Application of State and Federal Guidelines for Establishing Alternate Soil Clean-Up Levels for the Protection of Groundwater at the Hanford Site-8390

Kevin Leary (U.S. Dept. of Energy-Richland, WA), William McMahon (CH2MHill, Hanford Group), and James Hoover (Fluor Hanford, Inc.)

ABSTRACT
Risk-based soil cleanup levels that are protective of groundwater have been calculated for use in environmental remediation activities at the Hanford Site using vadose zone fate and transport modeling. The determination of soil cleanup levels is important because it involves the technical basis for the levels of contamination that can be left in place, which are protective of human health and the environment. The determination of risk-based soil cleanup levels is an especially important issue at the Hanford Site where site conditions such as a semi-arid climate, and a thick vadose zone of over 100 meters necessitate the use of appropriate risk-based methods. In the absence of an alternative risk-based approach, the cleanup levels default to background, detection limits, or simplistic formulas not intended for applications involving these distinctive site conditions. However, the use of vadose zone fate and transport modeling for risk-based applications such as the determination of soil cleanup levels in the vadose zone are not as well established as modeling for groundwater applications. Thus, the use of models in this manner involves additional challenges for the demonstration of the efficacy of its use for risk-based applications, in accordance with federal and state regulatory requirements and guidelines.

An approach has been developed to integrate with federal and state regulatory guidelines in conjunction with the development of the risk-based methodology. Demonstration of integration with these guidelines primarily involves documentation of the objectives of the problem to be solved, the technical basis and rationale associated with the selection of an appropriate risk-based method (e.g., model type and code selection), and documentation associated with the use of the model, e.g., conceptual site model, parameter estimation, uncertainty and assumptions analyses, and model results.

INTRODUCTION
The cleanup levels for soils in the vadose zone of the Hanford Site that are protective of groundwater affect environmental remediation efforts because they serve as the primary basis for the protectiveness of contamination that can be left in place. However, the soil cleanup levels for vadose zone contamination presently used, are not generally risk-based, but rather are prescribed default values based on background, detection limits, lookup tables, or formulas not intended for site-specific conditions. Although these prescribed values are protective, they are unnecessarily stringent and obviate the rationale for the development of federal risk assessment guidelines and risk-based cleanup levels. The cost, scope, and schedules for environmental remediation efforts at the Hanford Site are, therefore, adversely affected by the lack of more appropriate risk-based cleanup levels. Appropriate alternatives to the use of prescriptive default values that are compliant with federal and state regulations and guidelines are, therefore, needed. A methodology for the development of alternative risk-based soil cleanup levels that are protective of groundwater has been developed using vadose zone fate and transport modeling.

Background
The levels of soil contamination in the vadose zone that are protective of groundwater tend to dominate the establishment of soil cleanup levels at the Hanford Site because these contaminant levels generally yield lowest values of all the relevant pathways. These “protection of groundwater” pathway values are also the only pathway of concern for contaminants deeper than 15-ft below ground surface (bgs) because direct human contact pathways and ecological risk are not cleanup level drivers for soil contaminants below 15-ft bgs. The problem with the use of the prescriptive default values in establishing soil cleanup levels for this pathway is that they are unduly stringent because they were intended for site conditions

elsewhere in the State of Washington, and fail to appropriately represent groundwater impacts associated with the distinctively different conditions at the Hanford Site. These Site conditions are fundamentally important to the risk-based assessment of groundwater impacts from vadose zone contamination because contaminant behavior and the risk they pose to groundwater are greatly affected by the thick sequence of vadose zone sediments that extend to thicknesses of over 100 meters, and also by the semi-arid region climatic conditions with an average annual precipitation on the Hanford site of 6.98 inches/year.

