The definitive version of this paper can be found using the following citation:

Fannin, J. & Bowman, E.T. (2008) *Debris flows - Entrainment, Deposition and Travel Distance*. Geotechnical News, 25(4), pp. 3-6.

Debris flows - entrainment, deposition and travel distance

Landslides comprising soil, rock, water and organic material are termed debris slides or debris flows, with the distinction between the two made largely to recognize the form of movement along the event path as it progresses downslope. Where initial movement occurs as a slide, it often progresses quickly to a flow as a consequence of strength loss that occurs with movement.

Debris flows represent a natural hazard in mountainous terrain around the world. Numerous catastrophic events have occurred in recent years. In contrast to other types of landslide activity, debris flows may be considered to be a 'low-magnitude high-frequency' hazard. They result in damage to property and, in some circumstances, may also result in loss of life.

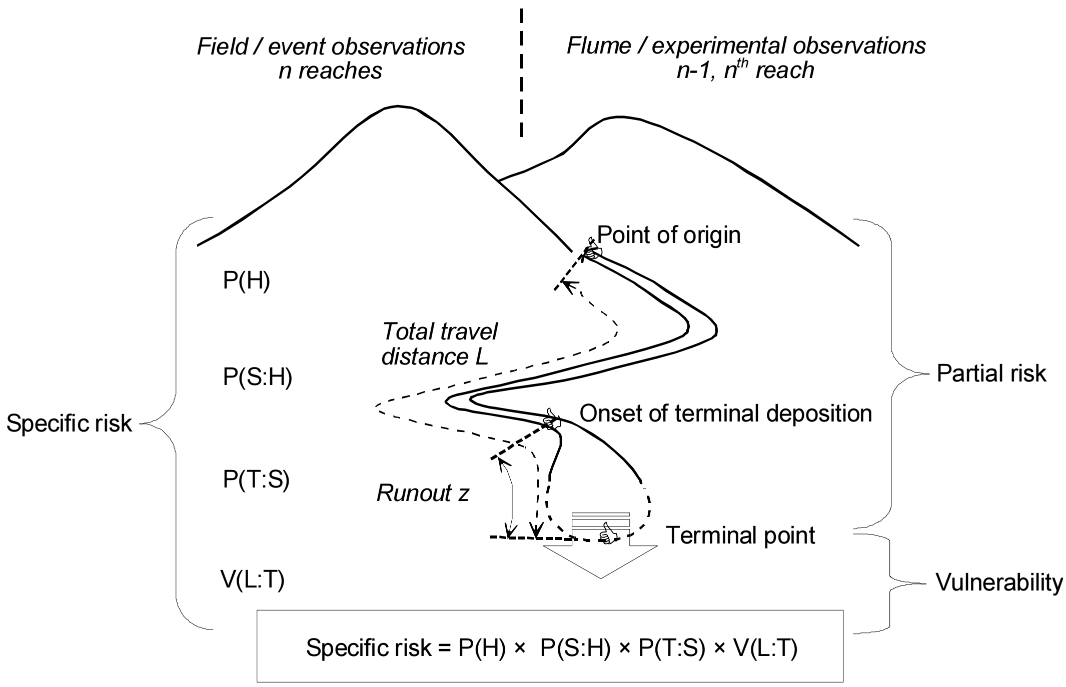

Figure 1: Debris flow risk: schematic illustration of an event path.

Travel Distance

The path of a debris flow comprises an initiation zone, a transportation zone and a zone of terminal deposition. The initiation zone, where the onset of failure occurs, is typically found within a gully channel or on an open hillslope. In the case of a gully, it may occur at the headwall, on a steep side slope, or within the steep bed of the gully channel. In the case of an open hillslope, it may take the form of shallowsliding on a translational plane of slip, else it may initiate at a discrete point of quasi-liquefied flow. Often, the initial failure volume is small in comparison to the peak magnitude of the resulting event. Travel distance commences at the point of origin of the event.

Downslope movement occurs through a transportation zone. Events hat initiate in a gully typically remain within it. Events that initiate on an open slope may remain on the slope, or may enter a gully as a consequence of topographic constraints. Movement is rapid and may, on occasion, involve more than one surge of debris. It is accompanied by processes of entrainment and deposition, yielding a cumulative flow volume that tends to increase with travel distance.

