Prediction of Sediment Yield from Swift Creek Landslide Using the Distributed Hydrology-Soil-Vegetation Model

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INTRODUCTION

The Swift Creek landslide is a large active landslide located east of Everson in northwest Whatcom County, WA (Figure 1). The slide produces large quantities of asbestos laden sediment that flows down Swift Creek, filling channels that frequently have to be dredged to prevent flooding and road damage. Swift creek also discharges into the Sumas River, which flows north in British Columbia, Canada. This is problematic because the asbestos fibers pose a risk to human health (Bayer, 2006; EPA, 2006). Knowledge of what factors affect the amount of sediment being eroded from the slide and an accurate quantification of the sediment discharge into the south fork of Swift Creek (Figure 2) is crucial to develop remediation plans.

Swift Creek Watershed

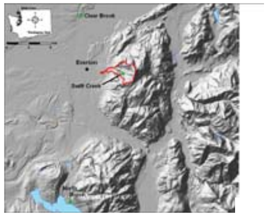

Figure 1: Location of swift creek watershed and nearby weather stations.

Watershed Characteristics

- Watershed Area ~ 6.5 km^2
- Elevation ranges from 35 m to 1040 m

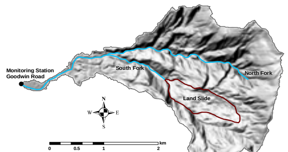

Figure 2: Swift creek watershed and landslide

Swift Creek Landslide

The slide is classified as slow moving and deep seated (McKenzie-Johnson, 2004) (Figure 3). There are three basic zones defined by their characteristic morphology and motion: the zone of depletion, the neutral zone, and the zone of accumulation (Figure 4). Small slides frequently initiate on the toe and release turbidity flows into the stream. These small surficial failures have been recorded by time lapse photography as part of the Western Washington Landscape Observatory (Linneman and Clark, 2006). In addition to small failures on the toe, abundant surface erosion results from rainfall on the unvegetated surface.

Figure 3: Swift Creek landslide looking East from the air. Photo by Doug Clark.

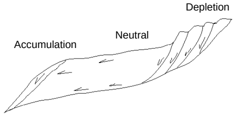

Figure 4: Schematic cross section of landslide, from McKenzie-Johnson, 2004.

Landslide Characteristics

- Area ~ 0.5 km^2
- Depth ~ 90 - 125 m
- Velocity 4 – 40 m/yr
- Composition ~50% Chrysotile

Research Objectives

We have used the Distributed Hydrology-Soil-Vegetation Model (DHSVM) to model the stream discharge and DHSVM turbidity module to model the suspended sediment concentration of Swift Creek. The model is intended to provide insight to the primary hydrologic parameters that are causing erosion from the landslide and to quantify a volume of suspended asbestiform sediment that is being transported and deposited downstream. Preliminary modeling results are shown on this poster.

The steps to accomplish my research objectives include the following tasks:

- ❖ develop the grid-based DHSVM input for the Swift Creek watershed
- ❖ collect stream discharge data for Swift Creek and calibrate the DHSVM stream-flow output to the measured data
- ❖ collect and format the meteorological time series for the model
- ❖ measure sediment concentrations in the creek at various flow rates and calibrate the DHSVM to the measured sediment load
- ❖ perform numerical experiments on the model outputs and analyze the results

Calibration Problems

- ❖ Limited discharge data and rapidly changing stream-bed morphology
- ❖ Unconstrained soil hydrologic and mechanical properties for the landslide material

MODELING METHODS

Distributed Hydrology Soils Vegetation Model and Sediment Module

DHSVM is a physically based, distributed hydrology model that simulates a water and energy balance at the pixel scale of a digital elevation model (DEM; Figure 5). It has been applied predominantly to mountainous watersheds in the Pacific Northwest to simulate hydrologic responses to weather and land use conditions (Wigmosta et al, 1994).

The turbidity module predicts mass wasting and hill slope erosion (Figure 6). The sediment module is coupled with DHSVM and relies on the soil moisture, surface water, and stream flow as inputs for predicting mass wasting and erosion in order to quantify sediment yield (Doten and Lettenmaier, 2004).

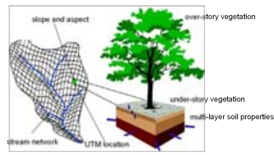

Figure 5: Conceptual model of DHSVM structure (Wigmosta, et al., 1994).

Figure 6: DHSVM turbidity module schematic (Doten and Lettenmaier, 2004).

GIS Input Grids

DHSVM requires the following GIS grids to characterize the watershed.

- ❖ 10 m x 10 m DEM (Figure 7)
- ❖ STATSGO Soil type (Figure 8)
- ❖ Stream network (Figure 9)
- ❖ NOAA landcover data (Figure 10)
- ❖ Soil thickness (Generated with ArcInfo AML)

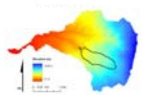

Figure 7: DEM of Swift Creek watershed

Figure 8: Soil type from STATSGO

Figure 9: Stream network

Figure 10: Landcover data from NOAA

Field Methods

Stream Data

A stream gauging station mounted on the Goodwin Road bridge crossing Swift Creek (Figures 2 and 11) was designed to continuously record creek stage and turbidity using the Turbidity Threshold Sampling (TTS) method. This method is commonly used by the Pacific Southwest Research Station of the United States Forest Service (Lewis and Eads, 2008). Physical water samples are drawn by an ISCO water sampler when triggered by rising or falling turbidity passing specified thresholds. The samples were analyzed for suspended sediment concentration (SSC). The stream gauge survived the erratic and turbulent nature of the stream, but a site with more consistent flow and constant bed shape would improve the data quality. Also, a pulley type stage recorder is unsuitable for this stream because of the changing stream bottom and turbulent water.

