

## Dynamics of Hazards within Watersheds

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### ABSTRACT

Geomorphic hazards within watersheds are dynamic involving three-dimensional changes along river systems which place lives (humans and animals), land and infrastructure in danger and these changes have short and long term consequences. The more common hazards are floods, landslides, debris flows, river bank erosion and these are interrelated; that is, the movement of water adjacent to or through soil changes the stability of the soil structure leading to failure which thereafter changes the character of the flowing water leading to additional failures. Hazards and water/sediment processes cannot be treated in isolation. A framework of study levels is presented which involves macro-meso-micro level assessment of hazards and watershed processes prior to developing programs for managing hazards. Several examples are presented which show the inter-relationships in space and time:

- debris torrents along Pattison Creek, British Columbia; and,
- glacier lake outburst floods in mountainous regions such as along the Sun Kosi in Nepal.

## INTRODUCTION

Geomorphic hazards within watersheds have been defined as any landform change, natural or otherwise that affects geomorphic stability at an isolated location and possibly further down the system (Schumm, 1988). The various hazards commonly occurring within watersheds, such as landslides, debris torrents, bank erosion and floods often occur in combination as opposed to isolated occurrences. For example, a logging operation in the upper portion of a watershed may cause a landslide adjacent to the logging road, then the downslope movement of the landslide material creates a debris torrent which moves down a steep channel and eventually drops the debris within a wide river valley resulting in diversion of flow currents and bank erosion. The short term changes during the debris torrent event (usually less than one hour) are generally followed by recurring long term events such as river bed aggradation and bank erosion. Schumm (1988) classifies hazards into three time frames:

- i) a catastrophic event
- ii) a progressive change that leads to an abrupt change; and
- iii) a progressive change with slow progressive results.

Often short term dynamic events such as landslides trigger long term river changes further down the system.

In order to understand the dynamics of various types of hazards a study framework should involve the following three space scales coupled to varying time scales as shown in Figure 1:

- i) macro-scale;
- ii) meso-scale; and
- iii) micro-scale.

The dynamics of the geomorphic hazards related to space as well as time.

## SCALES OF DYNAMIC STUDIES

Dynamic processes require dynamic studies in space and time.

The study of river basin processes and hazards becomes dynamic with the involvement of macro-meso-micro scales that are also linked through time. A macro-scale study provides a broad view of geomorphic processes and features of an entire basin as well as the utilization of the basin by man. An intermediate scale of study, meso-scale, thereafter concentrates on a specific reach of river that is undergoing change while the smallest scale study, micro-scale, focuses on a local landslide or bank erosion. These studies should also be over various time spans appropriate to the geomorphic processes, for example, a study of a debris torrent entails assessment of events over a period of the order of one hour while a longer time assessment is necessary for potential glacier lake outburst floods and mapping of historical landslides. Two case studies are presented illustrating the dynamic aspects of geomorphic hazards.

### DEBRIS TORRENT ALONG PATTISON CREEK BRITISH COLUMBIA

The lower Mainland region experienced a major storm between November 8 and 10, 1990. Although very significant in terms of 1 and 2 day rainfall (35 to 100 year return), the storm appears to have lacked the concentrated cells of high precipitation which are usually responsible for the generation of debris flow activity. Consequently, the predominant type of damage was due to flooding associated with the larger streams. Pattison Creek was one of a few small drainages which suffered instability during this storm (Thurber Engineering, 1990).

The debris flow was initiated by a landslide in

a small gully at el. 940 m (Figure 2). The landslide scar is up to 50 m wide, 100 m long and 10 m deep. It occurred on a section of slope inclined on average at 25°. The side scarp reveals glacial till consisting of silty sand, gravel and cobbles.

The initial slide occurred in an area clearcut some 30 years ago, at a point where a logging road crossed the head of the gully. However, causal connection between the occurrence of the landslide and logging is not clear. Certainly, decay of root strength, often used as an explanation of post-logging instability, could have played no significant role in this deep-seated failure. Also the cut and fill created by the road is very small compared to the depth of the sliding surface.

