A Post Fire Geomorphic Assessment of Tributary Streams at Lobs Hole

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Cover Photograph.

Watercourse 3, site 03. Image shows proximal overbank deposition of saltating load and bedload at both bank tops. Three stages of incision have cut through recent deposits into the floor of the old channel.

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Introduction

Catastrophic fires swept through the south east of New South Wales during January 2020. The Dunns Road fire, which was started by a lightning strike on 28 December near Adelong, entered into the Kosciuszko National Park on January 3, 2020 and passed through Lobs Hole ravine on January 4, 2020.

The area surrounding Lobs Hole was critically impacted by the fires, denuding the surrounding hills of cover and exposing the regolith to potential erosion.

Multiple periods of rainfall, of varying intensity and volume, occurred over the following months mobilising unconsolidated regolith, exposed by the fire, and moving the mobilised material downslope and into the drainage lines.

This mobilised sediment had catastrophic effects on the water quality of tributaries debouching into the Yarrangobilly River and subsequently on the Yarrangobilly River trunk.

Objectives

The objectives of this investigation were multi-faceted;

1. Provide a baseline characterisation of channel conditions extant post fire in selected tributaries of the Yarrangobilly River
2. Provide a comparison of pre and post fire channel conditions
3. To provide a snapshot of stream conditions during the recovery period post fires
4. Provide insight into recovery trajectory

Study Method

The study consists of three stages;

1. Desktop assessment;
    a. Review of existing literature pertaining to the potential for erosion in a post fire environment
    b. Analyse and interpret water quality and precipitation records
    c. Review and interpret aerial photographs
2. Detailed site investigation of selected tributaries;
    a. Unnamed stream known as Watercourse 3
    b. Sheep Station Creek
    c. Lick Hole Gully
    d. Wallaces Creek
3. Reporting

Desktop

To achieve the study objectives desktop reviews were completed of existing literature and data resources.

- Contemporary and historical aerial photograph interpretation was completed using QGIS cross-platform desktop geographic information system application. Aerial photography was accessed from Nearmap and was available for;
    - Monday October 21st, 2019: Seventy six days prior to the Dunns Road fire impacting Lobs Hole and surrounds.
    - Sunday January 26th, 2020: Twenty one days after fire.
    - Tuesday October 13th, 2020: Two hundred and eighty two days after the fire.
    - Tuesday December 1st, 2020: Three hundred and thirty one days after the fire.

- A literature review was conducted by searching for relevant publications that characterise the impacts on regolith of intense fire. The work completed by Geoff Humphreys and Kerrie Tomkins at Macquarie University was used as a starting point.
- Fire intensity mapping (FESM: SEED 2020A) was acquired and integrated into the QGIS platform
- Water quality (WQ) data from was acquired from EMM Consulting for the period 2nd of June, 2019 until the 7th of November 2020. This data was analysed for turbidity and total suspended solids (TSS) to determine any correlation between WQ data and rainfall.
- Lobs Hole automated weather station data was acquired for the period 1st of January 2020 to 13th of November 2020. This data was analysed to gain an insight into any correlation between periods of heavy rainfall and episodes of erosion or sedimentation.

Fieldwork

A field survey was completed by Peter Johnston, Fluvial Geomorphologist, on Tuesday and Wednesday the 10th and 11th of November 2020 to determine the current channel character. The field survey was completed using the procedure set out in the Geomorphological Field Manual (Gardiner and Dackombe, 1983) and the Australian Soil and Land Survey Handbook (CSIRO Publishing 2009).

Two channel feature layers were used in the QGIS interpretation of channels within the study area. These were the Strahler Watercourse shapefile and the NSW Named Watercourse layer (2011). Both were sourced from EMM Consulting for use during the EIS reporting. The channel position in both of these layers was inaccurate in most instances. Generation of longitudinal profiles using existing poly lines from these layers produced sub optimal results. Accurate profiling required manual plotting of the channel lines to identify areas of low channel slope as a proxy to identify areas

Subsequent to the field assessment a Digital Elevation Model (DEM) was produced using QGIS and the raw point cloud files sourced from Snowy Hydro. The acquisition date for the LiDAR data is April 2020. From this DEM profiles of the surface morphology were produced to gain insight into surface processes and landforms; especially channel slope. Geomorphic maps were rendered that interprets and presents the fluvial morphological landscape units identified during field work and the desktop assessment.

Limitations

While access to high resolution Nearmap aerial photography was available for this study, the aerial photography had insufficient resolution to gain detailed insights into channel character and behaviour that is essential for this study.

Two days in the field was insufficient to visit all the sub-catchments that debouch into the Yarrangobilly River at Lobs Hole. There was also insufficient time to conduct comprehensive, laterally extensive, surveys on the four tributaries that were chosen for this study.

