Manaaki Whenua
Landcare Research

Peer review of report: "The significance of sediment stored behind log jams to the 2005 Awatarariki debris flow; implications for risk management" by Prof. Tim Davies

Prepared for: Whakatāne District Council

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Peer review of report: "The significance of sediment stored behind log jams to the 2005 Awatarariki debris flow; implications for risk management" by Prof. Tim Davies

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Contents

Summary

Project and Client

- Whakatāne District Council approached Manaaki Whenua – Landcare Research (MWLR) to undertake a peer review of a report by Dr Tim Davies (Davies 2017) on the significance to the 2005 Awatarariki debris flow of sediment stored behind log dams. The review also includes an assessment of the approach, its veracity in terms of assumptions used, and the conclusions drawn to support the two Whakatāne District Council plan change proposals.

Objectives

- Review and assess the approach used in Davies (2017), its veracity in terms of assumptions used and indicated, and the conclusions drawn
- Scan the international and local literature on the occurrence and controlling factors for debris flow as they might relate to log jams and sediment dams
- Report results of the review in the context of the literature and the conclusions of the earlier report in terms of the implications for risk management and for properties within the high risk debris flow area on the Awatarariki fanhead.

Methods

- Review Davies (2017) report
- Undertake a literature scan to determine published accounts of log jam contributions to debris flow volumes
- Provide a report summarising peer review comments, any additional literature/evidence relating to the issue of log-jam contribution to debris flows, and conclusions drawn.

Results

- The methodology and assumptions used by Davies (2107) to calculate the volume of wood and sediment stored in log jams and its contribution to the total volume of the debris flow deposit were appropriate, given the limited information available
- The conclusions drawn by Davies (2017) considering the contribution of log jams to sediment delivery were also appropriate to the risk assessment
- The literature scan did not provide any significant additional evidence to change the interpretation or conclusions drawn by Davies (2017)

Conclusions

- Log jams, while posing a risk in principle to the generation and volume of future debris flows, are not likely to be significant in terms of total volume of sediment generated and future hazard
- In addition, the removal of such dams would be logistically difficult, involve on-going cost, and provide little benefit to the reduction in risk from future debris flows.

1 Introduction

In May 2005, heavy rainfall resulted in a debris flow in the Awatarariki stream in Matatā. It caused significant damage to land, buildings, and road and rail infrastructure. While there were no deaths or injuries, the destructive force of this natural hazard was such that these could easily have been an outcome.

Whakatāne District Council (WDC) approached Manaaki Whenua – Landcare Research (MWLR) to undertake:

1. a peer review of a report by Prof Tim Davies (Davies 2017) (Appendix 1) on the significance to the 2005 Awatarariki debris flow of sediment stored behind log jams, including an assessment of the approach, its veracity in terms of assumptions used, and the conclusions drawn to support the two WDC plan change proposals
2. a brief scan of the current international literature (and any recent NZ literature) that might pertain to the role of log jams, stored sediment, and their contribution to debris flows
3. a report detailing the assessment, the literature scan, and any additional information that might assist the council in relation to the issue of log jams and their contribution to debris flow hazards from the Awatarariki catchment at Matatā.

2 Background

Landslides leading to debris flows are common in many parts of New Zealand, particularly in steep terrain. Most occur in areas of steep slopes, high sediment supply, and high storm rainfalls, where the input of large amounts of sediment from landslides causes debris flows in the associated stream channels (McSaveney & Davies 2005; McSaveney et al. 2005; Bowman & Davies 2008; Welsh & Davies 2010; Bowman & Kailey 2010; Kailey 2013).

An investigation by GNS Science (GNS) into the causes of the debris flows in 2005 confirmed they were a natural event triggered by exceptionally heavy rain. GNS also confirmed there was evidence that equally as large, and larger, debris flows have occurred many times over the last 7,000 years and that historical records indicate that probably four smaller debris flows have occurred since 1860.

Between 2005 and 2013, the WDC investigated risk mitigation engineering options in the upper catchment and on the fanhead. Expert engineering advice subsequently confirmed that no viable engineering solutions existed to manage the risks associated with future debris flows from this catchment.