The selection of appropriate alternatives for risk assessment applications for the protection of groundwater pathway fundamentally stem from the principal requirements for compliance with the National Contingency Plan (NCP) [1] in the context of the Federal CERCLA and RCRA regulations [2,3]. The common objective of these regulations and associated State regulations is protection of human health and the environment. Risk assessment processes serve as the primary paradigm and technical basis for determining and demonstrating protectiveness, and are mandated for use by these federal regulations for these purposes.

Federal risk assessment guidelines indicate that the methods and tools used in risk-based applications must be appropriate for addressing the problem to be solved (e.g., assessment of risk, determination of cleanup levels), and must also be capable of the incorporating site-specific conditions and data in the assessments (e.g., [4]). Environmental regulatory models (ERMs) are among the methods and tools recognized in federal and state regulations and guidelines as appropriate for use in risk-based applications to demonstrate compliance and attainment of risk assessment objectives, and are commonly used, or required, for media-specific conditions such as the groundwater and the vadose zone.

Importance and Rationale for Site-Specific Conditions/Input Parameters for Modeling

The U-Plant Zone closure is the very first zone closure on Hanford's Central Plateau. As such, many of the decision made in this first ROD will set the stage for the remaining zone closures and, therefore, is considered precedent setting. Therefore, it is critical that soil clean-up values be established based upon risk and not the default values that are near background or laboratory detection limits.

Because environmental conditions are so dichotomous in WA State, let alone the physical and chemical environmental heterogeneity on the Hanford site, it is imperative that a detailed site characterization be completed for each specific area being modeled. Systematically gathering sufficient, representative model input data is one of the more important steps in completing a fate and transport model and resultant risk assessment. In addition to adequately characterizing the site, other factors such as short and long-term land-use, IC's, and Intruder Analysis are extremely important in determining alternate RAGs as they are key factors in completing a risk assessment.

The following is a brief overview of the 200-UW-1 CERCLA Operable Unit (OU) where alternate soil remedial action goals (RAGs) are being developed as well as a brief description of site-specific characteristics that are conducive to applying alternate fate and transport modeling used for establishing these alternate soil RAGs for groundwater protection.

200-UW-1 Operable Unit

The Hanford Site is a 1517 km^2 (586-mi^2) Federal facility located in southeastern Washington State along the Columbia River. From 1943 to 1990, the primary mission of the Hanford Site was the production of nuclear materials for national defense. In July 1989, the 100, 200, 300, and 1100 Areas of the Hanford Site were placed on the National Priorities List (NPL) [1] pursuant to CERCLA.

The Central Plateau is located in the central portion of the Hanford Site and is divided into three areas: 200 East Area, 200 West Area, and 200 North Area. Operations in the 200 East and 200 West Areas were related to chemical separation, plutonium and uranium recovery, processing of fission products, and waste partitioning. Major chemical processes in the Central Plateau resulted in delivery of high-activity waste streams to systems of large underground tanks called "tank farms." The liquid wastes often were neutralized before being sent to the tanks and later evaporated (concentrated). The storage tanks were used to allow the heavier constituents to settle from the liquid effluents, forming sludge. Low-activity liquid wastes were discharged to trenches, cribs, drains, and ponds, most of which were unlined. The U Plant Zone Closure Area, located on the Central Plateau of the Hanford Site, contains numerous contaminated waste sites, structures, and facilities that pose a potential risk to human health and the environment. To reduce these risks, the waste sites and facilities will be cleaned up (i.e., remedial actions will be implemented). The U Plant Area has been divided into five distinct components. The following five components make up the U Plant Area:

- 221-U Facility (to be addressed by the Canyon Disposition Initiative [CDI])
- Facilities that are ancillary or related to the 221-U Facility
- Underground pipelines
- Soil waste sites (such as the 200-UW-1 Operable Unit [OU])
- Groundwater underlying the area (200-UP-1 OU).

The 200-UW-1 Operable Unit (OU)/U Plant Area is approximately 0.84 km^2 (0.32 mi^2) and consists of the 221-U Facility, facilities that are ancillary or related to the facility, underground pipelines, soil waste sites, and the groundwater underlying the area. The 200-UW-1 OU addresses 33 soil waste sites located within the U Plant Area. These sites primarily are liquid-waste disposal sites with a few solid waste sites.

