INTEGRATION OF THE WEPP AND HEC-6T MODELS TO PREDICT SOIL EROSION AND ACTINIDE TRANSPORT IN SURFACE WATER

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INTRODUCTION

The surface soils over portions of the Rocky Flats Environmental Technology Site (Site) were contaminated by accidental releases of radionuclides including plutonium-239,240 (Pu-239/240) and americium-241 (Am-241) (actinides). The Pu-239/240 and Am-241 are strongly associated with the soil particles and do not dissociate significantly in water. Remediation of the actinide-contaminated soils is planned prior to Site regulatory closure. At that time, the soils must be clean enough so that when eroded and transported into streams and ponds, the surface-water Pu-239/240 and Am-241 concentrations will not exceed surface water-quality standards. Understanding the processes and variables that contribute to and control soil erosion is important to achieving a final remedial design that limits erosion, sediment transport, and associated migration of residual actinide contamination.

The Water Erosion Prediction Project (WEPP) model (USDA, 1995) was used to estimate the runoff and sediment yields from Site hillslopes and to estimate runoff and sediment loading to watershed channels. The WEPP sediment and runoff output were then input to the Sedimentation In Stream Networks (HEC-6T) model (Thomas, 1999) to estimate stream flow and sediment transport. The combined output of the WEPP and HEC-6T models was used to estimate surface water concentrations and identify sources, and sinks for Pu-239/240 and Am-241 in the watersheds (K-H/RMRS, 2000). The models were calibrated using Site monitoring data.

A comprehensive geostatistical analysis of the spatial distribution of actinide contamination in Site surface soils was developed using kriging, a geostatistical method for spatial contouring of soil concentration data (Chromec et al, 2000). Quantities of Pu-239/240 and Am-241 associated with the delivered sediment were estimated using the kriged distributions of Pu-239/240 and Am-241 activity-concentrations in the soil combined with data quantifying the particle-size distribution of the actinides in surface soil water-stable aggregates (RMRS, 1998a).

The kriged Pu-239/240 and Am-241 distributions and the erosion and sediment transport model outputs were linked to create: 1) Soil mobility maps; 2) actinide mobility maps; 3) estimated surface-water total suspended solids and actinide concentrations; and 4) tools to guide remediation and environmental management decisions at this Site and others.

METHODS

Model Development: Data used as inputs to WEPP and HEC-6T models must be representative of the degree of observed geographical variability of the landscape at the Site. The model requires that the parameters for each hillslope be constant laterally (perpendicular to the fall line). Watershed sub-basins and hillslopes boundaries were developed from a Digital Elevation Model (DEM) using ArcView Spatial Analyst™ and ground-truthing. The hillslope boundaries were entered into Arc/Info™ as polygons, and lengths and hillslope areas were calculated for each hillslope. The number and size of overland flow elements (OFEs) within each hillslope were derived from intersecting soil series and vegetation-type boundaries over the Site. The resulting OFE polygons were then overlain on the hillslope coverages in Arc/Info™ (Spitze et al., 2000).

The topographic data from the Site DEMs, in which slopes are constantly varying, were used to produce average WEPP hillslope profiles that were as realistic as possible (Figure 1). The best estimates of the slope values were made by placing multiple transects perpendicular to the elevation contours on each OFE, and sampling each transect arc at regular intervals for instantaneous slope values. These values were then averaged laterally across the OFE, and WEPP slope files were generated.

The predicted spatial distributions of soil erosion and Pu-239/240 and Am-241 movement were derived from Geographic Information System (GIS) interpretations of the erosion modeling results, combined with the kriging analysis of the Pu-239/240 and Am-241 contamination in the surface soil. The data on contaminant and erosion distributions were mapped separately, and the information was joined to create actinide mobility maps. The actinide mobility maps show areas that are both erosion prone and contaminated, and thus where the Site will benefit most from soil remediation and erosion/sedimentation control actions.

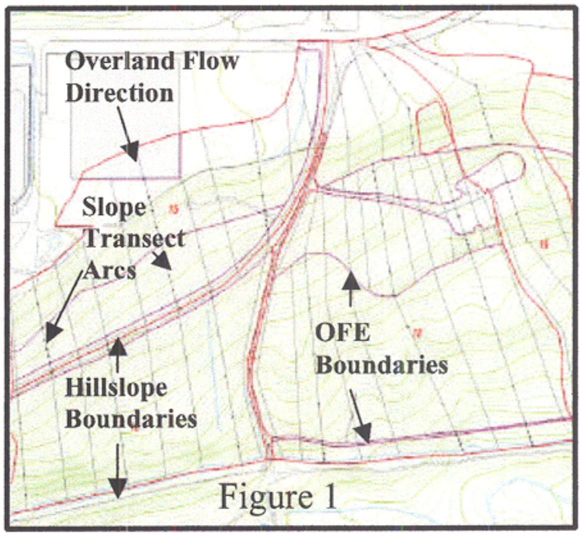


Figure 1

HEC-6T input included field data for channel geometry, bed sediment grain-size distribution, and channel roughness, supplemented by existing Site data, such as 2-foot contour mapping, floodplain mapping, and surface-water discharge and sediment yield data.