The most probable explanation of the slide is that the logging activity changed the surface flow and infiltration conditions at the head of a soil filled gully. The road may have diverted surface flow from adjacent drainage paths, changing the water balance in the gully sufficiently to raise pore-pressure and trigger sliding near the soil-bedrock contact. Such a trigger is very common on the B.C. coast, based on the authors' experience. In each case, there is an amazing contrast between the inconspicuous cause - diversion of water along a segment of an old road and the dramatic effect - a major and violent slide.

The initial slide volume was estimated as 25,000 m<sup>3</sup>. Of this total, approximately 7,000 m<sup>3</sup> remains deposited on the base of the landslide scar. The remaining 18,000 m<sup>3</sup> entered a small gully and then a minor branch of the creek, stripping a wide swath of young and old forest and soil. A large part of the debris flow track below the initial slide has been eroded down to bedrock, producing more than 60,000 m<sup>3</sup> of debris additional to that of the initiating slide.

At el. 600 m, the debris flow track widens and deflects to the left (east) on encountering a bench formed of ice contact deposits. At this point, the debris flow narrowly missed the head of the large slide scar formed during the 1960 debris flow, which is still actively eroding (Figure 2).

Below el. 600, the debris flow track follows a confined bedrock gorge to a confined alluvial fan. The peak discharge of the debris surges was probably of the order of 200 to 400 m<sup>3</sup>/s at the head of the fan.

The bulk of the debris deposited within approximately 800 m of the confined fan apex, on slopes ranging from 8° to 9°. The debris tongue in this main deposition area is up to 50 m wide and probably 2 m deep on average, containing an estimated volume of 54,000 m<sup>3</sup>. A further 30,000 m<sup>3</sup>, approximately, of finer material (afterflow) was spread over 1,250 m length of channel downstream of the main deposit. The afterflow volume was estimated by assessing the dimensions of the active flow channel existing through the debris deposition zone.

The water-sediment process during and directly after the debris torrent changed from deposition along the confined alluvial fan to one of erosion by afterflow. Of significance, is that the erosion process over the confined fan deposit will continue to supply sediment to the lower reaches of Pattison Creek and Lagace Creek which will entail annual gravel excavation if future flooding of the Hatzic Prairie floodplain is to be avoided.

In studying the impact of this geomorphic event, the scope of investigation involved assessment of about 10 km of channel as well as prediction of the consequences over the next 10 year period. This prediction into the future included the possibility of another debris torrent event especially if the older

landslide shown in Figure 2 headcuts into the 1990 landslide. If a time scale was not a part of the impact study, the community along the creek may not be prepared for another debris torrent.

## GLACIER LAKE OUTBURST FLOOD IN NEPAL

As another example, consider the glacier lake outburst flood that occurred on the Sun Kosi in 1980 and was followed by a similar debris torrent flood caused by a cloudburst in 1986 (Galay, 1989). The 1980 flood caused extensive damage to the Arniko Highway (see Figure 3), destroyed three major highway bridges and took out three control gates on the diversion structure of the Sun Kosi Hydro Plant. The glacier flood was believed to be caused by piping through an end moraine originating in China (the Boquot River). However, its consequences were not studied over an extensive reach of river (macro-scale). Also the time dimension was not considered as noted by the following facts:

- i) the second destruction of the Arniko Highway in 1986 by a debris torrent means that no consideration was given to the possibility of another flood event within the lifetime of the highway. The old highway was reconstructed at the same location and was not raised above the 1980 flood levels; and
- ii) the destruction of three gates (1986) on a diversion structure used to divert water to a hydro plant did not include clear instructions for procedures to open and close during flood events. Nothing was learned from the destruction of gates during the outburst flood of 1980.

There was no short term (1 or 2 hours) acknowledgement of characteristics of debris torrent events or glacier floods on the Sun Kosi. Studies did not include the macro-meso-micro space dimensions, nor the time scale which means that the study of hazards and processes along this system was not dynamic.

## DISCUSSION

Approaches to study of geomorphic hazards have generally been at isolated locations. Models of the mechanics of landslides have been developed by geotechnical specialists (Terzaghi and Peck, 1948); and Valdiya (1987), and bank erosion models were developed by Thorne (1982). These models are at isolated locations and attempts are being made to link these events through space by hazard mapping (Petak and Atkisson, 1982), but this representation generally does not adequately bring in changes with time. Some hazard maps designate the degree of hazard using terminology such as "high probability for damage" and "low probability for damage", but these terms are rarely defined numerically. This linkage of hazards in space and time is being researched (Clague, 1982; Ives, 1986) and will be receiving more attention.

