Lake Stream Sediment Management

Envirolink Report 2304-WCRC205

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Executive Summary

The short steep upper catchment of Lake Stream is prone to landsliding and slopes are well-coupled with the stream channel. Landslides have delivered significant volumes of sediment to the upper Lake Stream channel and provided source material for debris flows in the upper channel.

A significant debris flow event blocked the primary (eastern) channel of Lake Stream at the apex of the upper Lake Stream Fan at an unknown date. This event diverted flow and sediment transfer down a western channel course.

The western channel is now the primary channel for Lake Stream and this means that Crows Nest channel is now the primary channel in the lower catchment. The original Crows Nest channel does not have the capacity to accommodate sediment and discharge supplied to it by the western Lake Stream channel and it has enlarged and adjusted position accordingly.

Lake Stream is in a state of heightened sensitivity following a series of storms altering routeways of flow and sediment in the catchment. Sediment conveyance is likely to remain high for some time. Direct intervention in the catchment to manage sediment is unlikely to be successful while the catchment is in this state.

An active slope failure remains in the upper catchment, which will continue to deliver large volumes of sediment to the upper Lake Stream channel. Debris flows are likely to mobilise landslide debris within the upper channel and contribute to ongoing channel instability, as the river re-works significant sediment volumes associated with these mass flows. A substantial lag of sediment remains in the upper catchment to be re-worked, even if there were no further landslides or debris flows. The former (eastern) Lake Stream channel remains blocked by a significant debris flow lobe. Attempts to re-open this stream course risk remobilising significant quantities of sediment (including boulders) down the eastern course of Lake Stream.

The most pragmatic and sustainable approach to sediment management at present is to let nature run its course and adapt infrastructure and land-use accordingly. To do otherwise is to embark on a losing battle with a disturbed and highly active sediment conveyor.

Monitoring of the active geomorphic processes and associated sediment transfers is recommended in order to understand the rate and trajectory of adjustment in Lake Stream. Generation of a robust database and understanding of processes, risks and responses to key trigger events will enable a pro-active and precautionary approach to managing sediment in Lake Stream.

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1. Introduction

1.1 Aim & context

The aim of this work is to review the condition of Lake Stream catchment and recent changes observed in the catchment using available information provided by West Coast Regional Council and a day's on-site inspection. West Coast Regional Council has been monitoring a large highly active slip in the Upper Lake Stream catchment. Monitoring of the slip for over a year has revealed that with recent rain events in July 2021, and January / February 2022 substantial quantities of sediment have been released causing increasing levels of damage downstream where sediment is impacting lower watercourses and land. This report is intended to inform a strategy to address management of sediment delivery in Lake Stream catchment to reduce the environmental impact of these processes.

1.2 Lake Stream catchment and geomorphology

Lake Stream catchment comprises a small, narrow, steep catchment draining an area of ~1.2 km^2 on the northern flanks of Mt Rochfort (Figure 1), together with a larger lower catchment (~4 km^2), which crosses an alluvial fan and then drains northeast through humped and hollowed paddocks to join the Whareatea River (Figures 1 & 2). The total catchment area is 5.21 km^2.

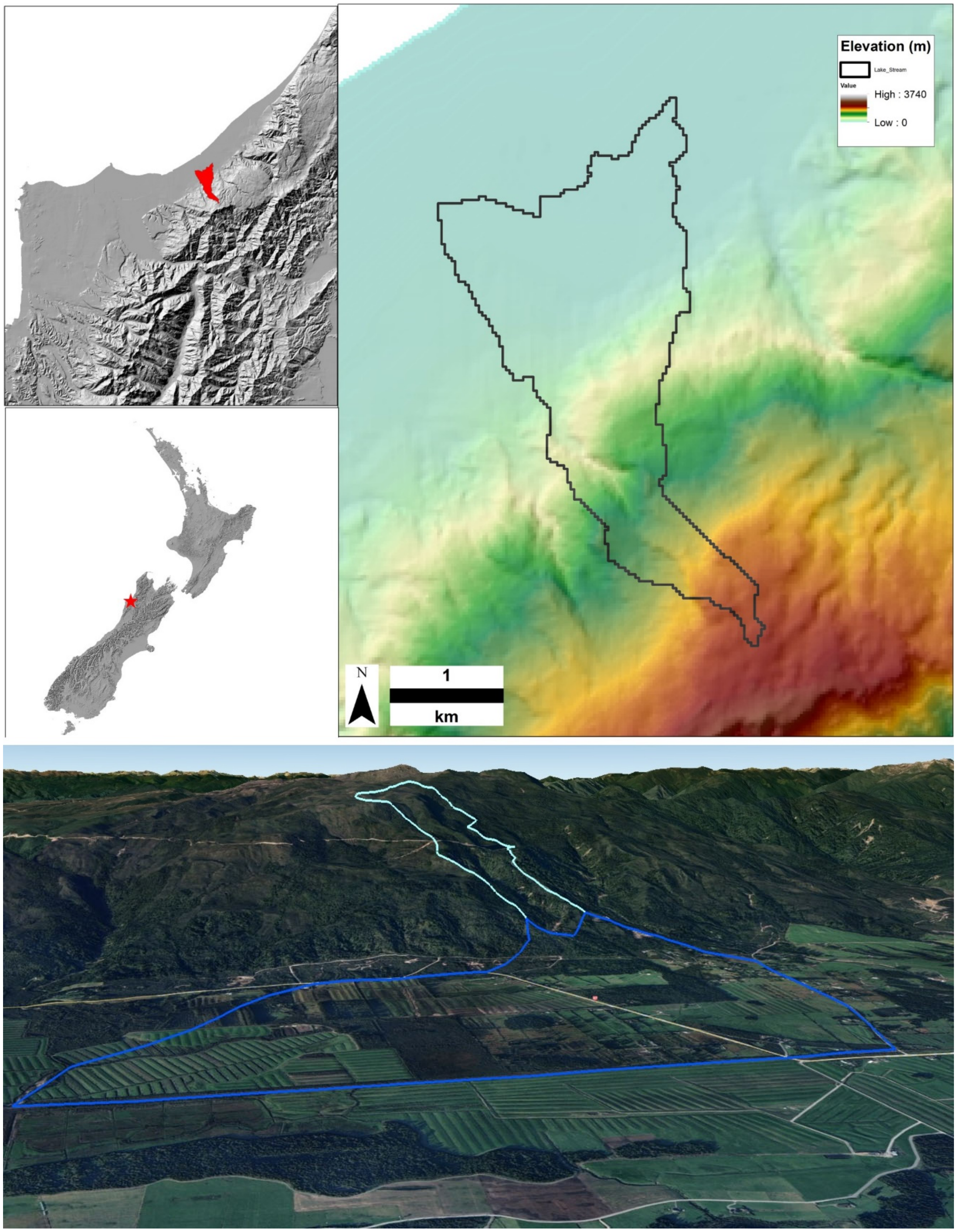

Figure 1. Upper: Lake Stream location. Lower: Oblique 3D Google Earth image of the Lake Stream catchment (approximate boundary) looking onto the Rochfort Range front. The catchment is divided into upper (lighter blue) and lower (darker blue) segments, highlighting the steep, narrow nature of the upper catchment in contrast to the much gentler and larger lower catchment.