Climate—Dichotomy of WA State

The Hanford Site lies east of the Cascade Mountains and has a semiarid climate caused by the rain-shadow effect of the mountains. Most precipitation occurs during late autumn and winter, with more than half of the annual amount occurring from November through February [6]. Normal average annual precipitation is 17.7 cm (6.98 in.). Because it typically receives less than 25.5 cm (10 in.) of precipitation a year, the climate is considered to be semiarid [6]. This is in contrast to Olympia ,WA which is located on the west side of the Cascade Mountains, which has an average annual precipitation of 50.59 inches/year

Groundwater Recharge

Recharge to the unconfined aquifer in the 200 West Area is primarily from past artificial sources with small contributions from natural sources. Any natural recharge originates from precipitation. Estimates of recharge from precipitation at the Hanford Site range from 0 to 10 cm/yr (0 to 4 in/yr) and largely depend on soil texture and the type and density of vegetation. For areas where the ground cover is assumed to remain undisturbed, a recharge rate of 3.5 mm/yr was assumed, which is within the range of values reported for shrub-steppe ground cover [7]. For the disturbed areas above the waste sites (i.e. stabilization cover), a recharge rate of 14.4 mm/yr has been assumed. Artificial recharge occurred when effluents such as cooling water and process waste water were disposed to the ground.

Geology

The following discussion of geology uses terminology from *Standardized Stratigraphic Nomenclature for Post-Ringold Formation Sediments Within the Central Pasco Basin;*[8]. Basalt of the Columbia River Basalt Group and a sequence of suprabasalt sediments underlie the 200 West Area. From oldest to youngest, major geologic units of interest are the Elephant Mountain Basalt Member, the Ringold Formation, the Cold Creek unit (CCU), the Hanford formation, and the Holocene deposits. The basalt is overlain by the Ringold Formation in the 200 West Area. The fluvial-lacustrine Ringold Formation is informally divided into several units.

Soils/Vadose Zone

In the 200 West Area, the vadose zone thickness ranges from 79 m (261 ft) in the southeast corner to 102 m (337 ft) in the northwest corner. Sediments in the vadose zone are the Ringold Formation (the uppermost Ringold unit E and the Upper Ringold), the CCU, and the Hanford formation. Erosion during cataclysmic flooding removed some of the Ringold Formation and CCU. Perched water historically has been documented above the CCU at locations in the 200 West Area. Because most artificial discharge to the surface was ceased in the late 1980s, perched water is infrequently encountered in the vadose zone. Although process information suggests that several mobile constituents may have been released to the crib, groundwater monitoring indicates that nitrate and Tc-99 are the only significant contaminants of concern that have been detected. Nitrate and Tc-99 are mobile in both the vadose zone and groundwater. The vadose zone is a continuing source of these constituents to the groundwater. Both nitrate and Tc-99 concentrations are declining as residual drainage from the vadose zone beneath the crib decreases. While the liquid waste disposal facilities were operating, many localized areas of saturation or near saturation were created in the soil column. With the cessation of artificial recharge in the 200 Areas, these locally saturated soil columns are dewatering. As the soil column dewaters, the moisture flux decreases. However, residual moisture in the vadose zone may remain for some time. In the absence of artificial recharge, the potential for recharge from precipitation becomes a primary driving force for contaminant movement in the vadose zone.