Since 2013, the WDC has focused on reducing the risk to life through a planning approach. This has included an assessment of risk from future debris flows, investigations of non-engineering solutions that might reduce the risk to residents, and initiating changes to the Whakatāne District Plan and the Bay of Plenty Regional Council Regional Natural Resources Plan. The non-engineering solutions have included provision of early warning systems and proactive catchment management.

3 Objectives

- Review and assess the approach used in Davies (2017), its veracity in terms of assumptions used and indicated, and the conclusions drawn.
- Scan the international and local literature on the occurrence and controlling factors for debris flow as they relate to log jams and sediment dams contribution to debris flow volumes
- Report results of the review in the context of the literature and the conclusions of the earlier report in terms of the implications for risk management and the Whakatāne District Plan.

4 Methods

4.1.1 Report peer-review

The report of Professor Tim Davies (Appendix 1) was provided by Whakatāne District Council (Jeff Farrell). It was reviewed, the calculations checked, and the conclusions assessed. While the scope of this review was limited to that report, some of the earlier reports relating to the Awatarariki stream in Matatā (including Douglas (2017), Arts (2005), and Tonkin & Taylor (2015)) were read to provide context for the peer review. However, comments in this report are restricted specifically to the Davies (2017) report.

As this report neared completion, Whakatāne District Council made available an undated report by local soil conservator John Douglas (Douglas 2017) that had been requested by residents of Matatā under a local government official information request. That report, which provides background information on the Awatarariki catchment including previous investigations, an account of the 2005 debris flow event, and details of the presence of debris storage structures (log jams), was also read in the context of the peer review.

4.1.2 Undertake a brief scan of relevant literature

A brief literature search using the Web of Science was undertaken using search terms, “log jams”, “debris flows”, “debris dams”. Over 1000 records were identified. They were reduced to 179 by Manaaki Whenua library services and then titles were scanned to produce a final number (40) that were assessed in terms of providing any additional evidence of the role of log jams, or sediment dam breaches relating to debris flow volumes.

I also informally contacted a colleague in Europe (Dr Massi Schwarz, board member of ecorisQ – a global community of professionals working on natural hazard risk management) who undertakes research on mountain hazards, protection forests, debris flows, and wood recruitment into streams and rivers to determine if there was any published or grey literature/information that might assist in understanding the specific contribution of log jams to debris flows.

5 Results

5.1.1 Report review

The approach taken by Prof Davies assumed that log jams within the tributaries and main stem of the Awatarariki stream channels had trapped both sediment and large woody debris above the stream bed and that the volume retained could be calculated as a simple wedge. Further assumptions on the number and heights of each debris dam were based on field observation from a reliable source (Douglas 2017).

The approach taken to assess the total volume retained was appropriate given the lack of detailed information on the number, frequency, and dimensions of the log dams. Unlike the case reported by Pearce & Watson (1983) where log jams where surveyed and the volumes of wood and sediment determined, the estimates provided by Douglas (2017) and the assumption on the number and their dimensions assumed by Davies (2017) suggest that this was an appropriate approach to take in the absence of more detailed information.

The calculations of the volumes retained by the log jams and their overall contribution to the total volume of the debris flow also seem appropriate. I concur that the total estimate of 40,000 to 50,000 m^3 should be treated as an upper limit due to the conservative estimates of dimensions and number of dams used in the calculations. There is one small error in relation to stream length as part of Davies' (2017) calculations that could be a rounding error in the calculation of the channel lengths. This does not, however, affect the result (Page 2 – "If we assume the spacing applies to the remaining 4.8 km of tributary channels…"). This should be 4.7 km as total channel length is 7.5 km, and the main channel is 2.8 km, which makes the remainder of tributaries equal to 4.7 km (7.5–2.8 = 4.7).

I concur with the conclusions drawn by Davies (2017) in terms of the log jam volumes contribution to the total volume deposited by the debris flow. There is little other information that would refute either the calculations or the conclusions presented. In the absence of any additional information, the conclusions drawn concerning the future risk and contribution of log jams to that risk are, in my opinion, sound.

I agree with Prof Davies conclusion: "thus while managing the log-jam storage artificially will in principle reduce the future risk to the fan, *it is not possible to estimate what the degree of risk reduction will be*; and in particular, the risk reduction cannot justify modification to the decisions already made about managing fanhead risk".

