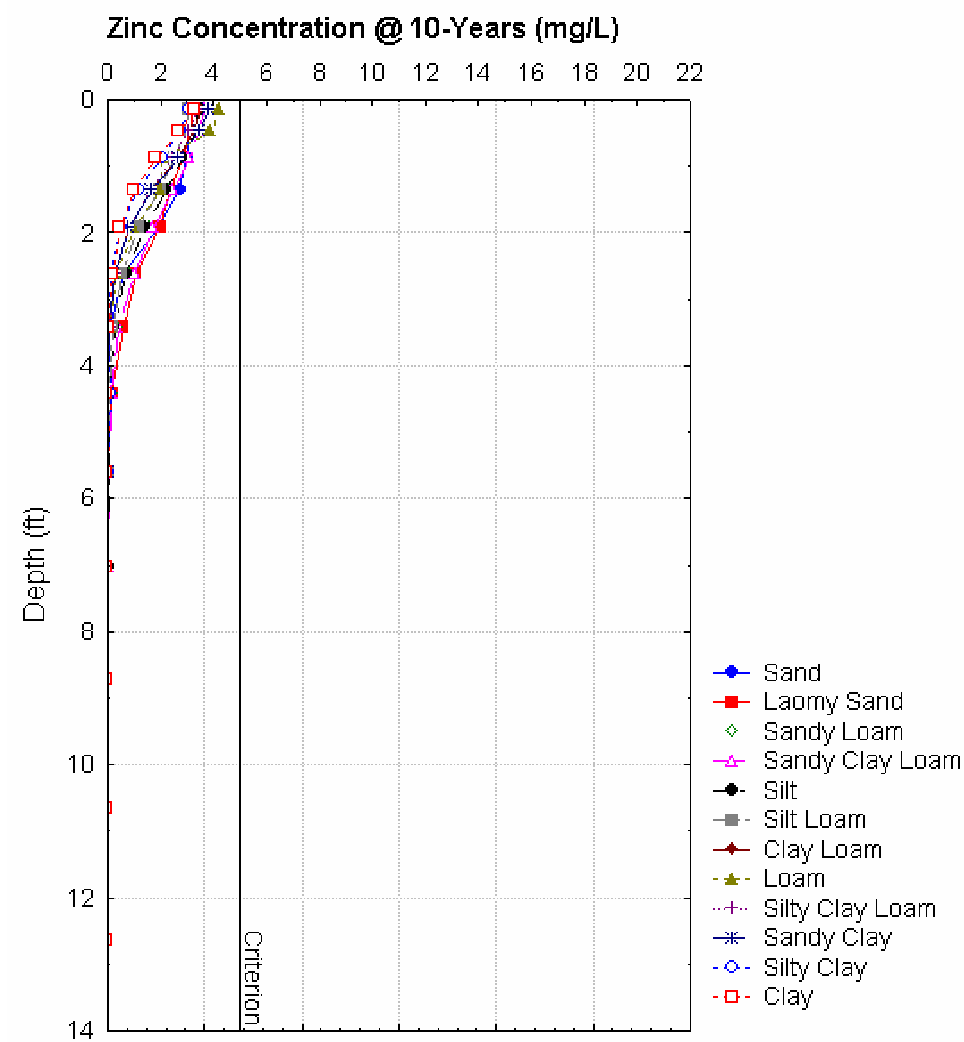


Figure 4. Groundwater concentrations for zinc at increasing depths based on output from VS2DT model runs.

