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Dispersion of channel-sediment contaminants in distributary fluvial systems: Application to fluvial tephra and radionuclide redistribution following a potential volcanic eruption at Yucca Mountain

Jon D. Pelletier [a,*], Stephen B. DeLong [a], Michael L. Cline [a], Charles D. Harrington [b], Gordon N. Keating [b]

[a] Department of Geosciences, University of Arizona, 1040 E. Fourth Street, Tucson, AZ 85721, USA
[b] Earth and Environmental Sciences Division, Los Alamos National Laboratory, Los Alamos, New Mexico, 87545 USA

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Abstract

Predicting the fluvial transport and mixing of channel-sediment contaminants is necessary for assessing and mitigating heavy-metal and nuclear-waste contamination in rivers. The dilution–mixing model is widely used for this purpose in tributary channel systems that transport contaminants as bed-material load without significant overbank sedimentation. Here a more general, three-dimensional (3D) contaminant transport numerical model is developed and tested based on bed scour, turbulent mixing of contaminant material with uncontaminated channel-bed sediments, and re-deposition of the mixture by the cumulative effect of many flood events. First, the model is applied to a synthetic alluvial-fan environment downstream from a localized contaminant source in order to illustrate the model behavior. Second, the model is validated against measured tephra concentrations in channels downstream from the Lathrop Wells scoria cone volcano, a localized source of basaltic tephra to downstream channels otherwise comprised of non-basaltic sediments. Third, the model is applied to the problem of predicting the concentration of radionuclide-bound tephra in channels downstream from the proposed nuclear-waste repository at Yucca Mountain, Nevada, in the event of a volcanic eruption through the repository. Contaminated tephra is mobilized from the landscape in this model using threshold criteria for hillslope gradient and channel stream power. Mobilized contaminated tephra is mixed with uncontaminated channel-bed sediments using the contaminant transport model and deposited in channels of the Fortymile Wash alluvial fan where the residents nearest to the proposed repository live. The results of twenty Monte Carlo simulations of eruption fallout and post-eruption redistribution corresponding to a range of wind conditions and eruption magnitudes provide information on the mean and variability of contaminated tephra concentrations to be expected in channels of the Fortymile Wash alluvial fan in the event of an eruption. Mean tephra concentrations are approximately 1% but vary from nearly zero to as high as 26%, reflecting the combined effects of wind direction, eruption magnitude, and dilution of tephra with uncontaminated channel-bed sediments during transport.

Keywords: Contaminant transport; Drainage networks; Flood scour; Radionuclides

* Corresponding author.
E-mail address: jdpellet@email.arizona.edu (J.D. Pelletier).

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1. Introduction

Predicting the transport and fate of channel-sediment contaminants is an important aspect of applied geomorphology. Worldwide, many river systems have sediments contaminated with heavy metals as a result of centuries of ore-mining activity (Miller, 1997). Similarly, radioactive contamination of channel sediments is a potential human health hazard downstream of areas where radioactive material has been processed or stored (Reneau et al., 2004).

Underground storage of nuclear waste primarily poses a hydrologic risk associated with contaminated groundwater. For that reason, plans to develop a nuclear-waste repository in the United States have focused on Yucca Mountain, a location with a closed groundwater basin and a water table approximately 600m below the surface (BSC, 2004a). While these features mitigate the risk to groundwater, volcanism in the Yucca Mountain region could pose a significant hazard. If an eruption were to intersect the repository, radionuclide-bound tephra would be deposited on the landscape. Probabilistic volcanic hazard analyses constrain the annual risk of an eruption through the proposed repository to be 1.5×10^{-8} (CRWMS M&O, 1996). In the event of an eruption, individuals living on the Fortymile Wash alluvial fan 18km south of the repository (i.e. the closest residents to the repository; Fig. 1) could be affected by radionuclide-contaminated tephra deposited as fallout or redistributed from upstream. Under most wind-direction scenarios (i.e. southerly winds), primary fallout tephra is concentrated to the north of the proposed repository location and entirely within the Nevada Test Site (BSC, 2004b,c). In such cases, however, fluvial redistribution of contaminated tephra from the primary fallout location to the Fortymile Wash alluvial fan could be significant. In order to evaluate the safety of the proposed repository, numerical models are needed that estimate the radioactive dosage to individuals living in the Fortymile Wash alluvial fan, deriving both from primary fallout and contaminated tephra redistributed from upstream. This paper describes a numerical model designed to model the second of those two pathways. The model quantifies the concentration of tephra and radionuclides in channels of the Fortymile Wash alluvial fan as a result of hillslope and fluvial redistribution processes in the event of a volcanic eruption through the repository.

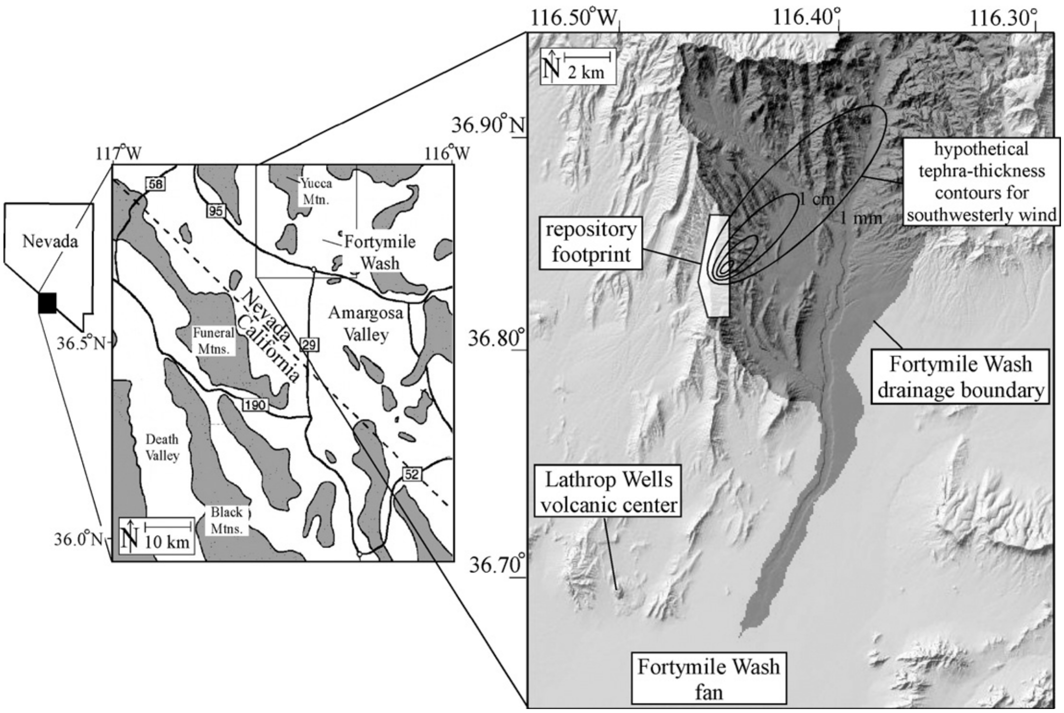

Fig. 1. Location map of the study areas in Amargosa Valley, Nevada. Shaded relief image includes Lathrop Wells volcanic center (site of the model application in Figs. 4 to 6), the footprint of the proposed nuclear-waste repository at Yucca Mountain, and the southern portion of the Fortymile Wash drainage basin (i.e. the site of primary fallout for tephra with potential for redistribution to the Fortymile Wash fan where the nearest population resides.