Figure 11: Stream gauging station. Stilling well is to the north, the turbidity sensor is in the creek suspended from the bridge, and data loggers are in the box to the south.

Meteorological Data

Meteorological inputs required by DHSVM:

- ❖ Precipitation (m)
- ❖ Temperature (^oC)
- ❖ Wind Speed (m/s)
- ❖ Relative Humidity (%)
- ❖ Longwave Radiation (W/m^2)
- ❖ Shortwave Radiation (W/m^2)

Meteorological data were obtained from nearby climate stations in Whatcom County, WA (Figure 1). The Swift Creek station is equipped to measure precipitation and temperature (Figure 12).

Figure 12: Swift creek weather Station

PRELIMINARY DATA

Discharge and Suspended Sediment Concentration

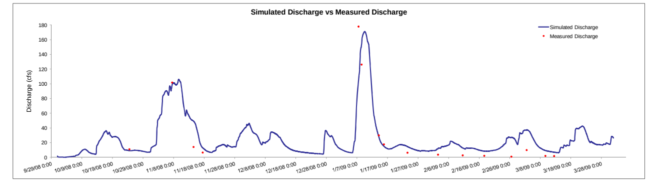

Figure 13: Simulated and measured stream discharge from October 1, 2008 to March 31, 2009.

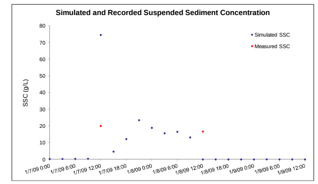

Figure 14: Simulated and measured suspended sediment concentration from January 7, 2009 to January 9 2009.

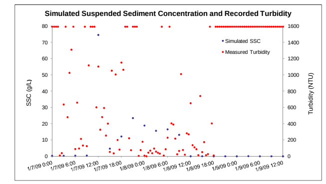

Figure 15: Simulated suspended sediment concentration and measured turbidity from January 7, 2009 to January 9, 2009. The sensor has maxed out readings from being buried by the aggrading stream bed.

Discussion

DHSVM Hydrologic Model

❖The model captures the major events but seems to over predict the latter sampling dates. Discharge measurements were collected infrequently and the stream gauge was unable to function properly due to rapidly changing stream bed and turbulent flow that would occasionally derail the collection device.

DHSVM Sediment Module

❖Preliminary calibration efforts focused on the first major storm (Jan 6, 09 to Jan 9, 09) where water samples were collected for suspended sediment concentration (SSC) analysis. Although the simulated series has an obscure point at the leading edge of the SSC curve, the magnitude of simulated and measured concentration coincide. This was accomplished by increasing the soil cohesion and decreasing the angle of internal friction of the landslide portion of the basin. We believe this reflects the conditions of the toe because of the highly disturbed setting and the ability of the material to rapidly flocculate, even in energetic water.

❖Before running the desired storm simulation, the module required running an initial 'spin up' simulation to remove excess sediment from the basin. Due to the quantitative nature of this model, separate simulations had to be run for individual storms to cut down on simulation time. This approach doesn't account for basin evolution during non-storm times, but does produce reasonable results because the sediment concentration in the stream becomes negligible in between storm events.

Collected Data

❖The turbidity data that was recorded during this storm has no correlation to measured SSC that can be determined with only two SSC measurements. However, over the entire sampling season there are time periods that had a visible correlation with discharge, usually found during times of mid-low flow.

❖Water samples were collected on each site visit. The ISCO sampler worked well once the appropriate threshold values were incorporated into the turbidity data logger sampling program. Other times the hose and sensor were either resting on the bottom, buried, or frozen causing erroneous or no data to be collected.

References:

Bayer, T.M., 2006, The Nature and Transport of the Fine-Grained Component of Swift Creek Landslide, Northwest Washington, MS Thesis, Western Washington University

Doten, C.O., and D.P. Lettenmaier, 2004, Prediction of Sediment Erosion and Transport with the Distributed Hydrology-Soil-Vegetation Model, Water Resources Series Technical Report No. 178.

Linneman, S., D.L. Clark, 2006, Western Washington University Landscape Observatory, http://www.wwu.edu/landscapeobservatory/index.shtml

McKenzie-Johnson, A.S., 2004, Kinematics of the Swift Creek Landslide, Northwest Washington, MS Thesis, Western Washington University

United States Environmental Protection Agency, Region 10, Office of Environmental Assessment (OEA), 2006, *Activity-Based Sampling at The Swift Creek Asbestos Site, August 21-25, 2006*.

Wigmosta, M., L. Vail, and D. Lettenmaier, 1994. A distributed hydrology-vegetation model for complex terrain. Water Resources Research, vol. 30 no. 6, pp 1665-1679.

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