I also concur that maintaining the Awatarariki channel free of log jams would be logistically difficult and would require on-going regular maintenance. This creates an on-going cost that is likely to be unjustified. A common practice in Europe to minimise the local risk of log build up in low order channels is to cut logs into smaller lengths for removal or so that they can move in more common flood events and pass infrastructure downstream (M. Schwarz pers. comm.). While this seems a practical solution, it essentially transfers the problem downstream if the logs are not removed completely from the channel and potential floodway. In the case of the Awatarariki stream, log removal would be impractical due to access to the channel.

5.1.2 Literature scan

The 40 returns from the Web of Science search produced little in the way of published papers that directly discuss the role of log jams or debris dams in debris flow formation, or to increasing the volumes of debris flows. There is considerable literature on the role of logs, log jams or barriers and woody material (large woody debris (LWD), large wood (LW)) pertaining to stream geomorphological controls, fish habitat, sediment storage and delivery, and their management to reduce downstream impacts of floods (e.g. Montgomery et al. 2003; Seo et al. 2010; Erskine et al. 2012; Dixon & Sear 2014; Wohl 2017). There is also considerable literature on debris flows – their occurrence, behaviour, control, influence on sediment delivery, and as a hazard. Many of the publications do not mention wood or logs and where mention is made, there is usually no information on the specific contribution of log jams to the increased risk of debris flows.

There is global literature related to landslide damming of stream channels and subsequent breaching contributing to debris flows that resulted in loss of life and damage to infrastructure (Adhikari & Koshimizu 2005; Ahmed et al. 2015); debris flows that caused fatalities (Dowling & Santi 2014; Rodolfo et al. 2016); weather-induced landslides and debris flows (Del Ventisette et al. 2012; Sepulveda et al. 2014; Lauro et al. 2017), lake outbursts causing catastrophic debris flows (Allen et al. 2015; Stefanelli et al. 2018); debris flows resulting from landslide dam breaches (Zhou et al. 2013; Ahmed et al. 2015); volcanic-related debris flows arising from lake breaches (Andrews et al. 2014; Wang et al. 2018); earthquake-induced landsliding resulting in debris flows (Ge et al. 2015; Chang et al. 2016); debris flows as landscape change agents (McCoy 2015); landslides and debris flows following fires (Diakakis et al. 2017); wood recruitment processes (Steeb et al. 2017); debris dams and debris flows (Lancaster et al. 2001, 2003; Lancaster & Grant 2006; Lancaster & Casebeer 2007); log jams' role in retention of coarse particulate organic matter (CPOM), its mobilisation in large floods (Ruiz-Villanueva et al. 2014, 2016; Jochner et al. 2015; Comiti et al. 2016); and the effects of log jams on hydraulics (Manners et al. 2007). Literature also relates to the use of vegetation as a mitigation tool in the control of landslides and debris flows (e.g. Phillips et al. 2013; Wang et al. 2017). Much of this literature is useful in understanding debris flows as a natural process and hazard, but is less relevant in the context of this report. Little additional evidence of the role of log jam volumes to debris flows has been found.

The New Zealand literature related to log jams, debris dams, and their impacts on subsequent debris flows is virtually non-existent, with the only reference being Pearce and Watson (1983), to which Prof Davies referred in his assessment. Following the pattern of the international literature there are limited publications on the topics listed above, including, for example, on weather-related landslides and debris flows (Phillips et al. 2017; Rosser et al. 2017) and earthquake-induced landslides and debris flows (Dellow et al. 2017).

In summary, there is little to no literature specifically and quantitatively linking log jams contribution to debris flows, i.e. to the issue discussed in Davies (2017).

5.1.3 Assess the conclusions in the report considering the literature scan

The literature scan of publications within the last 10 years revealed little that directly challenged the interpretation of Davies (2017). While there is a range of literature related to the role of organic material within channels that frequently are affected by debris flows, nothing was found that related directly to the situation as commented on by Davies (2017) for the Awatarariki stream in Matatā.

6 Summary and conclusions

The approach taken by Davies (2017) to assess the total volume of sediment retained by log jams was appropriate, given the lack of detailed information on the number, frequency, and dimensions of the log dams. Similarly, the conclusions drawn by Davies (2017) in terms of the contribution of log jam volumes to the total volume deposited by the debris flow is also appropriate, considering the precision of estimates of both the contribution from the log jams and the actual estimate of the debris flow deposits. There is little other information that would refute either the calculations or the conclusions presented. In the absence of any additional information, the conclusions drawn concerning the future risk and contribution of log jams to that risk are, in my opinion, sound.