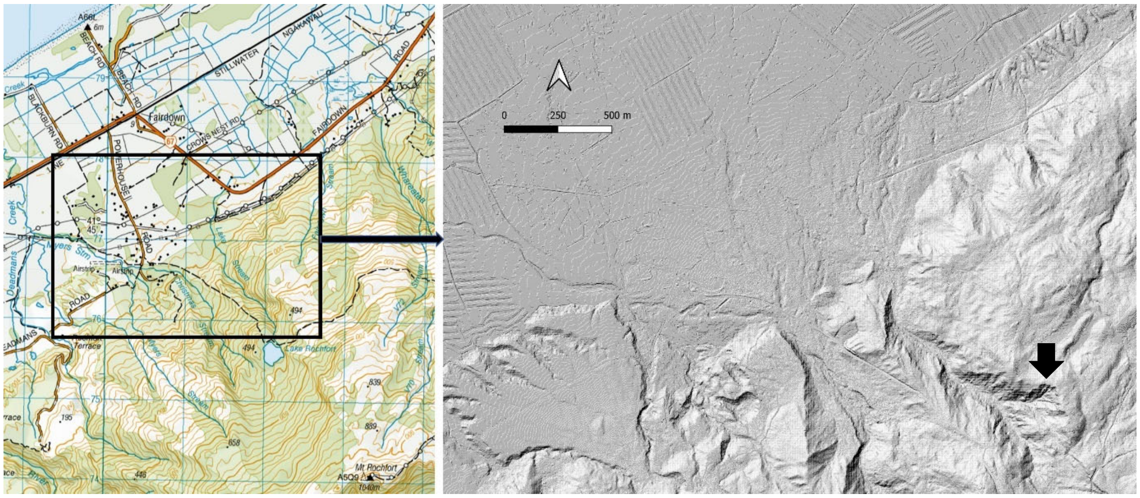

Figure 2. Topo map extract (left) of Lake Stream catchment. Lake Stream proper drains north from Lake Rochfort (labelled). Whareatea River is labelled in the right of the extract, the confluence with Lake Stream is ~300 m south of the Stillwater Ngakawau railway line. The extent of the hillshade digital elevation model (DEM) (right) is indicated by the black rectangle on the topo map extract. Location of the alluvial fan formed at the range front is shown in Figure 3. Vertical black arrow on DEM indicates location of Lake Stream landslide scarp.

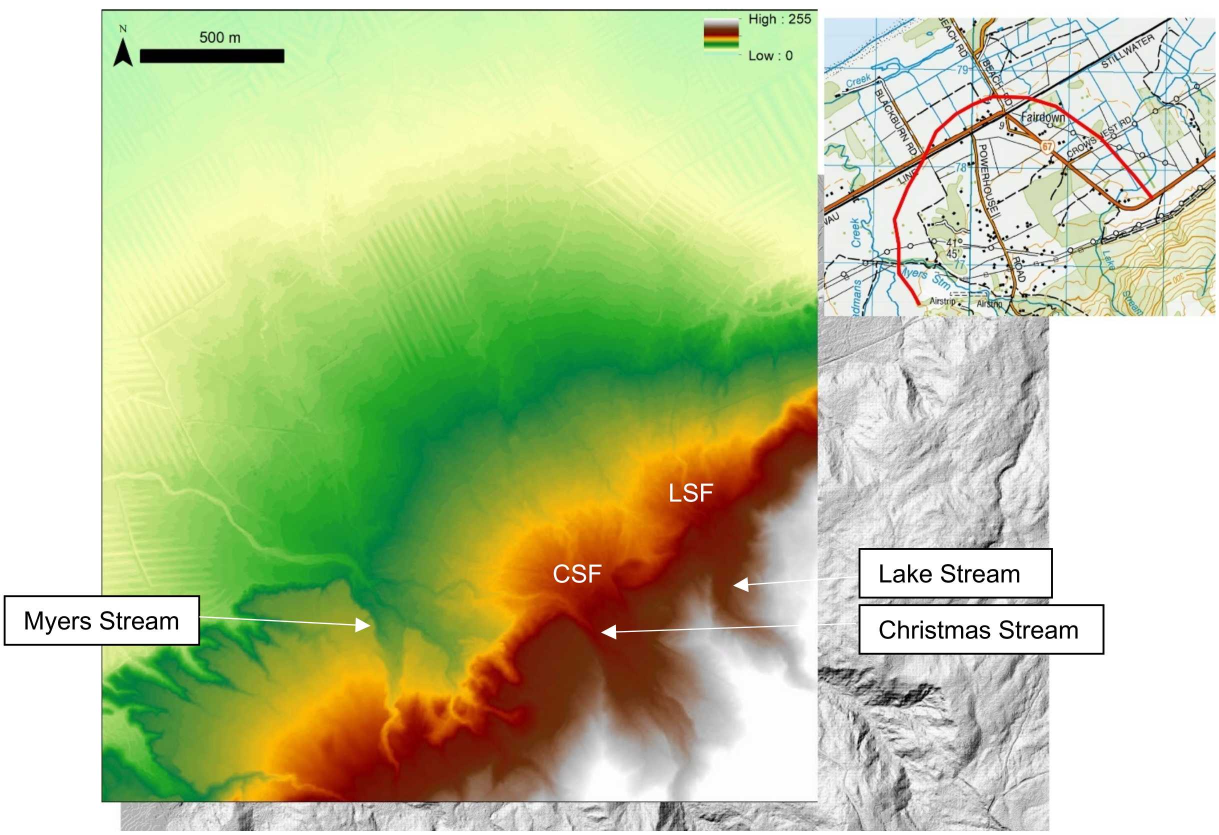

Figure 3. Lake Stream alluvial fan. The approximate extent of the alluvial fan is marked on the topo map extract in red. The feature shows up particularly well in the coloured DEM overlaying the hillshade (cf. Figure 2) (right). Lake Stream Fan (LSF) and Christmas Stream Fan (CSF) are labelled.

