# Fluvial Redistribution of Contaminated Tephra: Process-Level Modeling and Parameter Estimation

Donald Hooper and Roland Benke

Center for Nuclear Waste Regulatory Analyses, Southwest Research Institute®: 6220 Culebra Road, San Antonio, Texas, 78238-5166, USA, dhooper@swri.org or rbenke@swri.org

***Abstract*—**Following a potential volcanic eruption at the potential repository at Yucca Mountain, Nevada, radioactive waste and ejected volcanic material may be deposited on surrounding hillslopes. Contaminated volcanic deposits could be affected by subsequent surface processes and redistributed. Process-level modeling is being developed to evaluate the long-term remobilization and redistribution of volcanic ejecta (tephra) following a violent strombolian (or scoria cone) eruption. The objective of this paper is to highlight how this modeling approach supports the abstracted fluvial redistribution model for the Total-system Performance Assessment code through the determination of values for the five local input parameters of the abstracted model. Model parameters are being developed for expected dryland conditions in the Fortymile Wash drainage system following a potential volcanic eruption at Yucca Mountain.

## I. INTRODUCTION

In the unlikely event of a volcanic eruption in the potential repository at Yucca Mountain, Nevada, radioactive waste may be transported in the volcanic eruption plume and subsequently deposited on surrounding hillslopes. The volcanic ejecta (a mix of ash, cinders, bombs, and blocks collectively referred to as tephra) could be dispersed according to such factors as height of the eruption column, particle size distribution, and structure of the winds aloft. Contaminated tephra-fall deposits could be affected by subsequent surface processes and remobilized. Potential deposition of radionuclides at the receptor (reasonably maximally exposed individual) location could occur either from direct sedimentation from the eruption plume or from the redistribution of tephra by water and wind after initial deposition. Fortymile Wash, an ephemeral stream system, is the primary drainage for Yucca Mountain. The transport of material by surficial water processes is referred to as fluvial remobilization, which may include redistribution and sediment mixing of tephra in Fortymile Wash. Although not the focus of this paper, the transport of material by wind is eolian remobilization, which may include the resuspension of fine tephra following the initial deposition from a volcanic eruption plume. Since existing sediment deposition from fluvial redistribution near the southern boundary of the Nevada Test Site is close to the general area of the reasonably maximally exposed individual location, fine-grained particles contaminated by high-level waste could be resuspended and entrained by surface winds. These particles could then be inhaled by the receptor. Erosion and sediment transport rates in this arid to semiarid region are difficult to measure directly, but model parameters address uncertainties in data and site-specific processes. Hillslope processes are largely simplified because soil properties and slope characteristics for tephra-covered hillsides in this arid region are difficult to obtain in sufficient spatial detail.

In preparation for a regulatory review of a potential DOE license application and its performance assessment, the Center for Nuclear Waste Regulatory Analyses (CNWRA) and U.S. Nuclear Regulatory Commission (NRC) staffs developed the Total-system Performance Assessment (TPA) code to provide the capability to independently evaluate uncertainties in risk-significant features, events, and processes. A companion paper describes an abstracted model for fluvial redistribution. The objective of this paper is to highlight how process-level modeling supports the fluvial redistribution model for the TPA code through the determination of values for the input parameters of the abstracted model.

## II. WORK DESCRIPTION AND RESULTS

In an arid to semiarid region like Yucca Mountain in southern Nevada, sediment remobilization and redistribution processes are not well understood and supporting data are sparse.

Tephra could be eroded by mass wasting (including soil creep and shallow landslides), the combined effects of raindrop splash and sheet wash, channel erosion (including rilling and gullying), and eolian processes. Tephra remobilization is expected to follow a path similar to existing sediments (i.e., down the Fortymile Wash drainage system during periods of episodic overland flow). In the existing Fortymile Wash system, transported sediment begins to accumulate where the main drainage changes from a steep-sided incising channel to a broad distributary network or depositional basin in the Amargosa Desert (Figure 1). These surface processes affect the derivation of the five local input parameters first described in the companion paper.