The literature scan did not provide any additional evidence to change the interpretation or conclusions drawn by Davies (2017).

The conclusion, therefore, is that log jams, while posing a risk in principle to the generation and volume of future debris flows, are not likely to be significant in terms of future hazard and that removal of such dams would be logistically difficult, involve on-going cost, and would not provide any significant benefit to the reduction in risk from future debris flows.

7 Acknowledgements

Jeff Farrell is thanked for providing contextual information about the debris flow hazard and the Whakatāne District's planning response to earlier reports. Les Basher reviewed the report and Anne Austin edited it.

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Appendix 1 – Report by Prof Tim Davies (Davies 2017)

THE SIGNIFICANCE OF SEDIMENT STORED BEHIND LOG DAMS TO THE 2005 AWATARARIKI DEBRIS FLOW; IMPLICATIONS FOR RISK MANAGEMENT

Tim Davies, Dept of Geological Sciences, University of Canterbury

Summary

Based on field information and published data, it is unlikely that debris stored behind log-jams in the Awatarariki Stream prior to the 2005 debris flow contributed significantly to the magnitude of the event. Therefore the debris-flow risk on the Awatarariki fan cannot be reduced significantly by keeping the Awatarariki Stream channels free of log-jam dams.

Introduction

The 2005 debris flow in Awatarariki Stream, Matata, Bay of Plenty in 2005 deposited an estimated 300000 – 500000 m3 of debris (comprising boulders, gravel, sand, silt and organic debris) on the Awatarariki fan, severely damaging many properties (McSaveney et al., 2005). The future risk to dwellings on the fan, made evident by this event, is proposed to be managed by retreat from the area of the fan in which the risk is assessed as unacceptable. This area has been delineated by modelling potential future debris flows, based on the 2005 volume being 300000 m3, and by mapping of the spatial distribution of boulders on the fan after the event (Tonkin & Taylor, 2015).

The sources of the debris that made up the debris flow are (i) rainfall-induced hillslope debris avalanches that delivered sediment and organic material to the stream-bed (Appendix 1 Fig. A1); (ii) material comprising the stream-bed above bedrock that was eroded, in many places down to the bedrock, by the debris-flow (Appendix 1 Fig. A2); and (iii) material that was stored above the stream-bed in natural log-jam dams (Appendix 1 Fig. A3). While (i) and (ii) cannot be influenced by management, the possibility exists that artificial removal of log-jams, if feasible, could reduce the quantity of material in a future debris-flow and thus reduce the future risk to dwellings on the fan – perhaps to the extent that the current retreat policy can be relaxed.

The purpose of the present work is to estimate the volume of sediment in source (iii) prior to the 2005 debris flow, in order to assess the degree to which future risk can be managed by removal of log-jams, thus allowing the stored sediment to be moved down the stream by minor storms and thus not contribute to the volume of a future debris flow event.

Data

While information on log-jam dams in the Awatarariki stream system is sparse, John Douglas reports that such features were certainly present in the stream during his inspections since 1993. He recalls climbing over debris dams 6-8 m high which retained sediment to form a flat plain upsteam of the dam, upstream of which was usually a lake before the stream-bed appeared again (Fig. 1). He also re-calls finding about 10-12 such dams in the Awatarariki Stream.

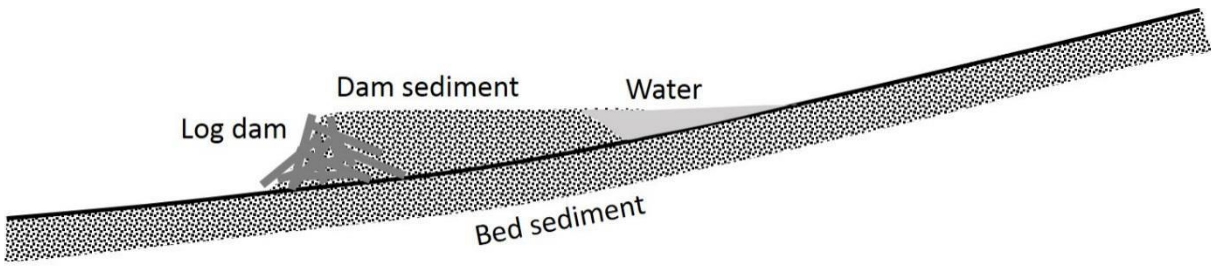

Figure 1. Schematic diagram of sediment storage by log-jam dam.