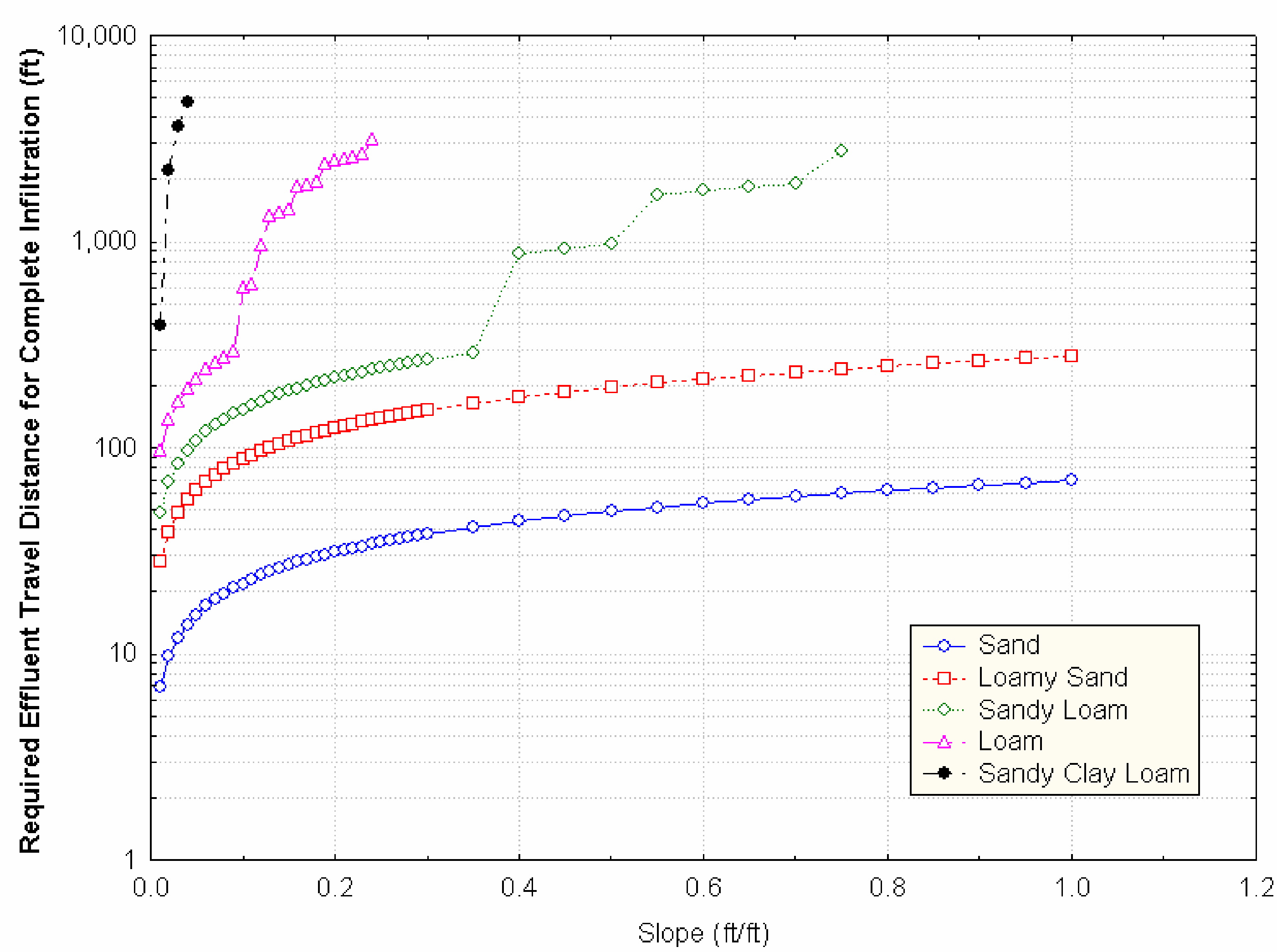


Figure 5. Travel distance required for complete infiltration of bridge washing effluent based on output from spreadsheet model.