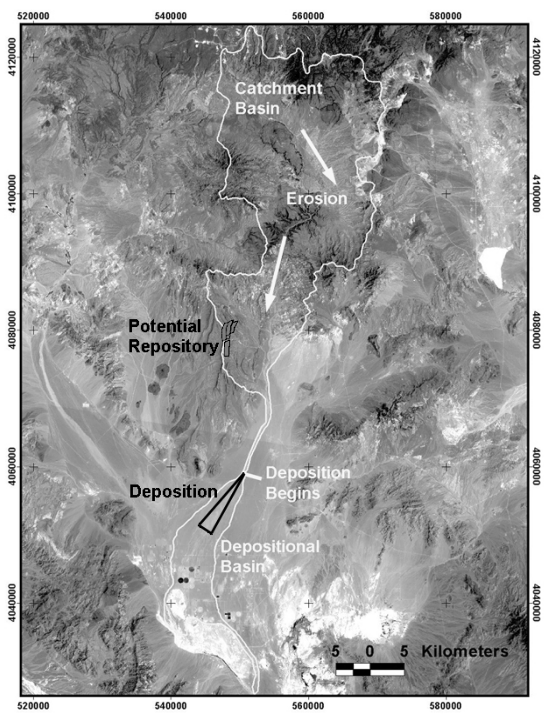


Figure 1. Landsat Thematic Mapper image showing the Fortymile Wash drainage system. The Fortymile Wash catchment basin has an area of $8.15 \times 10^8$ m$^2$ [315 mi$^2$], while the depositional basin has an area of $1.36 \times 10^8$ m$^2$ [52.5 mi$^2$]. The active portion of the depositional basin is outlined by a dark triangle. It has an area of $2.4 \times 10^7$ m$^2$ [$9.3 \pm 0.8$ mi$^2$]. Erosional and depositional outlines are determined from U.S. Geological Survey 7.5-minute topographic maps. Map projection: Universal Transverse Mercator, zone 11 north, in meters [1 m = 3.3 ft].

*II.A. Average Time Between Significant Flow Events ($T_f$)*

Fortymile Wash is an ephemeral stream system that drains from north to south along the east side of Yucca Mountain (Figure 1). The length of time between streamflow events or floods can be several years. Runoff is infrequent because of high evapotranspiration rates and a low annual precipitation of approximately 150 mm [6 in] per year [1]. Because streamflow is so infrequent, any flow may be considered locally to be a flood. The frequency and magnitude of floods control how sediment is routed through a dryland river system. Eleven floods have been recorded at the southernmost gage (Amargosa Valley, Station 10251258) over a 30-year period (prior to decommissioning) from 1969 to 1998 [1, 2, 3]. On average, there is a flood every 2.7 years. However, only 7 of these floods have a peak discharge greater than 0.1 m$^3$/s [3.53 ft$^3$/s]. Therefore, the time between flow events is assigned a value of 4 years. A minimal amount of hydrologic data is a common limitation for dryland streams.

*II. B. Total Area Of The Drainage Basin That Discharges Through Fortymile Wash ($A_{basin,f}$)*

Fortymile Wash has a watershed or catchment basin area of $8.15 \times 10^8$ m$^2$ [315 mi$^2$] (Figure 1). This is a standard spatial attribute derived from geographic information system and planimetric methods.

*II. C. Preeruption Sediment Volume From The Drainage Basin That Discharges Through Fortymile Wash Per Unit Area Per Discharge Event ($Y_{sediment,f}$)*

To abstract a redistribution model that is useful for TPA code calculations, all erosion is lumped into a single annual term, the sediment yield, rather than modeling the separate contributions from individual hillslope processes. Sediment transport data are lacking for Fortymile Wash, but the volume of sediment deposited in the Fortymile Wash depositional fan can be estimated by identifying the area of the active fan surface. The active depositional fan consists of non-varnished to lightly varnished desert pavement. These high-albedo surfaces are easily distinguished in Landsat Thematic Mapper imagery (Figure 1). Using this criterion, the area of the active depositional fan is $2.4 \times 10^7 \pm 0.2$ m$^2$ [$9.3 \pm 0.8$ mi$^2$]. The thickness of the recently active deposit is assumed to be 1 to 2 m [3.3 to 6.6 ft], as supported by the pattern of channel migration, bars, levees, abandoned lobes, and overall low topographic relief. Based on the satellite image data and surficial deposits [4], the age of sediment accumulation in the alluvial fan is estimated between 4,000 to 10,000 years. Uncertainties were propagated using uniform distributions and the resulting distribution for ambient sediment yield, in units of $m^3/m^2$-yr, was converted to units of $m^3/m^2$-event with a multiplication by 4 yr/event (i.e., the value of parameter $T_f$). In the TPA code, this parameter ranges from $1.0 \times 10^{-5}$ to $6.2 \times 10^{-5}$ m/event with a user-specified piecewise cumulative distribution function.