Model Integration: The WEPP output was formatted for input to the HEC-6T model, which produces output that predicts the transport and deposition of sediments. Integrating WEPP and HEC-6T was accomplished by the following procedure:

- The WEPP-estimated peak runoff (i.e., peak discharge) and runoff (i.e., total yield) values were used to compute triangular unit hydrographs for each tributary inflow (hillslope). The triangular distributions used for HEC-6T were constructed to match the rainfall intensity distributions such that peak discharge occurred at one-sixth of the runoff duration for the 6-hour events, one-fourth of the runoff duration for the 11.5-hour events, and one-fifth of the runoff duration for the 2-hour event;
- The time step for the runoff portion of each HEC-6T model was set using the shortest tributary runoff duration within a watershed. The time step was adjusted until each tributary in HEC-6T produced a runoff yield that matched the WEPP model output to within $\pm$ 10 percent;
- Sediment loads were calculated for each tributary inflow using a triangular unithydrograph methodology similar to that described above for runoff;
- The WEPP-estimated total sediment yield and the runoff duration calculated in the unithydrograph procedure (above) were used to compute the peak sediment load for each tributary inflow. The WEPP-estimated peak runoff rate (in cubic feet per second) and the peak sediment load (in short tons/day [short ton = 2,000 pounds]) were then paired for each design storm, thereby forming the data needed for the HEC-6T sediment discharge curve for each tributary inflow;
- Baseflow in the main channel, upstream from all of the tributary inflows, was set to simulate observed conditions based on monitoring data from Site stream gages;
- Discharges from hillslopes were loaded into the channel segment(s) as inflows. Where two or more hillslopes contributed flow and sediment load to the same point in the main channel, the flows for each hillslope were summed using the triangular unithydrograph method;
- The WEPP-estimated particle-size distribution (five size classes) and the estimated specific gravity of the inflow sediment were obtained for each hillslope and adjusted to the nine size classes required as input to HEC6-T by fitting the WEPP data to a log-normal distribution determined from data on Site surface soils; and
- Later, the measured particle-size distribution of the actinides in the parent soil was assigned to the WEPP and HEC-6T output data to calculate actinide concentrations in the surface-water.

Methods were developed to use the WEPP and HEC-6T output for estimating transport of Pu-239/240 and Am-241 associated with the suspended sediments. A model was created to calculate actinide transport based on the erosion of hillslope soils and kriged activity-concentration levels. Actinide contributions from channel erosion were not included in the calculated concentrations due to assumptions inherent in the channel erosion component of HEC-6T.

A soil actinide concentration adjustment model was created to estimate levels of soil contamination that can remain in the Site soils and be protective of surface water quality. The adjustment model can be used as a tool to develop the Site's final remedial design.

RESULTS

The following are a sampling of results derived from the modeling analysis (K-H/RMRS, 2000):

1. Uncertainties in the erosion and sediment modeling results and the assumptions have been identified, qualified, and quantified where possible. Comparisons of model estimates to surface-water monitoring data provide examples where erosion and sediment transport are underestimated and other examples where erosion and sediment transport appear to be overestimated by as much as a factor five. Figure 2 illustrates one problem encountered during model validation. The monitoring data are highly skewed towards small storms, total dissolved solids is not routinely collected and has a short period of record.

2. The 100-year annual average erosion rate for the three Site watersheds was estimated to vary from 0.384 metric tons per hectare (T/ha) to 0.221 T/ha (0.099 t/ac), resulting from about 4 to 6 percent of the annual precipitation leaving the Site as runoff. The great majority of the predicted erosion is due to large, infrequent storms and the average values do not convey the very large variation in annual values of runoff and erosion due to variation in precipitation from year to year. The annual erosion estimates for the watershed in Figure 3 vary from a minimum of 0.01 T/ha (0.004 t/ac) to a maximum of 3.54 T/ha (1.58 t/ac) for the 100-year simulation. Soil losses more than double the average can be expected about 16 years out of 100 years or about once every 6 or 7 years. The 100-year average is very similar tothe events with a 10- to 12-year return interval.