Hydrogeology

The groundwater underlying the U Plant Area is located approximately 255 ft below ground surface. The groundwater currently has elevated levels of nitrates, technetium-99, uranium, and carbon tetrachloride. The 200-UW-1 OU high-risk waste sites are suspected to have contributed to the already contaminated groundwater by supplying additional concentrations of uranium, technetium-99, and nitrates. Monitoring and treatment of the groundwater currently are ongoing within the 200-UP-1 groundwater OU. However, concentrations still exceed maximum contaminant levels. The unconfined aquifer in the Central Plateau occurs in the Hanford formation, the CCU, and the Ringold Formation. In general, groundwater flow through the Central Plateau occurs in a predominantly easterly direction, from the 200 West Area to the 200 East Area and discharges into the Columbia River.

Groundwater in the 200 West Area occurs primarily in the Ringold Formation. The depth to the water table varies from about 50 m (164 ft) in the southwest corner near the 216-U-10 Pond to greater than 100 m (328 ft) in the north. Beneath the 216-U-8 and 216-U-12 Cribs, depth to water measures approximately 78 m (255 ft), and groundwater flow is to the southeast. The water table beneath the 200 West Area is declining at a rate of approximately 0.36 m/yr (1.2 ft/yr).

Step wise release and attenuation of contaminants versus a simple, single partitioning event

Geochemical behavior of contaminants in the Hanford Site vadose zone can be described in terms of the primary geochemical processes affecting contaminant transport, including adsorption/desorption (ion exchange) and precipitation dissolution [9]. Adsorption/desorption typically controls contaminant retardation in areas where low concentrations of dissolved radionuclides exist, such as those associated with the far field environments of disposal facilities or spill sites. Precipitation/dissolution is typically an important process where elevated concentrations of dissolved radionuclides occur, such as in the near field environment of waste site facilities [9].

Unsaturated flow

Both the Ringold and the Hanford formations often contain relatively thin, fine grained stringers that contribute to the lateral spreading of moisture and slow down the vertical movement of contaminants within the vadose zone. Paleosols and some facies changes (i.e., the contact between fine grained and coarser grained facies) have been observed to be fairly continuous over the range of at least 100 m (328 ft) and have been found to promote lateral spreading of crib effluent on the same scale [10]. Thus, two of the most important FEPs required for meaningful simulation of vadose zone processes at the Hanford Site are (1) the uncommonly thick sequence of vadose zone sediments with associated hydrologic properties, and (2) the infiltration/recharge rates imposed by the semi arid climatic conditions in this region. The following is an excerpt provided in the Federal guidelines [5] regarding the importance of including vadose zone FEPs:

"If the risk assessment is based on arrival times and peak concentrations of contaminants (and radionuclides) arriving in groundwater, then consideration of transport through even a thin unsaturated zone is significant."

IMPLEMENTATION OF REGULATORY FRAMEWORK: 200-UW-1 EXAMPLE

The following example provides a demonstration of compliance with the risk assessment regulations in the context of establishing cleanup goals for a particular set of waste sites at the Hanford Site. The 200-UW-1 Operable Unit (OU), located in the 200 West Area of the Hanford Site, is currently undergoing final remedy decision making under the *Comprehensive Environmental Response, Compensation, and Liability Act of 1980* (CERCLA) [2]. The Record of Decision (ROD) for the 200-UW-1 OU will contain final cleanup levels or remedial action goals (RAGs) for the selected remedies. The proposed remedy for 15 of the waste sites is a removal, treatment, and disposal (RTD) remedial action. In accordance with the CERCLA remedial investigation/feasibility study process, proposed remedies must be protective of human health and the environment and comply with applicable or relevant and appropriate requirements (ARARs). The groundwater protection pathway dominates the establishment of the soil cleanup levels because those levels are generally the lowest values of all exposure pathways (typically defaulting to background levels or detection limits).

The objectives and regulatory purpose of the risk assessment is thus to establish cleanup standards for the 200-UW-1 RTD sites. Previous sections of this paper presented the general rationale for the selection of fate and transport modeling for risk assessments and to establish cleanup standards at Hanford, along with the rationale for the level of model sophistication, and that rationale applies to the 200-UW-1 RTD sites. The documentation of that rationale complies with and satisfies the requirement to define, justify, and document rationale for the need and use of the model.

