

## Geomorphic Fans and Their Watersheds: managing risky systems

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### Summary

History has demonstrated that hydrogeomorphic hazards exist for infrastructure on geomorphic fans, including loss of lives, damaged roads and drainage structures, destroyed homes, and overwhelmed water intakes (Figure 1). While site investigations are essential for developments on fans, it is critical to assess the associated watershed for hydrogeomorphic hazards. Natural processes such as wildfires and land use changes such as timber harvesting can influence the hydrogeomorphic processes in a watershed with potentially significant implications for downstream fans. A 5-step approach is presented to analyze risks from the perspective of the fan-watershed system.



Figure 1. A debris flow initiated as a result of a localized heavy summer rain shower in a watershed following wildfire. Two homes were destroyed and the highway was closed for several days. (Source: D. Boyer, B.C. Ministry of Environment.)

## Introduction

Fans are cone-shaped landforms resulting from sediment deposition where streams lose confinement. Commonly fans are found in valley bottoms, but they can also be located on benches in mid-slope positions. Sediment originates in a source-area watershed and is transported to fans by hydrogeomorphic processes—debris flows, debris floods, and floods. Transport can be episodic or frequent, and often results in the stream channel becoming overwhelmed with sediment and water and resulting in the disturbance of at least a portion of the fan surface. These events can pose a significant hazard to human life and infrastructure on fans (Sidle et al. 1985; Septer and Schwab, 1995; Wilford et al., 2003). Changes in watersheds, whether natural as in wildfires or due to land use as in forest harvesting, can change water and sediment regimes. This can lead to changes in the timing, magnitude, and frequency of hydrogeomorphic events affecting fans. Whether geoscientists are asked to analyze risks associated with planned land use changes on a fan or in the watershed, it is essential to analyze the entire fan-watershed system—not just the specific site under consideration. A 5-step approach was developed to assist land managers when planning land use in watersheds (Wilford et al. 2009). However, the utility of this approach goes beyond forestry, for example, assisting the analysis of risks associated with climate-induced changes (e.g., increased frequency and intensity of wildfires, forest health issues such as the mountain pine bark beetle in British Columbia). The 5-step approach provides a framework to manage and mitigate hydrogeomorphic risks on fans through the study of the fan-watershed system.

The 5-step approach is based upon a body of knowledge regarding fan-watershed systems from British Columbia and beyond. Notable sources include a multi-year investigation of forested fans across British Columbia (Wilford et al. 2005; Millard et al. 2006), *Land Management Handbook 56: Landslide Risk Case Studies in Forest Development Planning and Operations* (Wise et al. 2004), and *Debris Flow Hazards and Related Phenomena* (Jakob and Hungr 2005).

## Method

The framework of the 5-step approach for analyzing risk in fan-watershed systems is:

- **STEP 1: Identify Fans and Delineate Watershed(s)**
  - Identify the physical inter-connections that exist between source areas (watersheds) and fans.
- **STEP 2: Identify Elements-at-Risk on Fans**
  - Recognize and inventory values on the fan that may be affected by hydrogeomorphic processes generated in the watershed.
- **STEP 3: Investigate Fan Processes**
  - Identify the nature of hazardous hydrogeomorphic processes (type, frequency, and disturbance extent).
- **STEP 4: Investigate the Watershed Processes**
  - Identify watershed features controlling hydrogeomorphic processes (e.g., watershed hydrology, geomorphology, and the role of vegetation cover).
  - Identify the potential for incremental hazards associated with natural and land use changes in the watershed.
- **STEP 5: Analyze Risks and Develop Plans**
  - Develop planning options for the watershed and analyze the associated risks.
  - Document the process and establish a plan to monitor, evaluate and report.

## Example: Hummingbird Creek Case Study

Hummingbird Creek and its associated fan, Swansea Point, is located on the east side of Mara Lake in the southern interior of British Columbia. Approximately 250 people live on the Swansea Point fan, and the fan is crossed by Highway 97A. The watershed of Hummingbird Creek is essentially a plateau that drops steeply to Mara Lake, a situation referred to as “gentle-

over-steep” (Grainger 2002), and the stream channel is deeply dissected into the plateau surface. In 1997, a forestry-road related drainage diversion on the edge of the plateau resulted in a 25,000 m<sup>3</sup> debris avalanche that destabilized the mainstem streambed upon impact. A further 67,000 m<sup>3</sup> of sediment and debris was entrained from the channel as the debris avalanche evolved into a debris flow. Running out onto Swansea Point, the event deposited sediment and debris across the fan and into the lake. Two homes were destroyed, several homes were damaged, and Highway 97A and local roads were buried by sediment (Inter-agency Report 1997).

