Aeolian Research 18 (2015) 155–167

Contents lists available at ScienceDirect

Aeolian Research

journal homepage: www.elsevier.com/locate/aeolia

Development of a dust deposition forecasting model for mine tailings impoundments using in situ observations and particle transport simulations

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ARTICLE INFO

Article history:
Received 1 December 2014
Revised 7 July 2015
Accepted 7 July 2015
Available online 13 August 2015

Keywords:
Deposition
Dust
Wind erosion
Aerosol transport
Superfund

ABSTRACT

Mine tailings impoundments in arid and semiarid environments are susceptible to wind erosion due to their fine grain silt and sandy composition and lack of vegetative coverage. Aeolian transport of particulate matter from these mine tailings impoundments are potential hazards to human health due to the presence of metal and metalloid contaminants. Predicting windblown transport of mine tailings material can be a useful tool in characterizing the risk and environmental impact on neighboring communities. This work presents a model that can be used to forecast the transport and deposition of windblown dust from mine tailings impoundments. The deposition forecast model uses in situ observations from a tailings field site and theoretical simulations of aerosol transport to parameterize the model. It includes a method for simulating deposition patterns for several different size fractions and can be translated to other regions and applied to different windblown dust sources. The model was developed using data from the Iron King Mine tailings in Dewey-Humboldt, Arizona, a Superfund site that is heavily contaminated with lead and arsenic. A preliminary verification of the model was conducted using topsoil measurements of lead and arsenic as tracers of windblown dust from the tailings impoundment. The tailings tracers support the predicted deposition patterns generated by the deposition forecasting model.

1. Introduction

Aeolian transport of dust from mine tailings can be a significant problem in arid and semiarid regions, where the naturally dry and windy environment makes the tailings susceptible to wind erosion. Dust particles can have deleterious health effects and, as a result, particulate matter, specifically $PM_{2.5}$ and PM_{10}, are one of six air pollutants regulated under the National Ambient Air Quality Standards NAAQS (USEPA, 2011).

The US Environmental Protection Agency (EPA) recommends two models for predicting the dispersion of pollutants, including particulate matter: AERMOD and CALPUFF. AERMOD is a steady state Gaussian plume model designed for industrial sources (Cimorelli, 1998). It includes boundary layer turbulent structure parameterization and is applicable for transport up to about 50 km (USEPA, 2004). However, the steady state assumption prevents it from responding to temporal and spatial variations in meteorological conditions. CALPUFF on the other hand is a non-steady state plume dispersion and transport model that is recommended for long range transport simulations up to 1000's of kilometers (Allwine et al., 1998; Scire et al., 2000). However, CALPUFF's plume characteristics are dependent on a select few atmospheric stability classes. These classes were designed to maximize their accuracy for general use in a variety of environments and conditions, which often do not include site specific factors that affect windblown dust deposition patterns. Both of these models have difficulty simulating the transport of the largest particles that do not get fully suspended in the mean flow field and are transported very short distances. In addition, neither of these models can be initialized by operational weather forecasts to provide high temporal resolution forecasts of coarse ($D_p > 10$-μm) aerosol deposition.

In this work, we develop a site-specific dust transport and Deposition Forecast Model (DFM) for a mine tailings impoundment. The model is designed to be implemented with an

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http://dx.doi.org/10.1016/j.aeolia.2015.07.003
1875-9637/

Fig. 1. Visual satellite image of the Iron King Mine tailings and surrounding area. The tailings are identified by their yellowish discoloration and the locations of the two eddy flux towers and the MOUDI are marked by black and red outlined circles respectively. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

operational weather model to provide hourly deposition forecasts of particulate matter with aerodynamic diameter of 27-μm or less (PM_{27}). The DFM is initialized by operational weather forecasting model output using empirical relations derived from field observations. Following the initialization, the quantitative deposition patterns are generated using trajectories determined idealized particle transport simulations for multiple emission events.

The tailings impoundment is a part of the Iron King Mine and Smelter area, an EPA Superfund site since 2008 (EA Engineering, 2010). The Iron King Mine site is adjacent to the town of Dewey-Humboldt, located about 90 miles north–northwest of Phoenix, Arizona. The Iron King Mine tailings impoundment is contaminated with arsenic and lead, amongst other species and is located near the town Dewey-Humboldt, Arizona, with a population of 3,951 (US Census, 2005).

2. Methodology

2.1. Site description

The Iron King Mine and surrounding region is located in a semi-arid climate with an average annual rain fall of 47.7 cm. The average monthly maximum temperature during January and July are 50.9 and 88.3°F respectively (NCDC, 2004). The winds are subject to significant local diurnal variations with a predominantly strong southerly winds during the day and weaker northerly winds during the night. The vegetation is largely composed of grasslands, chaparral, and pinyon/juniper woodlands, but the mine tailings impoundment is devoid of vegetation except for a small phytoremediation test plot (7200-m^2). The topography ranges from rolling hills to rugged mountainous terrain with the Iron King tailings impoundment and surrounding mountains located at 1436-m and 2300-m above mean sea level respectively (EA Engineering, 2010).

The Iron King tailings impoundment is located 1.5 km west-southwest of Dewey-Humboldt and has two adjacent waterways that are dry except during precipitation events, the Galena Gulch south of the property and the Chaparral Gulch along the northern boundary. The tailings impoundment has a reddish brown color and rises vertically from a hillside with sloped sides and flat top (Fig. 1). The tailings material consists of gravelly and silty sands with a loam texture that consists of 34.7% sand, 44.8% silt, and 20.4% clay (Solís-Dominguez et al., 2012). The tailings material is acidic with a pH of 2.5 and is heavily contaminated with lead and arsenic with peak soil concentrations of 9830 mg/kg and 6300 mg/kg respectively (Ramirez-Andreotta et al., 2013; EA Engineering, 2010). Elevated concentrations of arsenic and lead in adjacent offsite soils are indicative of aeolian and ground water transport (Ramirez-Andreotta et al., 2013).

2.2. Instrumentation

Two eddy flux towers were installed on the Iron King tailings in 2012 (Fig. 1). Instrumentation includes: three TSI DUSTTRAK II 8530 monitor with omnidirectional inlets located at 1-m, 3-m and 10-m heights, cup anemometers at 3 and 10-m, a sonic anemometer at 1-m height on the south tower only, thermometers and hygrometers at 3 and 10-m height. The DUSTTRAKs sample PM_{27} (particulate matter with an aerodynamic diameter of 27 μm or less) and are operational from 5:00 AM to 9:00 PM. The