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Application of TREECS Modeling System to Strontium-90 for Borschi Watershed near Chernobyl, Ukraine

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ABSTRACT

The Training Range Environmental Evaluation and Characterization System (TREECS™) (http://el.erdc.usace.army.mil/treecs/) is being developed by the U.S. Army Engineer Research and Development Center (ERDC) for the U.S. Army to forecast the fate of munitions constituents (MC) (such as high explosives (HE) and metals) found on firing/training ranges, as well as those subsequently transported to surface water and groundwater. The overall purpose of TREECS™ is to provide environmental specialists with tools to assess the potential for MC migration into surface water and groundwater systems and to assess range management strategies to ensure protection of human health and the environment. The multimedia fate/transport models within TREECS™ are mathematical models of reduced form (e.g., reduced dimensionality) that allow rapid application with less input data requirements compared with more complicated models. Although TREECS™ was developed for the fate of MC from military ranges, it has general applicability to many other situations requiring prediction of contaminant (including radionuclide) fate in multi-media environmental systems.

TREECS™ was applied to the Borschi watershed near the Chernobyl Nuclear Power Plant, Ukraine. At this site, TREECS™ demonstrated its use as a modeling tool to predict the fate of strontium 90 (^{90}Sr). The most sensitive and uncertain input for this application was the soil-water partitioning distribution coefficient (K_d) for ^{90}Sr. The TREECS™ soil model provided reasonable estimates of the surface water export flux of ^{90}Sr from the Borschi watershed when using a K_d for ^{90}Sr of 200 L/kg. The computed export for the year 2000 was 0.18% of the watershed inventory of ^{90}Sr compared to the estimated export flux of 0.14% based on field data collected during 1999–2001. The model indicated that assumptions regarding the form of the inventory, whether dissolved or in solid phase form, did not appreciably affect export rates. Also, the percentage of non-exchangeable adsorbed ^{90}Sr, which is uncertain and affects the amount of ^{90}Sr available for export, was fixed at 20% based on field data measurements. A Monte Carlo uncertainty analysis was conducted treating K_d as an uncertain input variable with a range of 100–300 L/kg. This analysis resulted in a range of 0.13–0.27% of inventory exported to surface water compared to 0.14% based on measured field data.

Based on this model application, it was concluded that the export of ^{90}Sr from the Borschi watershed to surface water is predominantly a result of soil pore water containing dissolved ^{90}Sr being diverted to surface waters that eventually flow out of the watershed. The percentage of non-exchangeable adsorbed ^{90}Sr and the soil-water K_d are the two most sensitive and uncertain factors affecting the amount of export. The 200-year projections of the model showed an exponential decline in ^{90}Sr export fluxes from the watershed that should drop by a factor of 10 by the year 2100.

This presentation will focus on TREECS capabilities and the case study done for the Borschi Watershed.

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1. Introduction

The Training Range Environmental Evaluation and Characterization System (TREECS™) (http://el.erdc.usace.army.mil/TREECS™/) was developed for the Army to predict the fate of munitions constituents (MC), such as high explosives (HE) and metals, released to

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soil and transported from firing/training ranges to surface water and groundwater. The overall objective is to provide environmental specialists with tools to assess the potential for migration of MC into surface water and groundwater systems. The results of these assessments can be used to assess range management strategies to protect human health and the environment from MC exposure in receiving waters. TREECS™ was developed with two levels of capability. Tier 1 consists of screening-level methods that assume highly conservative, steady-state MC loading and fate. Tier 1 requires minimal input data requirements and can be easily and quickly applied by environmental staff to assess the potential for migration into surface water and groundwater. If surface water and/or groundwater MC concentrations predicted with Tier 1 exceed protective health benchmarks at receptor locations, then further evaluation with Tier 2 is recommended to obtain more definitive results.

Tier 2 provides time-varying analyses and solves mass balance equations for both solid and partitioned phase (hereafter referred to as the non-solid phase) MC with dissolution into water. Additionally, MC residue loadings to the range soil can vary from year-to-year based on munitions use. Thus, media concentrations computed with Tier 2 should be closer to those expected under actual conditions and lower than those computed with Tier 1 due to attenuating effects.

Although TREECS™ was developed for the fate of MC from military ranges, it has general applicability to many other situations requiring prediction of contaminant fate in multi-media environmental systems, including the fate of radionuclides in surface water and groundwater. TREECS™ Tier 2 was applied to the Borschi watershed near the Chernobyl Nuclear Power Plant, Ukraine, to demonstrate its use as a modeling tool to predict the fate of radiostrontium-90 that was deposited within the watershed following the Chernobyl reactor accident in 1986. This application also provided an additional validation test case for the TREECS™ Tier 2 soil model. This paper describes TREECS™ Tier 2 and the input data and results of this application to the Borschi watershed.