This case study is a retrospective analysis to highlight the application of the 5-step approach where it may have prevented a disaster from occurring. This analysis is not meant as a criticism of practices, which according to a review by the Forest Practices Board were to the standards of the day.

**Step 1. Identify fans and delineate watersheds** – This would bring attention to the connection between the upper plateau areas of the watershed where forest activities were planned, and the fan several kilometres away.

**Step 2. Identify elements-at-risk on fans** – The presence of many risk elements (residences, a provincial highway and other infrastructure) that could potentially suffer losses would be identified. Damage to residences, infrastructure and the highway would be considered a high consequence. Potential human injury or loss of life by residents or highway users would be considered a very high consequence. These consequences would require the risk investigation and field operations be carried out to a high standard.

**Step 3. Investigate fan processes** – This would reveal the presence of debris flow or debris flood deposits on the fan. With the potential for high consequences, a review of past events would be appropriate. Historical aerial photographs show evidence of past hydrogeomorphic activity in the form of a major channel avulsion. A review of published and oral history in the area, as was done subsequent to the 1997 event, confirmed the occurrence of at least one large event over half a century ago. From this evidence, it could be concluded that Hummingbird Creek could produce a large damaging event, and that a considerable period had elapsed since the previous event.

**Step 4. Investigate watershed processes** – Although an historical event was confirmed in Step 3, the exact hydrogeomorphic process was unknown. Therefore, linkages to be considered in light of natural and land use changes in the watershed would include both the production and delivery of sediment as well as increases in peak flow runoff. Landslides are the main source and delivery agent of sediment to channels, and the potential for natural landslides exists along the lower stream reach. A landslide entering the channel might deposit in the narrow valley, forming a dam that could be breached, initiating a debris flood or debris flow and travel downstream to the fan. Management of incremental landslide hazards on the steep slopes adjacent to the channel would be identified as a concern. Drainage diversions would also be of high concern on the moderate slopes above the steep stream-side slopes. Prior to the Hummingbird event, management of road and trail drainage on such “gentle-over-steep” plateau terrain was not widely recognized as a serious hazard. Subsequent to the 1997 debris flow, management of forest harvesting in gentle-over-steep terrain has been addressed through research and the development of best practices. An assessment of the channel above the fan to determine sediment and woody debris loads available to be mobilized would have found high levels of entrainable material prior to the 1997 event. This would have informed investigators of the potential for a large event. Given the state of knowledge prior to 1997 it would have been considered possible, but unlikely, that a landslide affecting the relatively low-gradient (average 27%) channel would initiate debris flow. Subsequent to this event, and several other recent events in southern interior British Columbia, there is an increased awareness of the potential of large debris flows in relatively low-gradient channels.

**Step 5. Analyze risk and develop plans** – If one were to complete this step today for a similar set of conditions as existed at Hummingbird Creek prior to 1997, and with the knowledge of forestry operations and watershed processes we now have, the available evidence would indicate that there was a moderate likelihood of a landslide affecting the channel and resulting in a hydrogeomorphic event that would reach the fan. With the very high consequences existing on the fan, there would be a high incremental risk associated with the proposed forest development on the upland plateau, and further risk management would be appropriate in any subsequent plans. From a forestry perspective, the most feasible course of action would be to reduce the incremental timber-harvesting-related hazards. With the hindsight we now have regarding management of gentle-over-steep terrain and resulting landslide hazards, it would be recognized as appropriate to fully deactivate the roads and trails within cutblocks immediately following harvesting to maintain natural drainage paths. This deactivation would likely have prevented the drainage diversion and prevented the initiation of the landslide.

If a steep area downslope of a potential timber-harvesting area is judged to have a moderate or higher natural landslide potential, harvesting could be restricted within a specified distance of the marginally stable slope. This was probably not the case at Hummingbird Creek prior to 1997. Although we can never know for sure what the outcome of various management options would have been, it is likely that if some or all of the above risk-mitigation steps had been taken, harvesting and road building on the upland plateau above Hummingbird Creek could have occurred without causing a major debris flow.

## Conclusions

Application of the five-step method for analyzing and managing risk in fan-watershed systems may not always prevent impacts, but it does provide a framework to rigorously explore hydrogeomorphic hazards, consequences, and risks.

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