These data can be compared with the only published information on log-jams in NZ streams, and the volume of sediment stored. Pearce and Watson (1983) surveyed six streams in the Notown area of Westland following a series of rainstorms, and documented 35 log-jams up to 8 m high retaining a total of 25200 m3 of sediment and 4700 m3 of logs in a total channel length of about 10 km; one longitudinal profile from this study is shown in Fig. 2.

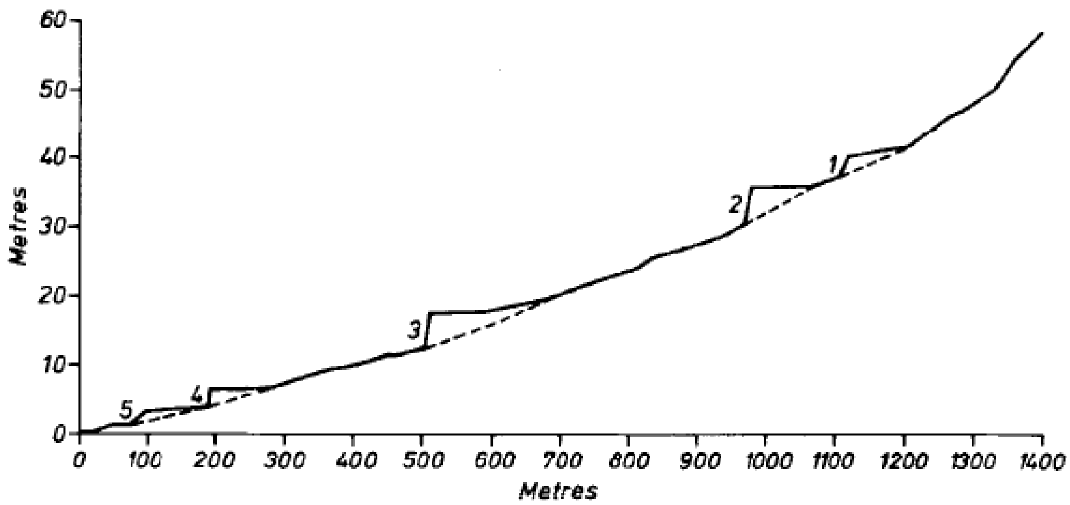

Figure 2. Ryan's Creek, Notown (Pearce and Watson, 1983); longitudinal profile with debris dams shown. Debris dams contained about 7000 m3 of sediment in total.

Retained sediment volume

The total channel length of the Awatarariki Stream, including tributaries, is about 7.5 km (Fig. 3). While the gradient of the 2.8 km long main channel is about 5%, that of the tributaries is about 10%. First we estimate the total number of dams in the system; John Douglas found 10-12, presumably in the main channel, which is about one every 250 m. If we assume this spacing applies to the remaining 4.8 km of tributary channels, we would expect about another 20 dams, making about 30 altogether.

In the main channel, with S = 0.05, 12 dams each say 7 m high would each retain 72/2 x 0.05 = 490 m2 of sediment longitudinal section area giving a total of about 6000 m2. To find the volume we need to multiply the longitudinal area by the width; this will obviously vary significantly, and will not be uniform with height, so we estimate an average width of 5 m, giving a volume of the order of 30000 m3.