2. Methods

2.1. *TREECS™ Conceptualization*

TREECS™ consists of a collection of mass balance-based, mechanistic fate and transport models for environmental media, as well as supporting pre- and post-processing components. Fig. 1 presents a schematic of the conceptual model that TREECS™ Tier 2 addresses. A number of previous models used for assessment of radionuclide fate in watersheds take a more empirical, holistic approach (Garcia-Sanchez, 2008; Monte et al., 2004; Joshi and Shukla, 1991; Smith et al., 2004), whereas TREECS™ uses a reductionistic approach, which attempts to account for the fundamental physical and chemical processes (Monte et al., 2004). Holistic models require field observations to adjust or fit empirical input parameters. Mechanistic models require estimates or measurement of process-based parameters, and field data are used indirectly to calibrate or adjust those parameters or to validate the model after process-based parameters have been set.

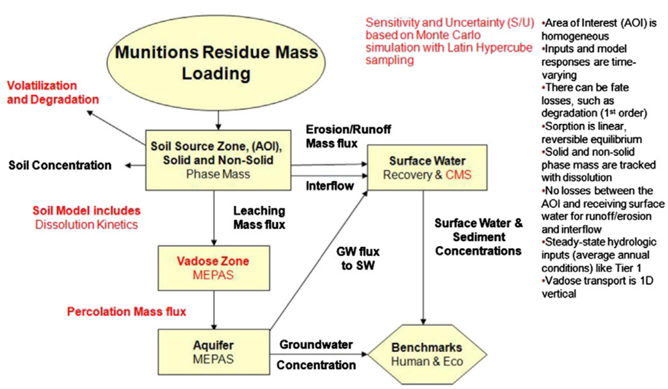

Fig. 1. TREECS™ Conceptualization.

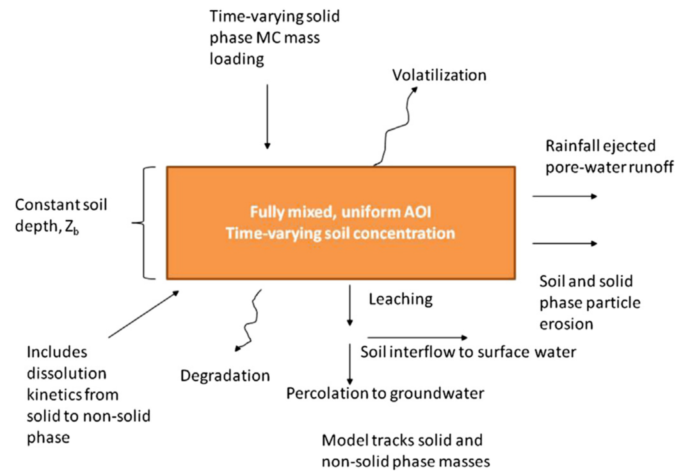

Fig. 2. TREECS™ soil model.

The source zone for MC (or other non-military contaminant) is the surface soil of the area of interest (AOI). The AOI could be the primary impact area of fired munitions for example. The MC residue loading to the AOI must be estimated or specified. Initial MC soil concentrations within the AOI can also be specified if such information is available. In addition to the loading model, fate and transport models are included for the four media of AOI soil, vadose zone beneath the AOI soil layer, groundwater (aquifer), and receiving surface water including sediment. All of the MC fate models within TREECS™ are models of reduced form, meaning that simplifications are imposed (such as spatial dimensionality) to reduce model complexity and facilitate ease-of-use.

Potential environmental and human receptors could be exposed to MC if it has migrated to groundwater wells or receiving surface waters. Thus, the end point metrics are the predicted MC concentrations at target groundwater wells and surface water body down-gradient of the AOI. These concentrations are compared to environmental and human health protective benchmarks (conservative screening values) developed by the DoD Range and Munitions Use Subcommittee to determine if more detailed site evaluations are required.

2.2. *TREECS™ model descriptions*

2.2.1. *AOI Tier 2 Soil Model*

The Tier 2 soil model, Fig. 2, is described in more detail than the other media models since this is a new model, whereas, the other models are legacy models. The AOI surface soil is treated as a homogenous, fully mixed compartment with a thickness Z_b (m) and a surface area A (m^2), which are both constant over time. Treating a heterogenous AOI as homogenous is not a compromising assumption because the total MC source mass loading and/or inventory are the driving variables for AOI mass export, not MC concentration, since the model is mass balance based. Thus, the mass export from the AOI to other media does not depend on AOI surface area or volume or the AOI MC concentration (Dortch et al., 2009, 2011).

Each constituent can exist in solid and non-solid (water-dissolved from solid) phases. The non-solid phase mass exists in