3. Areas with high erosion potential and actinide source areas that have the potential to impact surface water quality due to erosion and sediment transport were identified using the erosion and actinide mobility maps.

4. Figure 4 is a graphical presentation of model estimated sediment, Pu-239/240, and Am-241 concentrations in Site streams, identifying watershed areas impacted by soil contamination and stream reaches that act as sediment sinks.

Figure 2

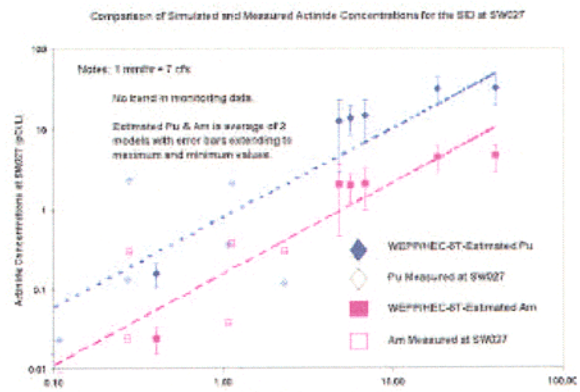


Figure 3

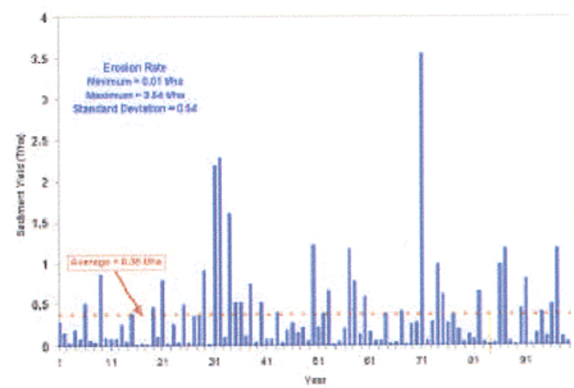
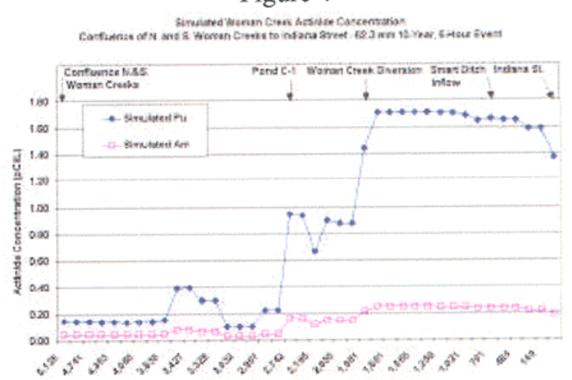
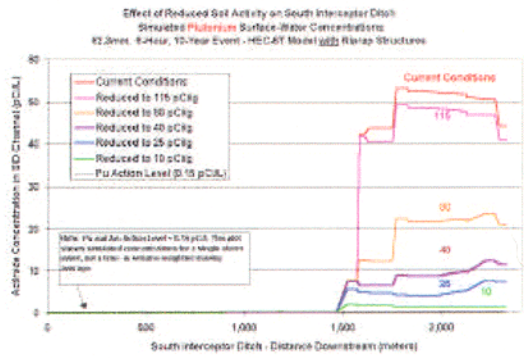


Figure 4



5. The model simulations for the 10- and 100-year events, coupled with the soil actinide concentration adjustment model results indicate that the Site needs to evaluate a combination of remediation, erosion controls, hydrologic controls, and management controls to protect surface water quality in a manner consistent with the goals of the Rocky Flats Cleanup Agreement (RFCA) (DOE, 1996a). The selection of a final remedial design for the Site watersheds will depend on the completion of several steps in the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) process.

Figure 5



Integration of these models has created tools for making informed decisions regarding remedial actions for actinide-contaminated soils at the Site. The tools will be used to evaluate combinations of soil remediation, erosion controls, hydrologic modifications, land uses, and other management alternatives to assess their impacts on mitigating the movement of Pu-239/240 and Am-241 via the soil erosion and sediment transport pathway. This modeling process can also be applied to soil contamination problems at other sites where contaminants are insoluble and have a strong affinity for sorption or binding to the solid phase (e.g., soil and sediment).

Conclusions derived from this modeling effort should be characterized as preliminary until the modeling work planned for fiscal year 2001 and other related investigations have been completed. Activities planned for fiscal year 2001 include: improved integration of the models; streamlining of data handling and reporting; modeling of future scenarios for soil remediation; hydrologic modifications; extreme natural disasters (floods, fires, etc.); and incorporation into a final land configuration design study for the Site.

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