## CONCLUSION

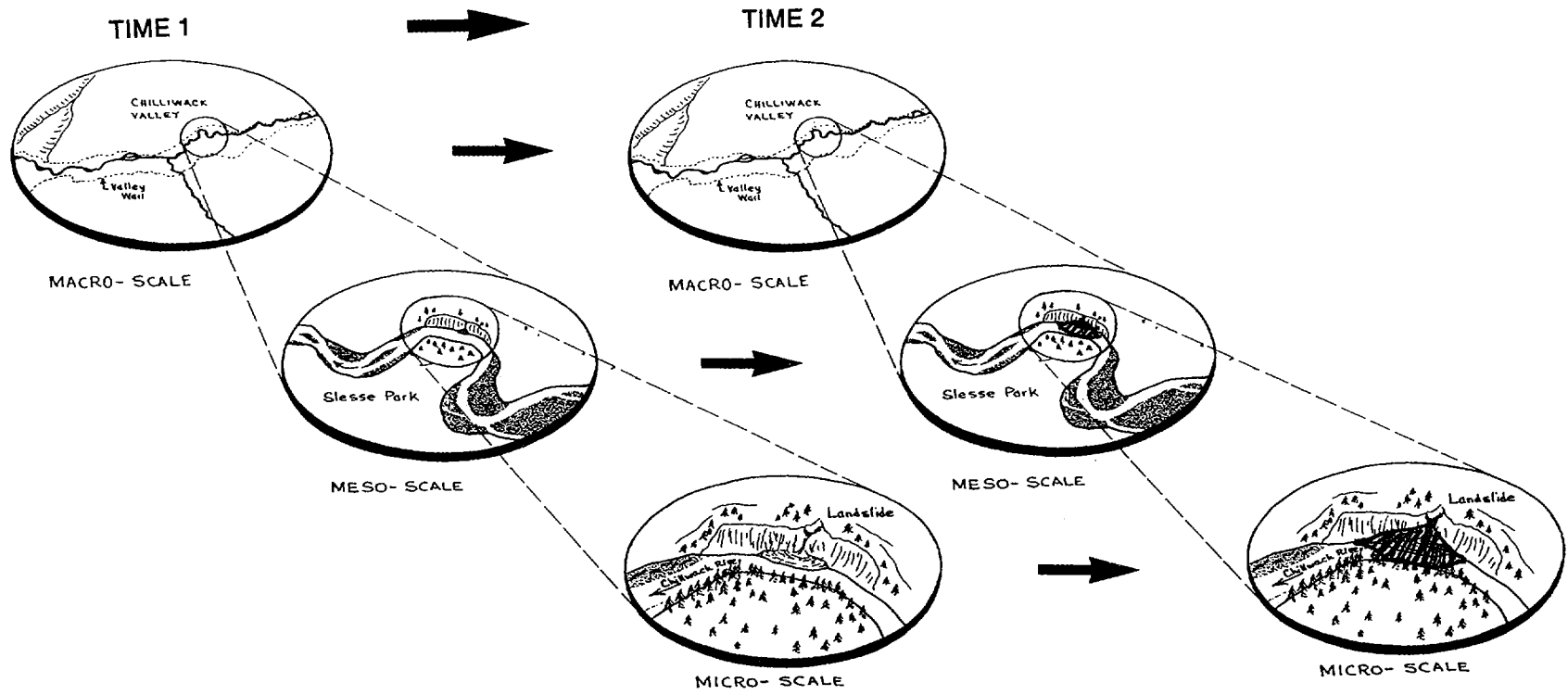
Geomorphic hazards within watersheds result in changes along river systems (space dimension) as well changes with time resulting in a dynamic response to hazard events such as landslides, debris torrents, floods etc.