APPENDIX A

Summary of VS2DT Model Inputs

Case Settings

Parameter	Value	Units
Transport Simulation	Linear Adsorption	(-)
Soil Hydraulic Function	van Genuchten	(-)
Initial Conditions: Water	Equilibrium Profile	(-)
Initial Conditions: Chemical	Uniform Concentration	(-)
Max. Simulation Time	3650	(days)
Evapotranspiration	No evapotranspiration	(-)

Solver Settings

Parameter	Value	Units
Flow Closure Criteria	0.00328	(ft)
Relaxation	0.900	(-)
Weighting Hydr. Cond.	0.5	(-)
Transport Closure Criteria	0.0001	(mg/l)
Min. Iterations	2	(-)
Max. Iterations	100,000	(-)
Space Differencing	Center-in-Space	(-)
Time Differencing	Center-in-Time	(-)
Maximum Number of Time Steps	5,000	(-)
Display Balance Every Time Step	yes	(-)

Observation Times

#	Time	Balance summary (-)
1	0.1	yes
2	1	yes
3	10	yes
4	20	yes
5	50	yes
6	75	yes
7	100	yes
8	200	yes
9	300	yes
10	365	yes
11	730	yes
12	1,095	yes
13	1,460	yes
14	1,825	yes
15	2,190	yes
16	2,555	yes
17	2,920	yes
18	3,285	yes
19	3,650	yes

Flow Upper Boundary

#	Start Time	End Time	Type	Value	Allowed Ponding (ft)
1	0	3650	Flux (in/year)	Varies[a]	0.03281

[a] Value varies depending on soil type in model run. See Table 5 in main text.

Flow Lower Boundary

#	Start Time	End Time	Type	Value
1	0	3650	Pressure Head (ft)	Varies [a]

[a] Value varies depending on depth to groundwater in model run; where value = 100 – Depth to groundwater.

Transport Upper Boundary

#	Start Time	End Time	Type	Value	Inflow Concentration (mg/l)
1	0	56.7	No Specified Boundary (-)	No Specified Boundary	Varies [a]
2	56.7	3650	No Specified Boundary (-)	No Specified Boundary	0.0

[a] Value varies depending on pollutant in model run. See Table 5 in main text.

Transport Lower Boundary

#	Start Time	End Time	Type	Value	Inflow Concentration (mg/l)
1	0	3650	No Specified Boundary (-)	No Specified Boundary	0.000000000000000

Profile Initial Conditions

Parameter	Value	Units
Groundwater Depth	Varies [a]	(ft)
Minimum Head for Equilibrium Profile	-3.28084	(ft)
Initial Concentration	0.000000000000000	(mg/l)

[a] Value varies depending on depth to groundwater in model run

Stress Period Defaults

Parameter	Value	Units
Initial Time Step	0.1000000	(days)
Time Step Multiplier	1.20	(-)
Maximum Time Step	10.0000000	(days)
Minimum Time Step	0.0100000	(days)
Reduction Factor	0.40	(-)
Maximum Head Change	3.28084	(ft)
Head Criterion	0.00328	(ft)

Profile Structure

Top (ft)	Bottom (ft)	Thickness (ft)
0.0000	-100.0000	100.0000

Soil Parameters

Parameter	Value	Units
Saturated Hydraulic Conductivity	Varies [a]	(cm/sec)
Specific Storage	0.000001	(1/cm)
Porosity	Varies [a]	(vol/vol)
Qr	0.15	(vol/vol)
Alpha' (van Genuchten)	-400	(cm)
Beta' (van Genuchten)	1.6	(-)

[a] Value varies depending on soil type in model run. See Table 1 in main text.

Transport Parameters

Parameter	Value	Units
Alpha L	100	(cm)
Dm (Molecular Diffusion)	0.1	(cm2/day)
Decay Constant	0.0	(/day)
Bulk density	1.4	(g/cu.cm)
Kd (linear adsorption)	Varies [a]	(L/kg)

[a] Value varies depending on soil type in model run. See Table 2 in main text.