The lack of rainfall intensity data (precipitation per unit time) restricted the ability to identify the erosivity of periods of rainfall. Rainfall data is available for 24 hour periods up until 09:00 each morning. Precipitation rates vary greatly over time and short duration periods of intense rainfall are much more erosive than the same volume spread over a greater period.

Water quality data collection is not consistent across all tributaries assessed by this study. Water quality data sample collection was usually completed in the first week of each month. The intervals between periods of rainfall and sample collection are shown in Table 2. Temporal variation associated sample collection and rainfall have a direct effect on variations in water quality.

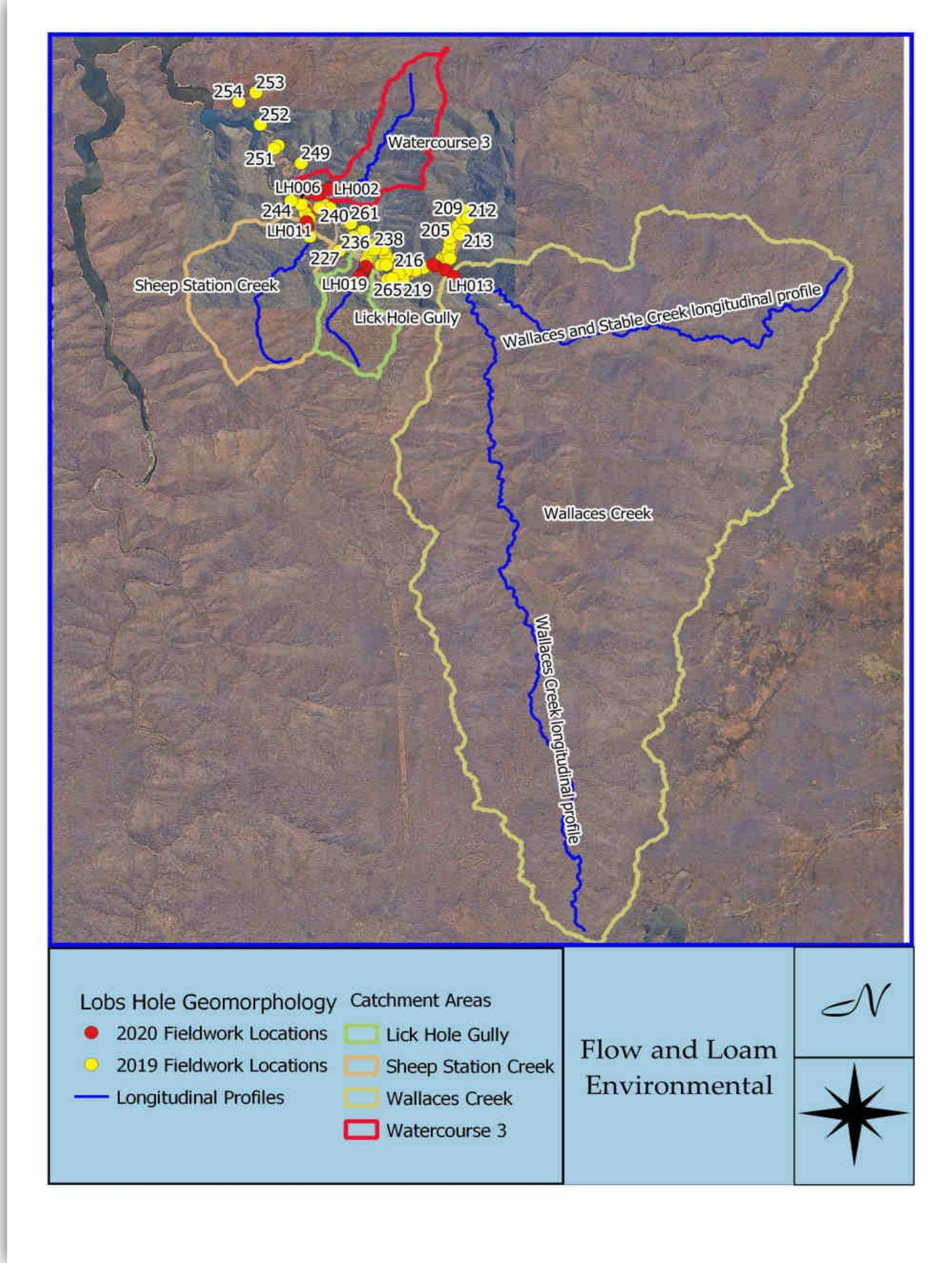

Figure 1 Location diagram showing catchment areas, longitudinal profiles and field assessment locations referred to in this report

Discussion

Global soil erosion rates are extremely variable and are not just dependent upon climatic and morphological variations (e.g. precipitation and slope) but the variability is also related to anthropogenic artefacts such as methods of measurement and recurrence interval of data collection. Land use also had a significant effect on soil erosion rates with agricultural lands having the highest erosion rates and forests and shrub lands having the lowest erosion rates (García-Ruiz et al. 2015).