Along the event path, entrainment typically dominates on steeper slopes, and deposition tends to prevail on gentler slopes. A zone of terminal deposition occurs toward the end of the travel distance. It is distinguished by the onset of major deposition, typically in response to encountering a relatively gentle slope angle, experiencing a loss of confinement, or a combination of both influences. The cumulative flow volume diminishes with runout distance (z) in the depositional zone, as debris is deposited and the event comes to a halt. Total travel distance (L) is measured from the point of origin to the terminal point of the deposit.

Debris flow activity has potential to impact the environment, to inflict property damage and, more tragically, to cause loss of life. Various types of risk analysis may be considered, including some that include vulnerability V(L:T) to account for loss and injury. In undertaking a partial risk analysis, for which vulnerability is not considered, effort is required to account for the probability:

- P(H) of a debris flow initiation at a specific point of origin
- P(S:H) of the event travel distance reaching a site of interest
- P(T:S) of an element being present on site at the time of the event arrival

The probability of occurrence is the hazard. Consequence is governed by the potential for the debris flow event to reach a location of interest, and the likelihood it impacts an element of interest at that time. Travel distance of a debris flow is therefore important to risk analysis, and any companion decisions on risk management, because it describes the potential for the event to reach a particular location along an expected path of movement.

Field Observations –Entrainment and Deposition

The travel distance of a debris slide or debris flow is governed by properties of the material and attributes of the path of movement. Upon initiation, one the most significant differences between a debris slide or flow, and other types of landslide, is the fact that the cumulative volume of the event can change enormously along the path of movement. The path is described as a series of reaches that have a distinct morphology, width and slope orientation. The changes occur as a result of entrainment and deposition of debris, which occur on a reach-by-reach basis along the event path. Accordingly, an event that initiates with a relatively small volume at the point of origin, may grow by orders of magnitude. This presents a considerable challenge for methods intended to predict the travel distance of an event, which must properly account for the impact of such changes.

	
Confined flow (CF) reach in a gully (view downslope along the event path).	*Debris flow event (view upslope from terminal point to point of origin).*

Concerted efforts have been made, in British Columbia, to conduct forensic surveys of debris flowevents that occur as a result of forest development activities. Data have been analyzed at the University of British Columbia, in collaboration with government and industry research partners. Field observations and inspection of the survey data have shown that reach morphology exerts a strong influence on flow behaviour.

During these studies, three modes of flow were identified: unconfined flow (UF) on an open slope; confined flow (CF) in a gully channel; and transition flow(TF) deemed to occur immediately upon exiting a gully channel onto an open slope. Transition flow typically occurs on the apex of a fan, but may also occur where a confined event crosses a road. Along the event path, UF reaches were found to exhibit a wide range of entrainment and deposition volumes. In contrast, CF reaches yielded moderate volumes of entrainment and small volumes of deposition. TF reaches experience large volumes of deposition and little, if any, entrainment. Although these findings arise primarily from fieldwork on the wet coastal region of British Columbia, they are corroborated by further work in the drier interior region of the Province. The findings of this work have supported the development and ongoing testing of an empirical approach to modelling debris flow travel distance.

Laboratory Observations - Deposition

Field observations of debris flowevents occurring are relatively few. Observations of laboratory tests using model scale flumes can aid our understanding of the mechanics of debris flows – and hence, help us to assess the spatial component of risk, P(S:H), given a particular geometry and set of materials. Of particular utility is that parametric studies can be undertaken with relative ease in flume studies.

A series of tests has been undertaken using a model-scale flume at the University of Canterbury in New Zealand. This flume, like many in use, effectively allows us to examine the penultimate reach (n-1) and final reach (n, the runout deposition zone) of a debris flow event. Material is contained in a hopper above the head of a sloped and confined section (the penultimate reach), which leads to a horizontal and typically unconfined section. For the sloped section, the apparatus may be configured to have either a fixed, non-eroding bed, such as found with bedrock, or to have an erodible bed. The volume and fall height of material, consisting of a soil and water mixture, is variable to enable a variable incoming flow quantity and rate. The slope angle and the geometry of the runout zone can also be altered. Studies thus far have examined the role of bed geometry and saturation on debris flow mobility and the influence of particle shape, size and size distribution on runout.