APPENDIX B

Summary of Groundwater Criteria Exceedances over the 10-Year Simulation Period for VS2DT Model

Table B-1. Summary of exceedances of the applicable groundwater criteria for chromiuma based on output from VS2DT model runs.

Soil type	Depth to Groundwater (ft)	Duration and Timing of Exceedanceb	Maximum Concentration
sand	0.15	day 10 until end of simulation (day 3,650)	0.258 mg/L at day 56.7
sand	0.48	day 2,199 until end of simulation (day 3,650)	0.065 mg/L at day 3,650
loamy sand	0.15	day 10 until end of simulation (day 3,650)	0.251 mg/L at day 56.7
loamy sand	0.48	day 2,433 until end of simulation (day 3,650)	0.062 mg/L at day 3,650
sandy loam	0.15	day 20 until end of simulation (day 3,650)	0.251 mg/L at day 56.7
sandy loam	0.48	day 2785 until end of simulation (day 3,650)	0.058 mg/L at day 3,650
sandy clay loam	0.15	day 15 until end of simulation (day 3,650)	0.244 mg/L at day 56.7
sandy clay loam	0.48	day 3,280 until end of simulation (day 3,650)	0.053 mg/L at day 3,650
silt	0.15	day 15 until end of simulation (day 3,650)	0.231 mg/L at day 56.7
silt loam	0.15	day 15 until end of simulation (day 3,650)	0.217 mg/L at day 56.7
clay loam	0.15	day 25 until end of simulation (day 3,650)	0.189 mg/L at day 56.7
loam	0.15	day 25 until end of simulation (day 3,650)	0.228 mg/L at day 56.7
silty clay loam	0.15	day 10 until end of simulation (day 3,650)	0.182 mg/L at day 56.7
sandy clay	0.15	day 10 until end of simulation (day 3,650)	0.184 mg/L at day 56.7
silty clay	0.15	day 20 until end of simulation (day 3,650)	0.147 mg/L at day 56.7
clay	0.15	day 20 until end of simulation (day 3,650)	0.130 mg/L at day 56.7

[a] The gound water criterion for chromium is 0.05 mg/L (WAC 173-200-050).

[b] Modeling was performed to simulate the movement of chromium in the soil profile over a 10-year period (3650 days).

Table B-2. Summary of exceedances of the applicable groundwater criteria for copper[a] based on output from VS2DT model runs.

Soil type	Depth to Groundwater (ft)	Duration and Timing of Exceedance[b]	Maximum Concentration
sand	0.15	day 10 until day 2,199	2.70 mg/L at day 56.7
loamy sand	0.15	day 10 until day 2,180	2.63 mg/L at day 56.7
sandy loam	0.15	day 26 until day 2,450	2.62 mg/L at day 56.7
sandy clay loam	0.15	day 20 until day 2,550	2.57 mg/L at day 75
silt	0.15	day 25 until day 2,750	2.51 mg/L at day 56.7
silt loam	0.15	day 30 until day 1,875	2.24 mg/L at day 56.7
clay loam	0.15	day 25 until day 2,900	2.04 mg/L at day 56.7
loam	0.15	day 20 until end of simulation (day 3,650)	2.46 mg/L at day 56.7
silty clay loam	0.15	day 20 until day 2,200	1.91 mg/L at day 56.7
sandy clay	0.15	day 26 until day 2,425	1.96 mg/L at day 56.7
silty clay	0.15	day 35 until day 1,600	1.54 mg/L at day 56.7
clay	0.15	day 50 until day 1,800	1.36 mg/L at day 56.7

[a] The gound water criterion for copper is 1.0 mg/L (WAC 173-200-050).

[b] Modeling was performed to simulate the movement of copper in the soil profile over a 10-year period (3650 days).

Table B-3. Summary of exceedances of the applicable groundwater criteria for lead [a] based on output from VS2DT model runs.