Erosion rates in Australia have been defined by many researchers in many different landscapes. Humphreys and Mitchel (1983) quantified erosion rates in sandstone landscapes in the Sydney Basin. Bierman & Caffee (2002) assessed granitic landscapes in Central Australia and Heimsath et al. (2010) reported great variation of erosion rates across wide variety climatic zones, however, the highest rates of erosion were found to be from south eastern New South Wales.

Tompkins and Humphreys (2008) found that while wild fires were a common event, and that post fire increased runoff and erosion was a predictable response, erosion events were highly dependent on the timing and magnitude of rainfall during the post fire recovery period as vegetation re-established itself. This rainfall can be patchy and difficult to predict because of the variability of weather patterns of south east Australia.

The reduction of vegetation caused by bushfires can lead to major soil erosion. The likelihood of erosion increases with increasing fire severity, increased rainfall intensity and steeper slopes (Shakesby et al. , 2007; Tomkins and Humphreys 2008).

Erosion events following wildfires in south-eastern Australia have shown that burnt areas represent a real risk to water quality in water supply catchments. Following the 2003 fires, Bendora Reservoir (the water supply for Canberra) experienced turbidity values 30 times the previously recorded maximum, forcing water restrictions to be put in place (Tomkins et al. 2007).

However, Tomkins and Humphreys (2008), found that despite causing significant destruction of vegetation and giving the perception of extreme erosion, wildfires alone appear to account for only a small proportion of landscape denudation (< 5 % or < -10.54 mm/kyr). Instead, erosion after fires is highly dependent on the timing, magnitude and characteristics of rainfall events in the short post-fire recovery window (Blake et al. 2009, Tulau, 2015).

Geomorphically effective rainfall, which triggers significant rainsplash and slopewash of material from hillslopes into the stream network, are typified by heavy, sustained falls with return intervals of one year or longer. These events do not always occur in the post-fire recovery period, especially in the initial months after fire when surface erodibility is greatest.

The variability in weather patterns affecting Southeastern Australia, as a response to climate change and other broad-scale climate drivers such as the El Niño-Southern Oscillation, make the recovery period notoriously difficult to predict.

Fire Extent and Severity Mapping

The Department of Planning, Industry and Environment (DPIE) and the NSW Rural Fire Service (RFS) have developed a semi-automated approach to mapping fire extent and severity and using Sentinel 2 satellite imagery (DPIE and RFS 2020).

The product, Fire Extent and Severity Mapping (FESM), is designed to estimate fire severity and uses the loss of biomass caused by fire to make this determination. To determine the net change in biomass from pre to post fire conditions an algorithm is used to determine canopy cover and uses canopy cover as a proxy for biomass.

The FESM severity classes include: unburnt, low severity (burnt understory, unburnt canopy), moderate severity (partial canopy scorch), high severity (complete canopy scorch, partial canopy consumption), extreme (full canopy consumption) Figure 2.