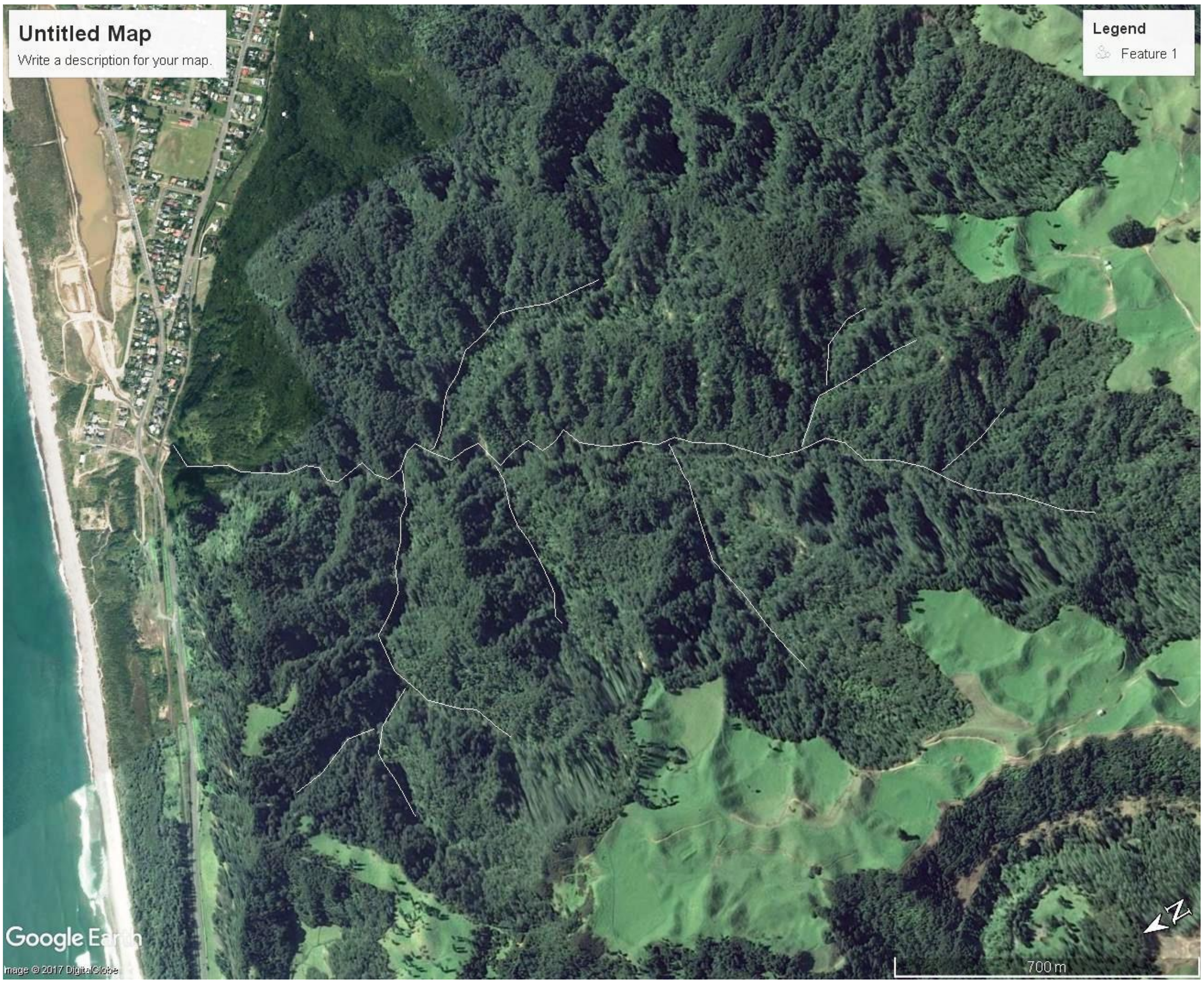

Figure 3. Google Earth image of Awatararíki Stream with channel network outlined in white.

The volume of sediment retained in a dam depends on the dam height and channel slope (Fig. 4); here we ignore the small lake often present (Fig. 2).

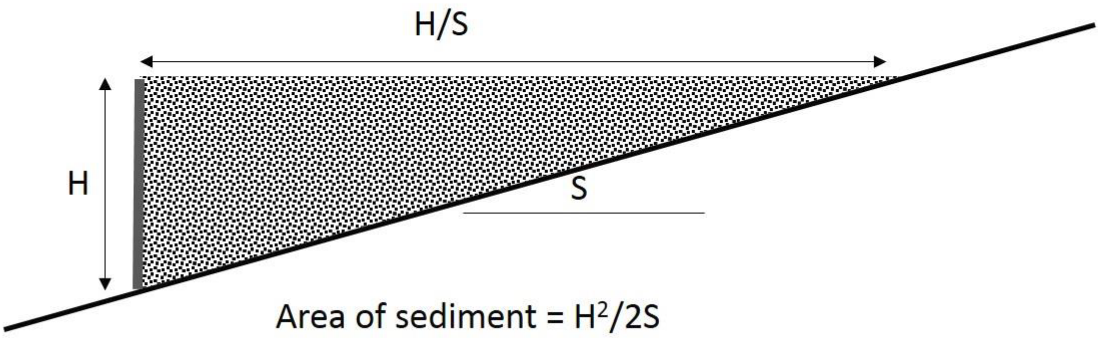

Figure 4. Sediment area behind a dam; longitudinal section.