The alluvial fan at the range front is a compound feature that has developed over an indeterminate period of time in response to sediment deposited by both Lake Stream and Christmas Stream (cf. Figures 2 & 3). It appears unlikely that Myers Stream has contributed to the alluvial fan in its present form, since there is no geomorphological evidence of any fan feature at the point it exits the range front. Lake Stream and Christmas Stream have both developed discrete fans at the apex of the larger compound alluvial fan feature (LSF and CSF, Figure 3). Lake Stream is the most northerly of these contributing systems and is currently the only stream flowing across the surface of the compound fan. Christmas Stream appears incised into the fan surface and flows in an easterly direction to join Myers Stream.

Alluvial fans are depositional features formed where a stream emerges from a confined narrow valley at a range front. The absence of confining valley sides allows the stream to migrate freely and spread its load in an apron of deposits. Stream channels tend to block with sediment, prompting an avulsion, which is the rapid switching of the channel to another location on the fan. The convex shape of alluvial fans makes prediction of these channel positions difficult. Stream channels are generally not incised when the alluvial fan is actively forming and channels are often perched on the top of the fan. Blockage of channels and diversion of water and sediment into a new course generally takes place rapidly and is associated with flood events, when energy for this 'geomorphic work' is maximised. Avulsion-triggering blockages can reflect deposition of sediment transported under Newtonian flow within the stream channel. In addition, higher energy mass flows (debris flows and debris floods) can mobilise large volumes of sediment, often also of a very coarse size, including boulders, which may completely overwhelm the stream channel.

Beyond the alluvial fan, Lake Stream flows north-east across a flat coastal plain towards its confluence with the Whareatea River. This low elevation, low gradient plain is characterised by wetland and humped and hollowed paddocks, drained by a network of ditches, such as the drain that parallels Crows Nest Road (cf. Figure 2). This geomorphic setting produces low gradient channels, in contrast to the steeper stream across the fan, and even steeper channel emanating from Lake Rochfort (Figure 4).

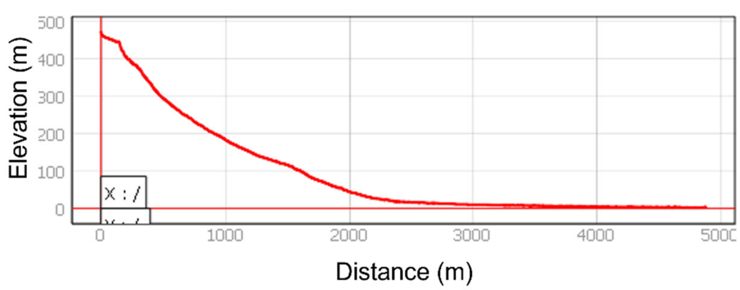

Figure 4. Lake Stream profile. The step in the profile at ~1600 m is visible in the oblique 3D perspective in Figure 5.

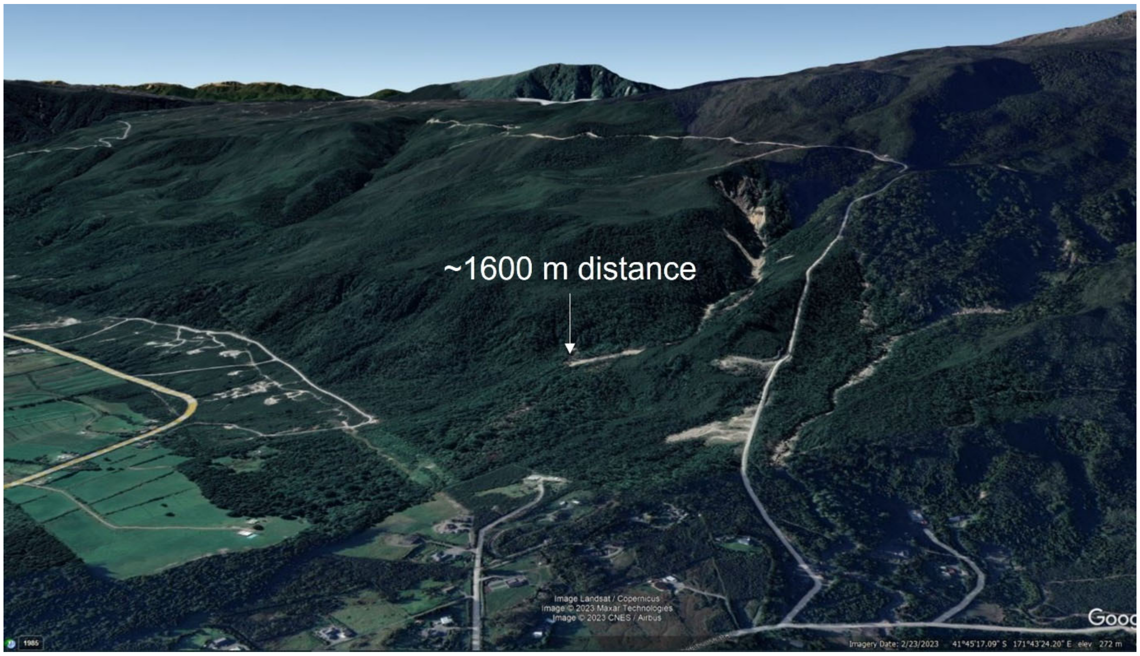

Figure 5. The upper Lake Stream profile flattens around 1500 m before steepening at ~1600 m at the apex of LSF (cf. Figures 3 & 4). Google Earth image, imagery date 2023. Landslides are visible on the true right of the upper Lake Stream valley.

