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Two-Stage Stochastic Mixed-Integer Nonlinear Programming Model for Post-Wildfire Debris Flow Hazard Management: Mitigation and Emergency Evacuation

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Abstract

Post-fire debris flows are natural disasters capable of destroying structures and endangering human lives. These events are prevalent in certain geographic regions and are expected to increase in frequency. Motivated by the literature on operations research in disaster relief operations, we present several novel formulations for hazard management of post-fire debris flows. The deterministic model allocates a budget towards various mitigation options including preventative efforts that reduce the probability of debris flow initiation and reduction efforts that reduce volume conditional on initiation. The objective minimizes expected damage to structures while weighting different storm scenarios according to Poisson process probabilities. A two-stage multi-period decision-dependent stochastic programming model is then developed to address the prevention of loss of life through emergency vehicle routing. This stochastic program considers different storm scenarios and allows mitigation actions taken in the first stage to affect second stage parameters and scenario probabilities. The program routes emergency vehicles to pick up injured people at damaged residences and then delivers them to a hospital. Case study results are presented using real data based on Santa Barbara after the 2009 Jesusita wildfire. Case study optimal mitigation measures focus on primarily on three out of the 17 basins. The deterministic results focus mostly on check dams given our parameter values, while the stochastic results incorporate pre-positioned emergency vehicles. Smaller budgets have a large marginal benefit from mitigation. We also generate a larger simulated data set based on this case study to test the computational tractability of our formulations.

Keywords: OR in disaster relief, Decision support systems, Stochastic programming, Decision-dependent stochastic programming, MINLP, Routing, Debris flows, 2009 Jesusita wildfire

1. Introduction

Debris flows are fast moving water-laden masses of unsorted sediment and other debris that run down mountain slopes in response to gravity. They can occur with little warning and even moderately-sized flows can strip vegetation, clog drainage ways, damage structures and endanger human lives (Iverson, 1997). For example: during the December 1999 debris flows in Vargas State of Venezuela, an estimated 19,000 people lost their lives with economic damages estimated to be over US$1 billion (Osti and Egashira, 2008); during August 2010 debris flows in Gansu Province of China resulted in 1,476 deaths and 298 missing people (Liang et al., 2012); in March 2010 debris flows in Uganda resulted in 94 deaths and 320 people missing (Liang et al., 2012). Between 1950 and 2011 various sources documented 213 events with 77,779 fatalities (Dowling and Santi, 2014).

Post-wildfire debris flows are of particular interest because they can be triggered by less rainfall than typically required in an unburned area (Cannon et al., 2008) and have been observed to produce significantly more debris (Santi and Morandi, 2012). This is because fires consume rainfall-intercepting vegetation and litter while depositing ash (Parise and Cannon, 2012; Gartner et al., 2008), enhancing water-repellent soils (Woods et al., 2007), and generally

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