In the tributary channels the 20 dams each say 7 m high would each retain 72/2 x 0.1 = 245 m2, giving a total of 4900 m2. The tributary channels will be narrower than the main channel, so if we estimate a width of 3 m this gives a total volume of the order of 14700 m3. The grand total volume of sediment

retained in log-jam dams is then 44700 m3, or, to a realistic degree of precision, 40000 – 50000 m3. That this is of the same order of magnitude as the Notown figure of Pearce and Watson (1983) encourages some confidence in the estimate.

Nevertheless in my opinion 40000 – 50000 m3 is probably an upper limit, as the data estimates used have been largely conservative; this applies in particular to dam height, where I have assumed that all dams are 6-8 m (taken as 7 m) high. Since sediment volume is proportional to the square of dam height (Fig. 4), the fact that many dams would probably have been less high would significantly reduce the total sediment storage volume. If an average dam height of 5 m had been used the volumes would have been halved. This is also suggested by comparison with the Pearce and Watson (1983) data, which record about half the volume of sediment in about 30% more channel length.

Discussion

Bull et al. (2016) estimate that 350000 ± 50000 m3 of material deposited on the Awatariki fan and lagoon in the 2005 debris flow; previously Costello (2005) had estimated 390000 ± 100000 m3. The up to 40000 – 50000 m3 of sediment that may have been stored behind log-jam dams is (i) up to 8 - 14% of the total volume material involved and (ii) within the margin of error of the total volume estimates. The risk estimates for the Awatarariki fan are based on assumed volumes of debris involved in the flow (50000, 150000, 300000 and 450000 m3), so one critical question is, what difference does subtracting up to 50000 m3 from these scenarios make to the risk assessment? This is best answered by reworking the risk analysis (Tonkin & Taylor, 2013).

However, given that the log-jam sediment storage is within the error of the best volume estimates, then any difference to the risk figures that results from subtracting the log-jam storage volume must also lie within the error of the risk figures. Thus while managing the log-jam storage artificially will in principle reduce the future risk to the fan, *it is not possible to estimate what the degree of risk reduction will be*; and in particular, the risk reduction cannot justify modification to the decisions already made about managing fanhead risk.

Maintaining the Awatarariki stream channel free of log-jams will be difficult logistically. It is not sufficient simply to demolish the log-jam dams, because they will reform in subsequent floods; removal or chopping up of the logs will be needed. The catchment will need to be inspected regularly, and any new dams removed, so the cost will be ongoing. In addition, log-jams are part of the natural ecology of steep wooded streams, so maintaining the stream free of log-jams would alter the natural ecology.

Conclusion

1 It is estimated that a maximum of about 40000 – 50000 m3 of debris may have been present in Awatarariki stream in storage behind log-jam dams prior to the 2005 debris flow.

2 This is up to 8 – 14% of the estimated total volume of the event, and is less than the margin of error of the total volume estimate.

3 Recalculating the risk assessment for the fan by reducing scenario volume by up to 50000 m3 (Tonkin & Taylor, 2015) will indicate the reduction in risk that could be achieved by maintaining the stream channel free of log-jams.

4 The fact that the volume change is less than the margin of error in total volume estimates suggests that this recalculation is not necessary.

5 There is no evidence that maintaining the catchment free of log-jams will contribute usefully to reducing debris-flow risk on the Awatarariki fan.

References

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Appendix 1: Illustrations of sediment sources

Figure A1. Debris avalanche from slope into stream.

Figure A2. Stream bed sediment several meters deep eroded to bedrock by debris flow

Figure A3. Log-jam in Blackjacks Creek, Notown in 1979. Jam height is 6.4 m (Pearce and Watson, 1983)