1.3 Lake Stream geology and slope failures

Lake Stream catchment lies within the Kongahu Fault Zone on the western margin of the West Coast Basin and Range Province (Figure 6). On the west of Mt Rochfort, Tertiary Brunner Coal Measures have collapsed onto the coastal plain in a large-scale failure complex (Inwood, 1997), mapped most recently as landslide adjacent to the geomorphological coastal environment by Barrell et al. (2021). Slope failures in the Brunner Coal Measures are a combination of deep and shallow translational rock and debris slides developed along bedding planes, fault crush, shear zones and joints (Inwood, 1997). This setting indicates a geology predisposed to mass failures, into which Lake Stream has deeply incised (cf. Figure 2). It is therefore not surprising that the steep slopes confining the upper reaches of Lake Stream have been subject to recent landsliding (cf. Figure 5). The most recent of which is the catalyst for this report.

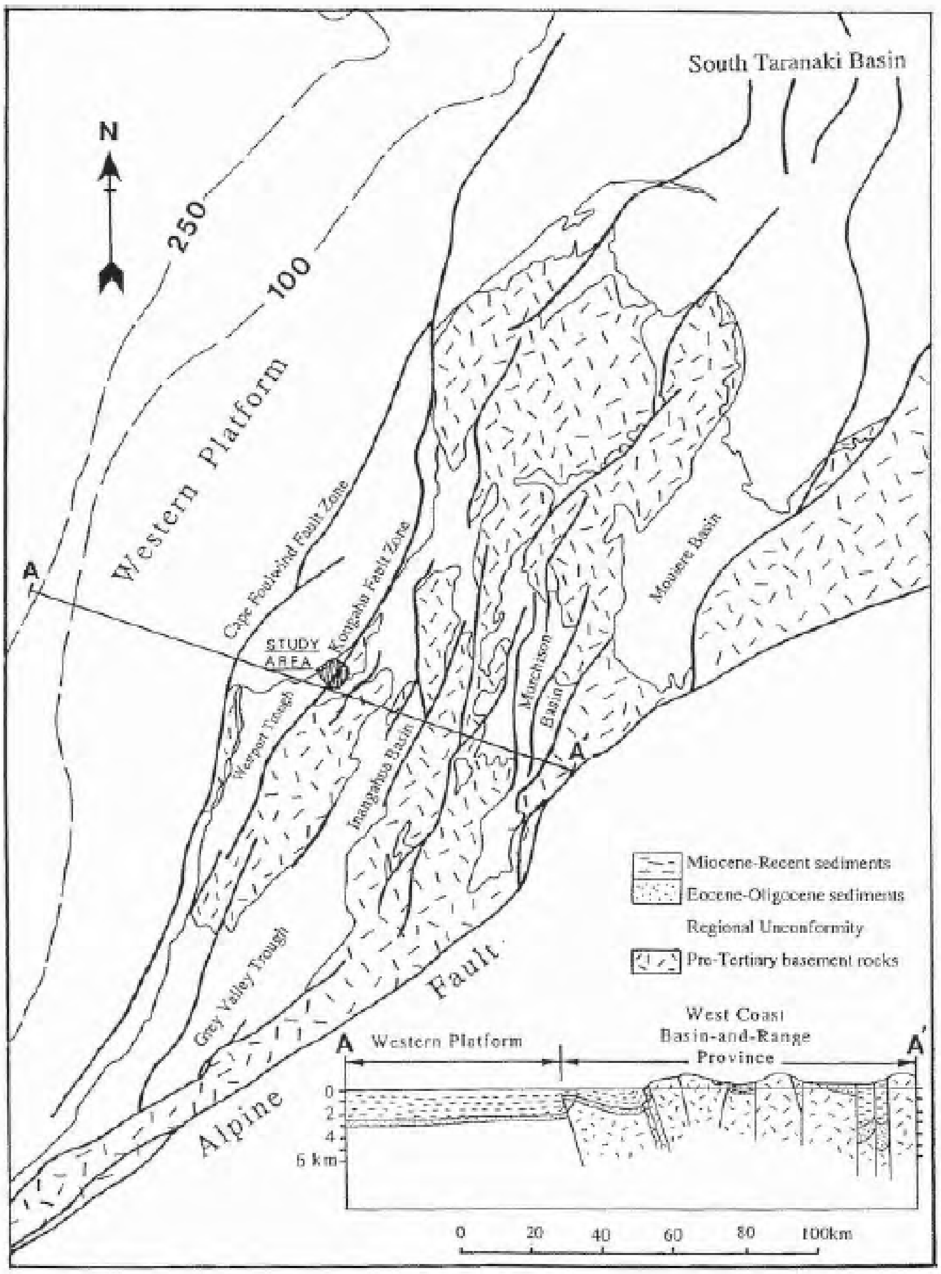

Figure 1.7. Sketch map and cross-section illustrating major structural elements of the West Coast (Adapted from Nathan et al 1986).

Figure 6. Geological setting for Lake Stream catchment at the western margin of the West Coast Basin and Range Province in the Kongahu Fault Zone (source: Figure 1.7, Inwood, 1997).

1.4 Lake Stream connectivity and sediments

Catchment connectivity refers to the transfer of material from source to sink in a catchment system. Of particular interest in Lake Stream is sediment connectivity, which is the connected transfer of sediment from a source to a sink via sediment detachment and sediment transport (Bracken et al., 2015). Sediment connectivity is controlled by how the sediment moves between the various geomorphic zones in a catchment. Key geomorphic zones are highlighted in Figure 7. The source zone in the catchment headwaters comprises low order tributaries and slopes that are coupled with these small, steep river channels. Where sediment generated from the slope is delivered directly into a channel, connectivity, or slope-channel coupling, is strong.

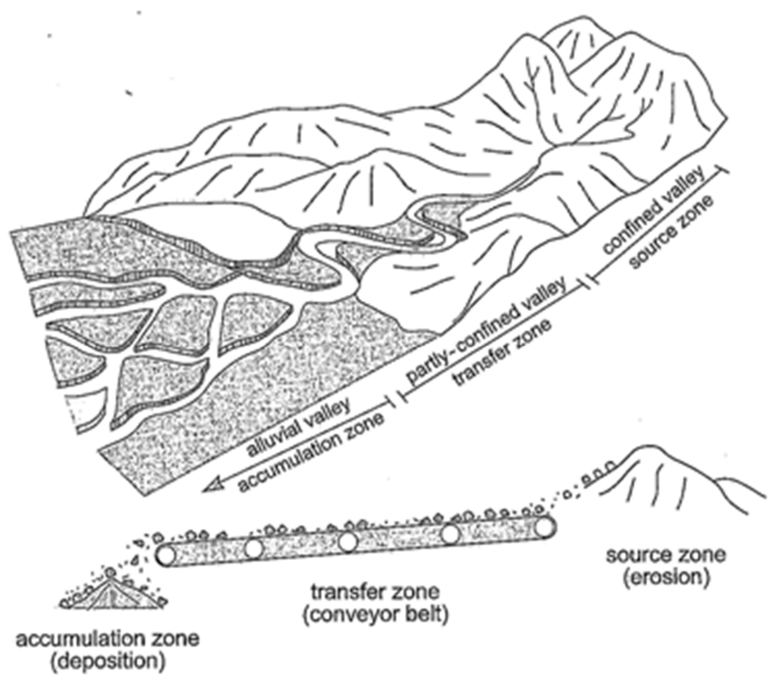

Figure 7. The catchment sediment conveyor (from Brierley & Fryirs, 2005).