Soil type	Depth to Groundwater (ft)	Duration and Timing of Exceedance [b]	Maximum Concentration
sand	0.15	day 10 until end of simulation (day 3,650)	1.95 mg/L at day 56.7
sand	0.48	day 140 until end of simulation (day 3,650)	0.578 mg/L at day 3,650
sand	0.88	day 1170 until end of simulation (day 3,650)	0.196 mg/L at day 3,650
loamy sand	0.15	day 10 until end of simulation (day 3,650)	1.90 mg/L at day 56.7
loamy sand	0.48	day 130 until end of simulation (day 3,650)	0.560 mg/L at day 3,650
loamy sand	0.88	day 1450 until end of simulation (day 3,650)	0.172 mg/L at day 3,650
sandy loam	0.15	day 10 until end of simulation (day 3,650)	1.89 mg/L at day 56.7
sandy loam	0.48	day 160 until end of simulation (day 3,650)	0.550 mg/L at day 3,650
sandy loam	0.88	day 1500 until end of simulation (day 3,650)	0.151 mg/L at day 3,650
sandy clay loam	0.15	day 10 until end of simulation (day 3,650)	1.84 mg/L at day 56.7
sandy clay loam	0.48	day 170 until end of simulation (day 3,650)	0.527 mg/L at day 3,650
sandy clay loam	0.88	day 1650 until end of simulation (day 3,650)	0.135 mg/L at day 3,650
silt	0.15	day 15 until end of simulation (day 3,650)	1.75 mg/L at day 56.7
silt	0.48	day 200 until end of simulation (day 3,650)	0.486 mg/L at day 3,650
silt loam	0.15	day 15 until end of simulation (day 3,650)	1.63 mg/L at day 56.7
silt loam	0.48	day 200 until end of simulation (day 3,650)	0.454 mg/L at day 3,650
silt loam	0.88	day 2000 until end of simulation (day 3,650)	0.105 mg/L at day 3,650
clay loam	0.15	day 15 until end of simulation (day 3,650)	1.43 mg/L at day 56.7
clay loam	0.48	day 365 until end of simulation (day 3,650)	0.331 mg/L at day 56.7
loamy sand	0.15	day 15 until end of simulation (day 3,650)	1.72 mg/L at day 56.7
loamy sand	0.48	day 308 until end of simulation (day 3,650)	0.400 mg/L at day 3,650
loamy sand	0.88	day 3285 until end of simulation (day 3,650)	0.059 mg/L at day 3,650
silty clay loam	0.15	day 26 until end of simulation (day 3,650)	1.37 mg/L at day 56.7
silty clay loam	0.48	day 380 until end of simulation (day 3,650)	0.321 mg/L at day 3,650
sandy clay	0.15	day 25 until end of simulation (day 3,650)	1.39 mg/L at day 56.7
sandy clay	0.48	day 485 until end of simulation (day 3,650)	0.295 mg/L at day 3,650
silty clay	0.15	day 5 until end of simulation (day 3,650)	1.11 mg/L at day 56.7
clay	0.15	day 5 until end of simulation (day 3,650)	0.980 mg/L at day 56.7

[a] The gound water criterion for lead is 0.05 mg/L (WAC 173-200-050).

[b] Modeling was performed to simulate the movement of lead in the soil profile over a 10-year period (3,650 days).

Table B-4. Summary of exceedances of the applicable groundwater criteria for zinc [a] based on output from VS2DT model runs.