*II. D. Post-Eruption Volume of Fluvial Redistributed Tephra at the Fortymile Wash Depositional Region Per Unit Area Per Discharge Event ($Y_{ash,f}$)*

Emplacement of tephra-fall deposits can disrupt the supply of sediment to rivers and perturb runoff hydrology. A large amount of easily eroded sediment derived from these deposits, coupled with the loss of protective vegetation, can trigger accelerated erosion and substantially increase sediment yield following a volcanic eruption. The rate at which these sediment yields rapidly increase and then decrease to preeruption levels depends upon climatic setting, terrain, and the nature of erupted material. Based on a current model for an eruption producing basaltic tephra at Yucca Mountain [5], accelerated erosion elevates the sediment yield to approximately 5 times the preeruption yield after 500 years before slowly returning to a normal preeruption rate (Figure 2). To

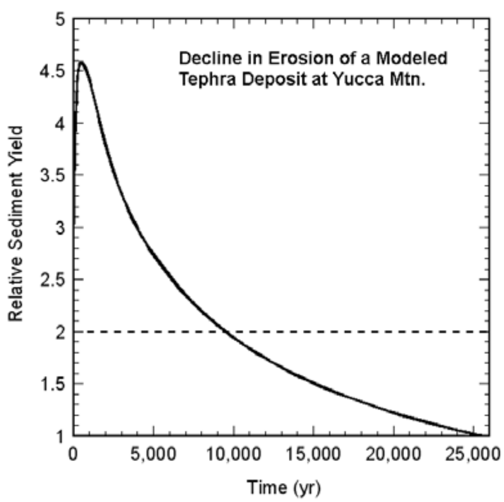


Figure 2. Plot of calculated accelerated erosion following potential tephra fall in the Fortymile Wash drainage system. Following an eruption, there is an increase in sediment yield (accelerated erosion) and then a gradual decrease in sediment yield until conditions return to the preeruption yield {which is a relative sediment yield of 1.0 [unitless]}.

account for accelerated erosion in TPA code calculations, the mean post-eruption sediment yield is two times the ambient sediment yield over the lifetime of the potential tephra deposit. Therefore, this is a correlated parameter with a value set to twice the sampled value of $Y_{sediment,f}$.

The post-eruption sediment yield affects (i) the time period that fluvial redistribution contributes contaminated airborne particulates for inhalation dose calculations and (ii) dilution of fluvial deposits due to mixing with clean sediment.

*II. E. Density of Proximal Ash Deposit ($\rho_{ash,f}$)*

This term is a constant with a value of 1.2 g/cm$^3$ and is derived from granulometric analysis of the tephra-fall deposit from the 1995 eruption of Cerro Negro volcano, Nicaragua [6].

## III. CONCLUSIONS AND DISCUSSION

In the unlikely event of a volcanic eruption through the potential repository, contaminated tephra could be deposited over hundreds to perhaps thousands of square kilometers [tens to perhaps hundreds of square miles]. Over time, some tephra can be eroded and transported by water and wind, with later deposition at or near the hypothetical location of the reasonably maximally exposed individual or receptor. Resuspension of contaminated fine-grained ash particles produces airborne concentrations (or the airborne mass load) of ash and high-level waste. Inhalation of resuspended volcanic ash or tephra dominates the total dose for the igneous activity scenario. Airborne mass load for the years following a potential volcanic eruption is a high-sensitivity parameter in total-system performance assessment calculations [7], and uncertainties in this parameter strongly affect calculations of expected annual dose. An influx of redistributed tephra could affect the airborne particle concentrations at the receptor location, depending on the rate of remobilization and dilution with existing sediments. An abstracted model was developed for the TPA code to evaluate tephra redistribution effects in system-level calculations.

## DISCLAIMER

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