In Lake Stream, steep slopes in a narrow valley (cf. Figures 2 & 5) deliver sediment generated by slope failure efficiently and directly into Lake Stream. Slope-channel coupling is strong because there is very little opportunity for sediment to be stored at the toe of the slope and sediment generated by slope erosion (landslides) is delivered directly into the channel (Figure 8). In turn sediments delivered into the channel by mass movement processes are effectively conveyed downstream along a steep, confined channel (cf. Figures 4, 9). Large-scale slope failures injecting sudden, large quantities of sediment will be likely to generate debris flows in this geomorphic setting. These will travel downstream until their energy wanes, either as a result of drainage, reducing pore water pressures, or reduced gradient. Debris flow sediments comprise a large range of grain sizes from boulder to sands, silts and clays, which reflect the sediments delivered to the channel from slope failure (Figure 8). These deposits are reworked by stream flow processes over time, with preferential entrainment and transport of finer grained material downstream. Sediments are transferred downstream as far as the river has sufficient energy to transport them. The relatively steep gradient of Lake Stream across the alluvial fan means that gravel and cobble sized sediment can be transported during high flows. At the distal margins of the fan, towards the coastal plain, the river gradient flattens considerably (Figure 4), which reduces stream energy for sediment transport and means that this zone of the catchment equates to the 'accumulation zone' of Figure 7.

Figure 8. Debris supplied into the channel network from landsliding in the upper Lake Stream catchment (lobe of sediment in channel highlighted). Wetting and mobilisation of the material sitting in the bed of the channel is likely to be in the form of a debris flow or debris flood, given the steep nature of the channel bed at this point in the catchment and the apparent range of grain sizes in this material. The nature of sediment supplied to the Lake Stream channel from slope failure appears to include a range of crushed rock from the Kongahu Fault Zone, as well as boulders of more coherent sandstones from the Coal Measures. WCRC, supplied, dated 18 February 2021.

Figure 9. Debris routed along the narrow, confined upper Lake Stream from the headwater source landslide (WCRC, supplied), dated 18 February 2021.

1.5 Lake Stream overview

In summary, Lake Stream comprises a short steep upper catchment, where slopes are prone to landsliding and well-coupled with the stream channel. The upper catchment terminates at the apex of an alluvial fan. Lake Stream steepens at the apex of the fan before flattening progressively across the surface of this feature and running across low elevation, low gradient coastal plain. Sediments in Lake Stream are conveyed efficiently along a steep, confined channel in the upper catchment. Debris flows are likely generated by a combination of mass failures injecting significant quantities of sediment directly to the channel and wetting during significant rain events. These mass flows are likely deposited as the channel emerges from its confined valley. Significant sediment transport by stream flow can mobilise sands and gravels in channels across the steep upper fan, before depositing this material at the distal margins of the fan and the coastal plain.

2. Recent geomorphic history reviewed

2.1 2014 Cyclone Lusi landslide

The catalyst for this report is the ongoing impact on Lake Stream of sediment sourced from a landslide in the upper catchment on steep slopes (cf. Figure 2, Figure 10). This landslide was thought to have been initiated during Cyclone Lusi, March 2014. A sequence of Google Earth images of Lake Stream provides some context for this event (Figure 11). This sequence reveals some erosion in the catchment present in 2003 (earliest available Google Earth imagery), but more substantial slope failure and sediment delivery after 2014.

Figure 10. Photos of upper Lake Stream landslide (WCRC, supplied), dated 18 February 2021.