Soil type	Depth to Groundwater (ft)	Duration and Timing of Exceedance [b]	Maximum Concentration
sand	0.15	day 18 until day 1,475	20.77 mg/L at day 56.7
sand	0.48	day 145 until day 1,275	6.83 mg/L at day 365
loamy sand	0.15	day 10 until day 1,590	20.33 mg/L at day 56.7
loamy sand	0.48	day 155 until day 1,250	6.65 mg/L at day 365
sandy loam	0.15	day 20 until day 1,640	20.07 mg/L at day 56.7
sandy loam	0.48	day 180 until day 1,300	6.43 mg/L at day 365
sandy clay loam	0.15	day 20 until day 1,966	20.37 mg/L at day 75
sandy clay loam	0.48	day 170 until day 1,580	6.87 mg/L at day 365
silt	0.15	day 10 until day 1,750	19.13 mg/L at day 56.7
silt	0.48	day 235 until day 1,290	5.92 mg/L at day 365
silt loam	0.15	day 20 until day 1,386	16.41 mg/L at day 56.7
silt loam	0.48	day 700 until day 756	5.07 mg/L at day 730
clay loam	0.15	day 25 until day 1,740	15.50 mg/L at day 56.7
loam	0.15	day 18 until day 2,550	18.14 mg/L at day 56.7
loam	0.48	day 460 until day 1,820	5.75 mg/L at day 730
silty clay loam	0.15	day 18 until day 1,590	14.77 mg/L at day 56.7
sandy clay	0.15	day 5 until day 2,085	15.96 mg/L at day 56.7
silty clay loam	0.15	day 34 until day 1,350	11.64 mg/L at day 56.7
clay	0.15	day 25 until day 1,450	10.64 mg/L at day 56.7

[a] The gound water criterion for zinc is 5.0 mg/L (WAC 173-200-050).

[b] Modeling was performed to simulate the movement of zinc in the soil profile over a 10-year period (3,650 days).

APPENDIX C

Sample Output from the Spreadsheet Model Used in Surface Water Impact Evaluation

Manning's kinematic solution for Sheet Flow up to 300 feet

$$Tt = \frac{0.42(n_s L)^{0.8}}{(P_2)^{0.527}(So)^{0.4}}$$

Tt= Travel Time (minutes)
ns= Sheet flow Modified Manning's effective roughness coef
L= Flow length (ft)
P_2= 2-year, 24-hour rainfall (in)
So= Slope of hydraulic grade line (land slope, ft/ft)

Tt= 1.0
ns= 0.06
L= 34.69
P_2= 1.68
So= 0.25

Shallow concentrated flow (after first 300 ft)

$V = 16.1345 * S^{(0.5)}$

V=	8.06725	ft/s
	484.0	ft/min

Bridge washing inflow

flow	18	gal/min
across	1000	sf
loading	0.0289	in/min

Infiltration Rate	
0.50	inch/hour
0.0083	inch/min

Soil group	**in/hr**
Sand	2.00
Loamy Sand	0.50
Sandy Loam	0.25
Loam	0.13
Sandy Clay Loam	0.04

T (min)	Inflow (in)	Infiltrated (in)	Depth (in)	Distance (ft)
0	0.0289	0.0000	0.0289	0.0
1	0	0.0083	0.0205	34.7
2	0	0.0083	0.0122	69.4
3	0	0.0083	0.0039	104.1
4	0	0.0083	0.0045	138.8
5	0	0.0083	0.0128	173.4
6	0	0.0083	0.0211	208.1
7	0	0.0083	0.0295	242.8
8	0	0.0083	0.0378	277.5
9	0	0.0083	0.0461	761.5
10	0	0.0083	0.0545	1,245.6
11	0	0.0083	0.0628	1,729.6
12	0	0.0083	0.0711	2,213.6
13	0	0.0083	0.0795	2,697.7
14	0	0.0083	0.0878	3,181.7
15	0	0.0083	0.0961	3,665.7
16	0	0.0083	0.1045	4,149.8
17	0	0.0083	0.1128	4,633.8
18	0	0.0083	0.1211	5,117.9
19	0	0.0083	0.1295	5,601.9
20	0	0.0083	0.1378	6,085.9
21	0	0.0083	0.1461	6,570.0
22	0	0.0083	0.1545	7,054.0
23	0	0.0083	0.1628	7,538.0
24	0	0.0083	0.1711	8,022.1