The STOMP computer code has been selected to conduct vadose zone flow and contaminant transport modeling at the Hanford Site based on the evaluation of the capabilities of this code to meet the necessary model attributes. This evaluation was based on model criteria and attribute requirements identified in ("mandatory technical criteria" and "mandatory administrative criteria") [11] because the evaluation was developed specifically for vadose zone fate and transport modeling at the Hanford Site Central Plateau. The STOMP code is capable of one, two, and three dimensional, multi-phase simulations with essentially unlimited heterogeneous and anisotropic hydrogeologic layers. The grid scheme allows for almost any scale of problem, including some grid refinement techniques to evaluate some preferential flow pathways. The code can accommodate temporal variations in input parameters, and can provide output for both the near and long term. The code can also account for radiological, biological, and inorganic decay.

Conference paper number 8389 [12] provides thorough documentation of the vadose zone conceptual model components, including those associated with the geologic setting, contaminant source term, the groundwater domain and characteristics, hydrogeology and transport, recharge, and geochemistry. The document also provides the technical basis for many of the simplifying assumptions incorporated into the model, such as the use of averaged hydrogeologic parameters for the vadose zone geologic units, the use of linear contaminant partitioning models, and the use of time-averaged recharge rates as a surface boundary condition. Conference paper number 8389 provides the technical basis for many of site-specific parameter estimates used in the model, and also provides the uncertainty and sensitivity analysis, which gauges the extent to which the model results are useful or sufficient for assessing the risk at the site in order to make remedial action decisions.

Key findings/Results

The key findings and results of the risk assessment modeling were that cleanup levels could be 40-200 times higher than the default levels without compromising the risk to human health and environment. These cleanup levels still incorporate substantial conservatism; over 70 percent of the 40 assumptions identified in the model, as well as several of the parameter estimates contained some conservative bias. Finally, the sensitivity analysis identified contaminant inventory, contaminant mobility, and recharge as the factors with the greatest impact on the model results. Providing a technical basis for submission of alternate soil clean-up values for protection of the underlying groundwater is paramount. Risk-based application for the protection of groundwater provides a technically sound approach for developing clean-up values that are protective of Human Health and the Environment.

SUMMARY AND CONCLUSIONS

The determination of risk-based soil cleanup levels that are protective of groundwater is an important issue for environmental remediation at the Hanford Site because it involves the technical basis for the levels of contamination that can be left in place, which are protective of human health and the environment. In the absence of a site-specific risk-based approach, the cleanup levels default to unduly stringent background, detection limits, or simplistic formulas not intended for applications involving the distinctive physical setting and site conditions at the Hanford Site. These site conditions are fundamentally important to the risk-based assessment of groundwater impacts from vadose zone contamination because contaminant behavior and the risk they pose to groundwater are greatly affected by the thick sequence of vadose zone sediments that extend to over 100 meters, and by the semi-arid region climatic conditions. However, the use of vadose zone fate and transport modeling the derivation of soil cleanup levels involves additional challenges for the demonstration of compliance with federal and state regulatory requirements and guidelines.

An approach has been developed for the demonstration of federal and state regulations and guidelines pertaining to the use of modeling in risk-based applications for the protection of groundwater pathway. The development of this framework identifies the commonalities between federal guidelines and state expectations. Demonstration of consistency with these expectations primarily involves documentation of the objectives of the need for modeling, the technical basis and rationale associated with the selection of an appropriate risk-based method (e.g., model type and code selection), and documentation associated with the use of the model, e.g., conceptual site model, parameter estimation, uncertainty and assumptions analyses, and model results. This framework has been developed in conjunction with a model-based methodology for the derivation of soil cleanup levels for the protection of groundwater (vadose zone) pathway. The use of modeling in this type of risk-based application also has implications for the use of this methodology to improve the technical and cost basis for remedy decisions and characterization, in addition to cleanup applications.

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