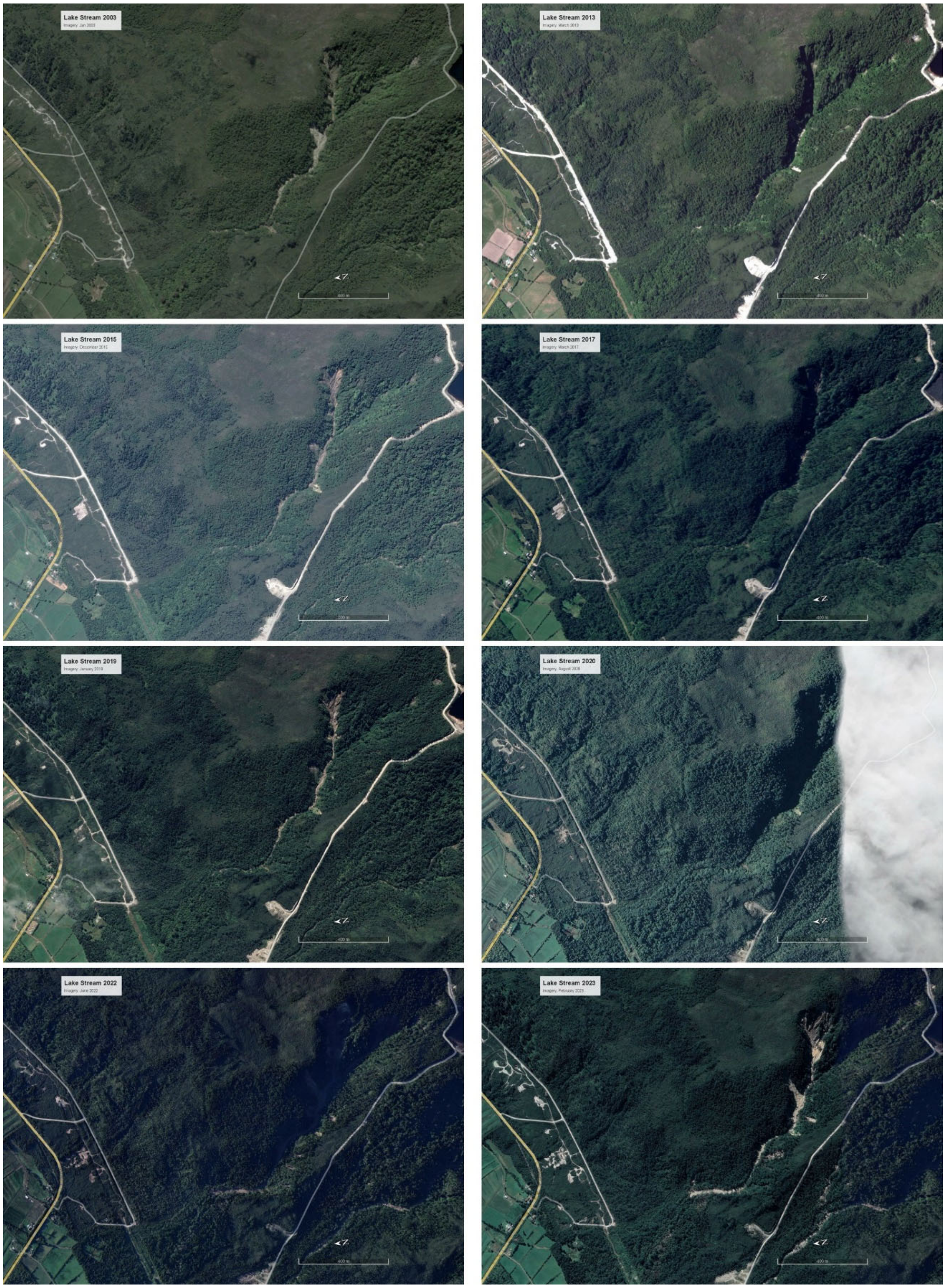

Figure 11. Sequence of Google Earth images dating from 2003, showing immediate historic context of the event. Note shadow in some imagery obscures the erosion scars on the true right of the catchment. Slope erosion and sediment lining the channel is evident in the earliest photo (January 2003).

2.2 Site visit, May 2022

2.2.1 Upper Lake Stream

Photos taken in the upper Lake Stream catchment in a site visit in May 2022 reveal the extent of impacts sediment delivery from the landslide upstream has had on the upper channel (Figures 12-17). Debris flow deposits have filled the valley floor and Lake Stream is reworking this material. Within the upper valley there appear to be alternating zones of incision and accumulation. Stream incision of the loose debris transfers material a short distance until it is deposited. Alternating reaches of incision and deposition reflect pulsed sediment transfer along the channel system. In this way the stream reworks the 'overload' of the debris flow deposits in its channel bed.

Figure 12. Upper Lake Stream, indicating coarse sediment accumulation in the steep channel bed in a narrow, confined valley. Note the wide range of grain sizes from boulder to sand and relatively chaotic arrangement of material in the valley floor, indicating minimal reworking by fluvial processes, and typical of mass flow deposits. 11 May 2022 (ICF).

Figure 13. Upper Lake Stream, immediately downstream from Figure 12 indicating incision of the channel bed with terrace surfaces present (labelled). Note the large range of grain sizes in the channel (boulder to sand) and a bouldery lag developing in the wetted channel, as distinct from sandy matrix observed in cut faces of the terraces. 11 May 2022 (ICF).

Figure 14. Upper Lake Stream, local accumulation zone downstream from local incision zone (Figure 13). This site shows more evidence of fluvial reworking of these (smaller) sediments, which are less chaotically arranged, with a smoother surface. Fewer boulders are evident here and they have likely been buried by stream deposition of this material. 11 May 2022 (ICF).

Figure 15. Upper Lake Stream, coarse, bouldery lobe downstream from Figure 14, note significant accumulation of sand downstream of large boulders. 11 May 2022 (ICF).

Figure 16. Upper Lake Stream, incision of lower debris flow deposits, note valley widening and chaotic arrangement of deposit indicative of mass flow deposition. Significant wood has been recruited. 11 May 2022 (ICF).

Figure 17. Upper Lake Stream, limit of debris flow deposits observed, looking upstream from the lobe crest (top) and downstream towards this limit (bottom). Approximate location given by red waymarker on topo map insert. Lake Stream now flows to the true-left (western) margin of this deposit and is not visible in these photos, which are taken mid-lobe. The re-routing of Lake Stream towards the west is described in the text. 11 May 2022 (ICF).

2.2.2 Middle Lake Stream (alluvial fan)

The debris flow lobe (Figure 17) has plugged the former Lake Stream channel (Figure 18). The blockage of this eastern channel has resulted in reoccupation of former channel courses and / or cutting of a new course to the west. Across the alluvial fan, downstream of the debris flow lobe, along the new (western) course of Lake Stream, there is evidence of gravelly splays over the fan surface and subsequent downcutting (Figures 19 & 20). Farther from the channel sediment splays are more sandy in nature (Figure 21). Prior to apparent abandonment of the eastern route of Lake Stream the stream was competent to transport boulders where the gradient remained steep across the fan (Figure 22),but flattening of the gradient towards the distal margin reduced flow competence (Figure 23). Figures 22 and 23 also show far less flow compared with the western Lake Stream channel (Figure 24).

Figure 18. Lake Stream channel plugged by debris flow lobe.

Figure 19. Lake Stream distributary channel downcutting, following deposition of gravelly splays across the fan surface.

Figure 20. Splays of coarse gravel and sand across the fan surface, subsequently incised by the stream.

Figure 21. Splays of sediment beyond Lake Stream channel across the fan surface

Figure 22. Coarse sediment (boulders) within stream bed of (former) Lake Stream channel, steep gradient of channel bed still evident

Figure 23. (Former) Lake Stream channel towards margin of alluvial fan, stream gradient begins to flatten compared with steeper section upstream (Figure 22), the channel is far less bouldery, but appears to be moving large quantities of sand and gravel.

Figure 24. Current Lake Stream channel, sited further west (cf. Figure 25), most of the flow appears to be routed down this western distributary channel across the fan (Figure 25, cf. Figures 19-20, with the debris flow deposit plugging the previous primary channel, cf. Figure 18).