	
Model flume deposition:confined to unconfined flow (low viscosity).	*Model flume deposition:confined to unconfined flow (high viscosity).*

Flume studies can be used for parametric studies, in order to explain the significance of field observations and to explore, in a controlled manner, the influence of select variables. Accordingly, where field observations are used to develop empirical approaches to modelling debris flow travel distance, flume studies will inform on the applicability to different types of debris material. With careful attention to scaling laws, flume studies can also help to explain how, for example, deposition and entrainment are related to confinement and changes from one reach to another through reference to the underlying mechanics of materials.

Estimating Travel Distance

Analytical methods for determining travel distance may be categorized either as empirically-based or mechanics-based. Empirical models are typically based on limiting criteria or on statistical relations. Mechanics-based models may incorporate a rigid body analysis, energy-based approach, or the principle of continuum mechanics, with simplifying assumptions often made where input parameters cannot easily be measured. In contrast, empirical approaches do not address the material rheology or mechanics of movement.

In many situations where our understanding of material properties is limited and the flow path is controlled by subtle changes in terrain, empirical methods offer a practical means for predicting behaviour. However, there is an inherent limitation with empirical techniques, given the dependence of prediction on an adequate database of field observations for model development, and uncertainty in applying them in new areas that may differ from that used in model development.

UBCDFLOW

UBCDFLOWis an empirical model intended primarily to assist the user to better understand factors influencing the travel distance of debris flows. Accordingly, it is a decision-support tool, intended to supplement judgement and experience. For an assumed initial failure volume, changes in event magnitude arising from volumetric entrainment and deposition along the downslope path of movement are used to establish total travel distance. The model was recently made available on-line (http://www.civil.ubc.ca/ubcdflow). The UBCDFLOW user guide describes how to run a simulation, and includes a tutorial exercise for illustrative purposes. The UBCDFLOW model is launched from this site. Equations on which the model is based are reported, together with a list of published literature on development and application of the model.

The volume-based approach of the model involves the following controls. Initiation occurs for a user-defined initial failure volume in the first reach of the event. Thereafter, the morphology of each subsequent reach determines the flow behaviour (UF, CF or TF), and slope angle of the reach determines the mode of flow (entrainment or deposition). The volume of entrainment and (or) deposition is calculated using regression equations developed from analysis of field data. Given an initial failure volume, changes in event magnitude arising from entrainment and deposition along an anticipated event path are used to establish the point at which the cumulative flow volume diminishes to zero, and therefore the total travel distance.

Concluding Remarks

Concerted efforts are now being made to better understand the nature of debris flow hazards and, importantly, to develop improved tools and techniques in support of decisions on matters of risk management. In this article we provide insight to some of those efforts, with reference to ongoing use and analysis of field data at the University of British Columbia, Canada, and with reference to a program of flume experiments at the University of Canterbury, New Zealand. We believe that laboratory observations offer a means to understand the significance of field behaviour, based on principles of mechanics, and thereby lend confidence to the use of field observations in engineering practice.

UBDFLOW was developed using field survey data from debris flow activity on the Queen Charlotte Islands, British Columbia, based on an empirical statistical approach. Accordingly, it should only be used where the terrain is similar and where its suitability can be demonstrated through verification and experience.

Jonathan Fannin

Dr. Fannin is a Professor of Civil Engineering at the University of British Columbia. He has worked on processes of debris flow initiation through in-situ direct shearbox testing of hillslope soils, and piezometric monitoring of the groundwater response to precipitation. He has worked on processes of debris flow travel distance through field surveys and analysis of entrainment and deposition along the path of an event.

Elisabeth Bowman

Dr. Bowman is a Senior Lecturer at the University of Canterbury. She has worked on the mechanics of debris flow deposition through flume tests and has worked on the mechanics of debris flow entrainment through both flume and centrifuge tests.