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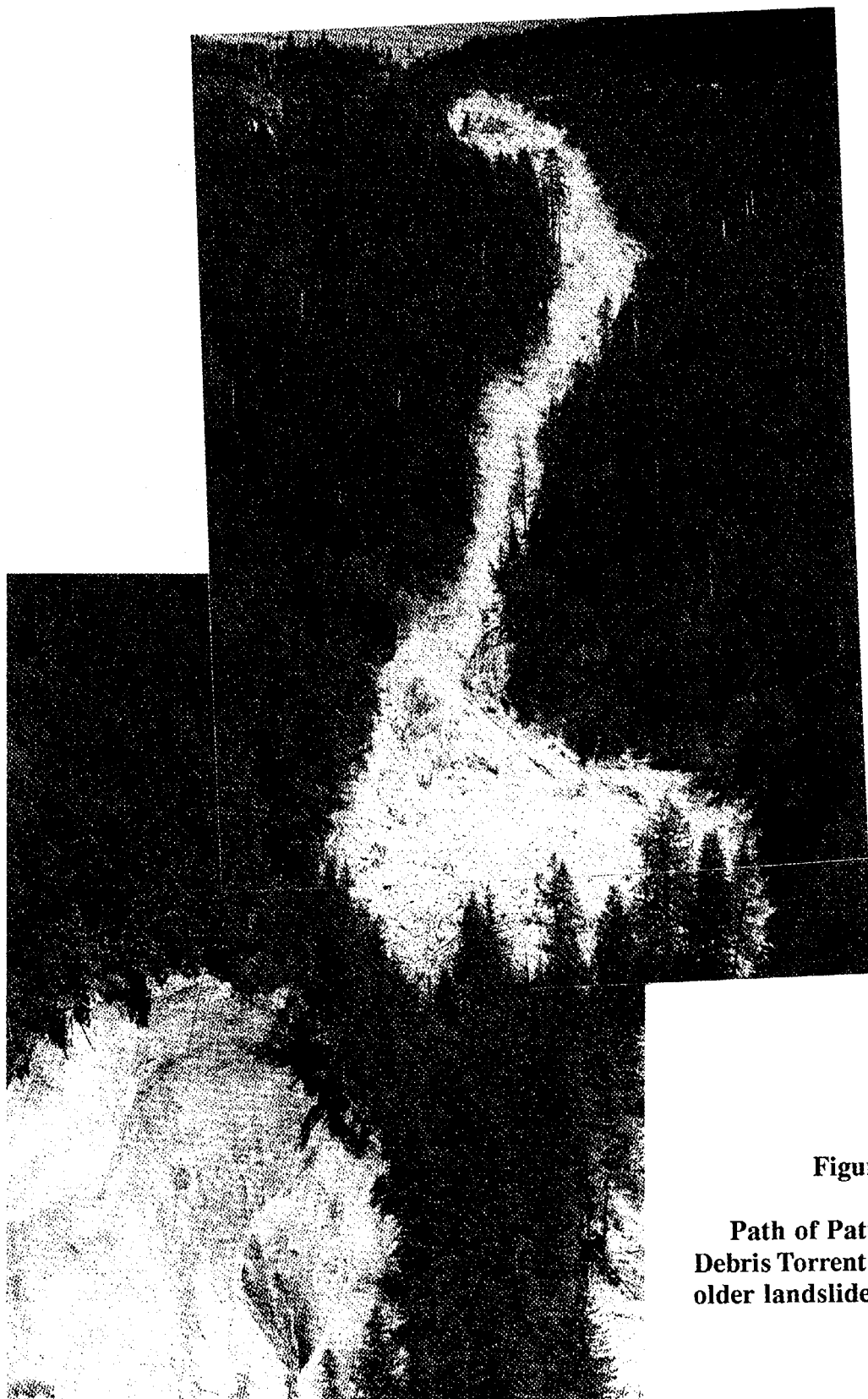
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**FIGURE 1**  
**SCOPE OF GEO-HAZARD STUDIES**  
**INVOLVING SPACE AND TIME**



**Figure 2**

**Path of Pattison Creek  
Debris Torrent just bypassing  
older landslide shown at left.**



**Figure 3**

**Arniko Highway - Nepal**

**Highway was destroyed by debris torrent  
in 1986 after being previously destroyed  
by a glacier lake outburst flood in 1980.**



**Figure 4**

**Diversion Structure on Sun Kosi - Nepal.**

**The three left gates have been totally destroyed  
by a debris torrent in 1986.**

**The three gates on the right were being opened  
just prior to the flood surge.**