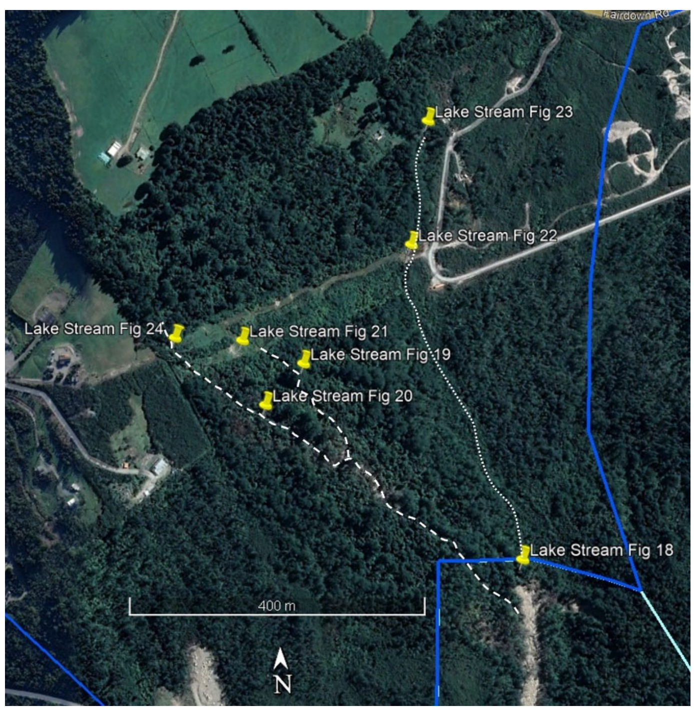

Figure 25. Key for location of photos in Figures 18-24, highlighting abandonment of former (eastern) Lake Stream channel (dotted) in favour of western routing (dashed). Channel positions approximate.

2.2.2 Lower Lake Stream

In the lower Lake Stream catchment as a consequence of flow diversion across the fan, the channel that runs alongside Crows Nest Road has become the primary channel for Lake Stream. This diversion required clearance and upgrade of a culvert underneath SH 67 (Figure 26). The Crows Nest channel now appears to transport most of the Lake Stream sediment in the lower portion of the catchment and significant sediment deposition has occurred in the vicinity of and downstream from Crows Nest Road (Figures 27-30).

Figure 26. Lower Lake Stream channel (Crows Nest channel) in the vicinity of SH 67. Inset shows SH 67 culvert. 11 May 2022 (ICF).

Figure 27. Sediment deposition in the Crows Nest channel alongside Crows Nest Road. (A) looking along the channel, (B) sediment splays into humped and hollowed paddocks, (C) channel invicinity of blocked culvert, which routed the current channel to the east (D), where it has deposited significant splays of sediment into humped and hollowed paddocks (C,D). (F) shows the contrasting channel dimensions between the former channel (narrow, straight, to the right of the photo, and the new channel, wide, sinuous, to the middle-left of the photo. Note the former channel does not have the capacity to transport the sediment and discharge now being routed along this course. WCRC supplied (photos obtained July 2022).

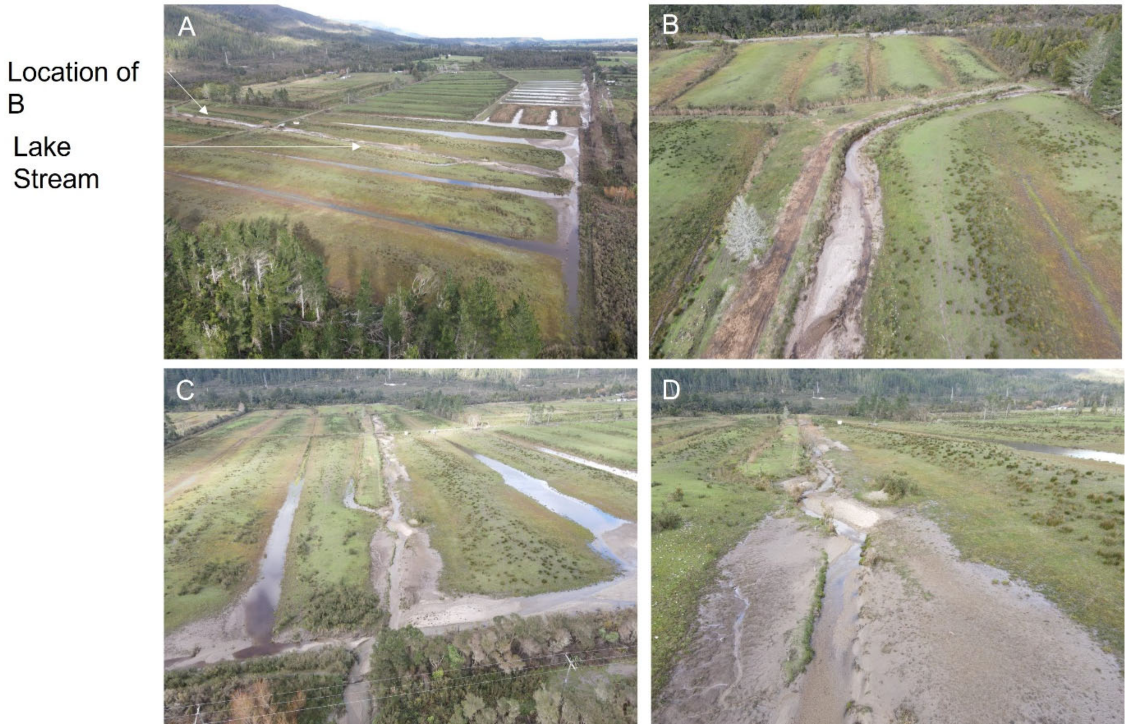

Figure 28. Former primary Lake Stream channel. (A) looking upstream along Crows Nest channel, original Lake Stream perpendicular to Crows Nest (labelled). (C) and (D) looking upstream along original Lake Stream channel from confluence with Crows Nest, note large area of fines deposited out of channel, likely a backwater effect from Crows Nest channel. WCRC supplied (photos obtained July 2022)

3. Discussion

3.1 Interpretation

A large landslide (or sequence of landslides) in the upper Lake Stream catchment has delivered significant volumes of sediment to the upper Lake Stream channel. A significant debris flow event (date unknown) was likely triggered by a combination of landslide debris emplaced in the channel and subsequently, or contemporaneously, being mobilised during a significant rainfall event. This debris flow reached the upper Lake Stream Fan, where a flattening gradient and reduced confinement resulted in it coming to a halt and plugging the Lake Stream channel (eastern). Prior to this event, coarse material had been routed down the steep channel and boulders are evident some way down-fan (Figure 22). Blockage by the debris flow lobe diverted the majority of Lake Stream flow and associated sediment transport to the west. It is not known whether this channel was entirely new, or a reoccupation of a former course. Alluvial fans are formed by multiple channel switching (avulsion) events as streams spread their load as they exit steep confining valleys and as such their surface morphology is characterised by multiple channel courses across the surface. A series of gravelly and cobbly sediment splays have been emplaced across the fan, which have since been incised. Lake Stream (west) continues to rework this material, and will continue to receive sediment as the upper

Lake Stream channel incises and reworks the substantial debris flow deposits in its bed (Figures 13 & 14). It is highly likely that future slope failures in the upper catchment will continue to deliver equivalent volumes of sediment to Lake Stream.

As a consequence of erosion and conveyance of large volumes of sediment in the upper catchment and across the Lake Stream Fan, sediment loads in the lower Lake Stream have increased. Furthermore, avulsion to the west is now delivering significant sediment loads to the Crows Nest channel. The Crows Nest channel has responded by enlarging and depositing significant sediment quantities in the hollows of adjacent humped and hollowed paddocks. The former Crows Nest channel no longer has the capacity to transfer water and sediment supplied to it and a new channel has formed immediately to the east (Figure 27).

3.1.1 Sediment management

Attempts to directly control sediment transfers in the Lake Stream catchment are likely to be problematic for the following reasons:

1. An active slope failure remains in the upper catchment, which will continue to deliver large volumes of sediment to the upper Lake Stream channel.
2. Debris flows are likely to mobilise landslide debris within the upper channel and contribute to ongoing channel instability, as the river re-works significant sediment volumes associated with these mass flows.
3. A substantial lag of sediment remains in the upper catchment to be re-worked, even if there were no further landslides or debris flows. Reworking of the material present in the upper catchment alone will continue to elevate sediment supply to the fan and lower catchment for some years to come.
4. The former (eastern) Lake Stream channel remains blocked by a significant debris flow lobe. Attempts to re-open this stream course risk remobilising significant quantities of sediment (including boulders) down the eastern course of Lake Stream.
5. In light of 1-4, sediment loads into Crows Nest channel are likely to remain high for some indeterminate length of time – effectively until the system 'settles down' after the disturbance events of landslide, debris flow and avulsion.

Lake Stream is in a period of heightened sensitivity and will take time to adjust to the change in boundary flux conditions (enhanced sediment supply and conveyance) and altered flow routing in the catchment. Aggradation and channel transformation to accommodate these changes is inevitable, and will be most particularly evident in the accumulation zone of the catchment, i.e. Crows Nest channel. While the channel continues to adjust in this way, the most pragmatic and sustainable approach to sediment management is to let nature run its course and adapt infrastructure and land-use accordingly. To do otherwise is to embark on a losing battle with a disturbed and highly active sediment conveyor.

4. Recommendations

I do not recommend 'do nothing'. It is important to track and understand the trajectory of Lake Stream. To do this I recommend a monitoring programme across the catchment, which will provide a robust dataset and understanding of processes, risks and responses to key trigger events that will enable a pro-active and precautionary approach to managing sediment in Lake Stream. Future interventions as required will then be informed and adapted to the behaviour of the Lake Stream sediment system.

4.1 Landslide monitoring

The landslide should be monitored to understand sediment delivery into the channel system. I recommend a full assessment of slope stability in the upper catchment, since it is formed on apparently crushed and erodible terrain. There is a risk of a far larger slope failure than has to date been witnessed, which has the potential to threaten life, property, and infrastructure on Lake Stream Fan should it occur and trigger a major mass flow event in the catchment. To this end it would be advisable to engage landslide experts who have the capability to run Rapid Mass Movement Simulation (RAMMS).

4.2 Upper Lake Stream monitoring

Lake Stream is actively incising and reworking debris flow deposits along its upper reach. Future debris flows are also likely to be routed along the channel and be reworked. Monitoring of morphological adjustments of the upper channel as it responds to these processes and reworks these deposits would provide a valuable means of assessing sediment volumes being generated from the upper catchment and ultimately being delivered to the fan. A morphological budgeting approach utilising helicopter- or drone-mounted LiDAR would probably be the most cost-effective way of capturing the surface morphology of the upper Lake Stream channel. Repeat surveys at an annual or significant event frequency would allow generation of difference models from which volumetric changes can be derived and morphological adjustments assessed.

4.3 Middle Lake Stream monitoring

Monitoring of the section of Lake Stream where it flows across the Lake Stream Fan is problematic due to dense vegetation cover. However, sufficient ground-strikes should be feasible using a helicopter-mounted LiDAR (drone equipment may not be sufficiently powerful?). I recommend a one-off high resolution survey of the Lake Stream Fan to capture surface topography and assess any changes since acquisition of regional LiDAR (acquired between May 2020 and February 2022). Thereafter, repeat surveys along the active channel distributaries should suffice to assess morphological adjustments and sediment transfers (as per monitoring of the upper channel – at least annual or significant event frequency).

4.4 Lower Lake Stream monitoring

The lower Lake Stream (and Crows Nest channel) should be monitored following each storm event to assess rates of sediment accumulation and potential for blockage of the SH 67 culvert because this sediment is most mobile. Since these surveys would be at an event scale and across open terrain, there is probably no need to deploy LiDAR at such a frequency. Surface morphologies can be generated using Structure from Motion photogrammetry, with photography acquired using a drone platform. However, I would also recommend that LiDAR monitoring in the upper and middle catchments be extended into the lower catchment to provide a 'whole of catchment' understanding of sediment conveyance in the system.

5. Postscript: Christmas Stream

During a public meeting in Westport (23 May 2023) at which the findings in Lake Stream were communicated to the community, concerns were raised around the potential threat to property on the lower Christmas Stream and Lake Stream fan posed by potential catastrophic slope failure and resulting debris flows / floods in these catchments. Detailed comment and recommendations are beyond the scope of this work. However, I make the following observations and recommendations to allay concerns raised:

1. Consider monitoring Christmas Stream alongside Lake Stream as outlined in 4.1-4.3 to understand sediment sources, pathways and potential catchment responses to significant sediment-generating storm events.
2. Consider limiting development on the Lake Stream – Christmas Stream alluvial fan to prevent people from putting themselves in harm's way. Hazard zoning of this location should be reviewed, particularly in light of recommended Rapid Mass Movement Simulation (RAMMS) (4.1).

Professor Ian Fuller
21 June 2023

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