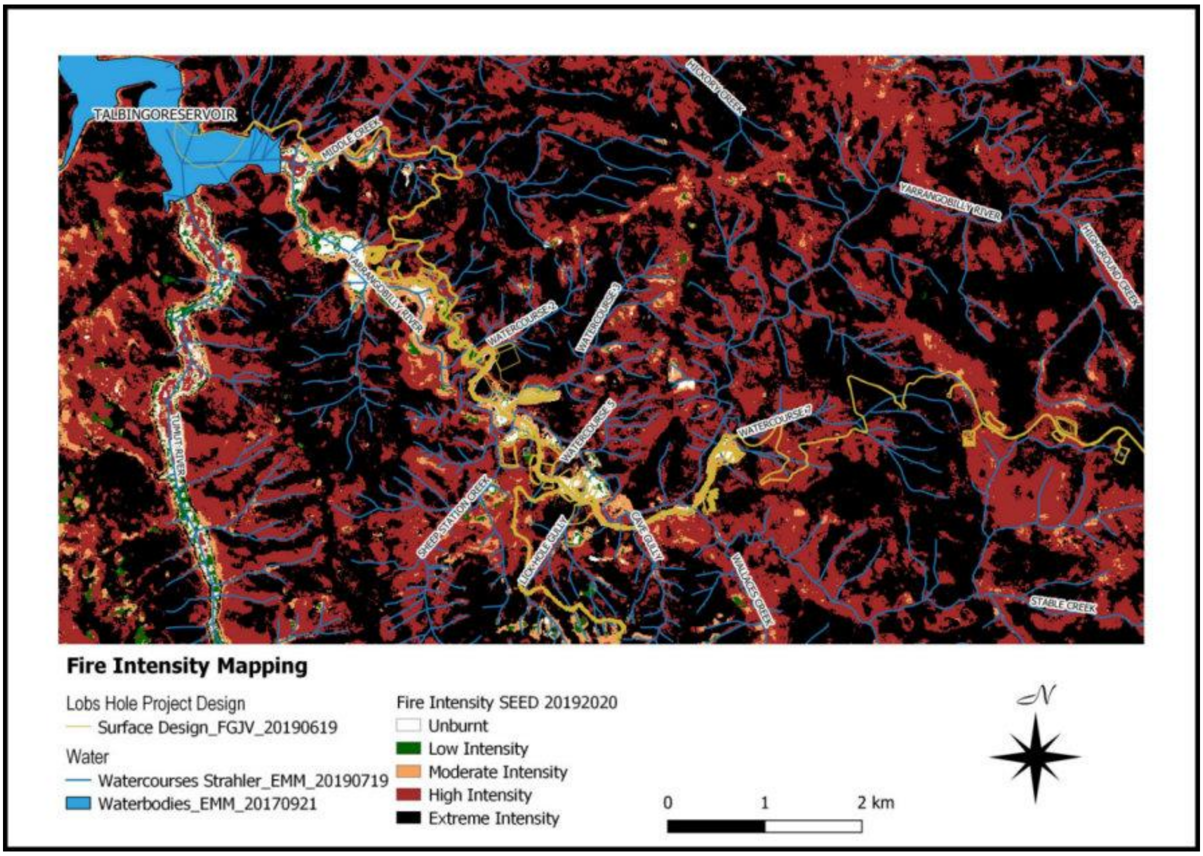

Figure 2 Two dimensional image of Fire Intensity Mapping at Lobs Hole.

While the loss of canopy is important when assessing the potential for soil erosion in a post fire landscape. It is not as important as the loss of ground cover. This ground cover does not just consist of vegetation but also includes organic debris such as leaf litter and sundry sizes of twigs, sticks and larger woody debris.

During periods of intense rainfall part of the precipitation infiltrates into the regolith but rates of infiltration are variable and decrease over the duration of the event.

Infiltration is the process by which precipitation or water soaks into subsurface soils and moves into rocks through cracks and pore spaces. Infiltration rates vary depending upon the pore spaces, the hydraulic connectivity of the pore spaces and clay content.

Infiltration rates have been estimated as being between 5 – 10 mm/hr for a clay loam. Precipitation of 12.7 mm has been suggested as the threshold rainfall amount to initiate erosion. This threshold value has been employed in the Universal Soil Loss Equation (USLE), Revised Universal Soil Loss Equation (RUSLE), and other researches for calculating rainfall erosivity worldwide (Liang et al. 2019).

That portion of precipitation that cannot infiltrate quickly enough is exported as surface wash or sheet flows. Under normal circumstances this surface flow will collect the various vegetation debris and wash it into litter dams that serve to decrease the velocity of the overland flow. A decrease in velocity reduces the (stream) power that is available to initiate erosion.

The total loss of ground cover during the catastrophic fires at Lobs Hole left the regolith surface completely exposed and susceptible to erosion by surface flows initiated by rainfall. This susceptibility to erosion is exacerbated by the ground surface being hydrophobic in the initial period of the post fire recovery period.

Fire severity differs from fire intensity, which is the energy output of the fire. While severity and intensity may be correlated, factors such as climate, weather conditions, topography, and vegetation community composition strongly influence how fire intensity is translated into fire severity.

The FESM has a spatial resolution of 10 m (SEED 2020B) and as such does not present a detailed map of ground conditions post fire. It presents a broad overview of the effects of the fire and is useful in predicting how fires will behave in the future.

It is somewhat difficult to understand the data that is presented by the mapping (Figure 2) to gain insight into the impacts of the fires on the ground. Bushfire intensity is dependent on variables such as fuel load, moisture content, relative humidity, ambient air temperature, slope and aspect. Ambient pre heating is a factor that determines that a fire will always travel faster uphill rather than on flat ground. Another factor is that the study area is south of the Tropic of Capricorn. That means that the sun is always in the northern sky and the northern sides of hills will have more exposure to the drying effects of the sun and preferentially less moisture than the southern facing slopes.

To gain some insight into the behaviour of the fire when taking those criteria into consideration the FESM was draped on to a DEM to gain a three dimensional view of Lobs Hole, and surrounds. There does not appear to be any immediately apparent relationship between surface morphology and fire intensity. However, in some areas, the crests of the hills appear to have been preferentially subjected to more intense fire (Figure 3.)

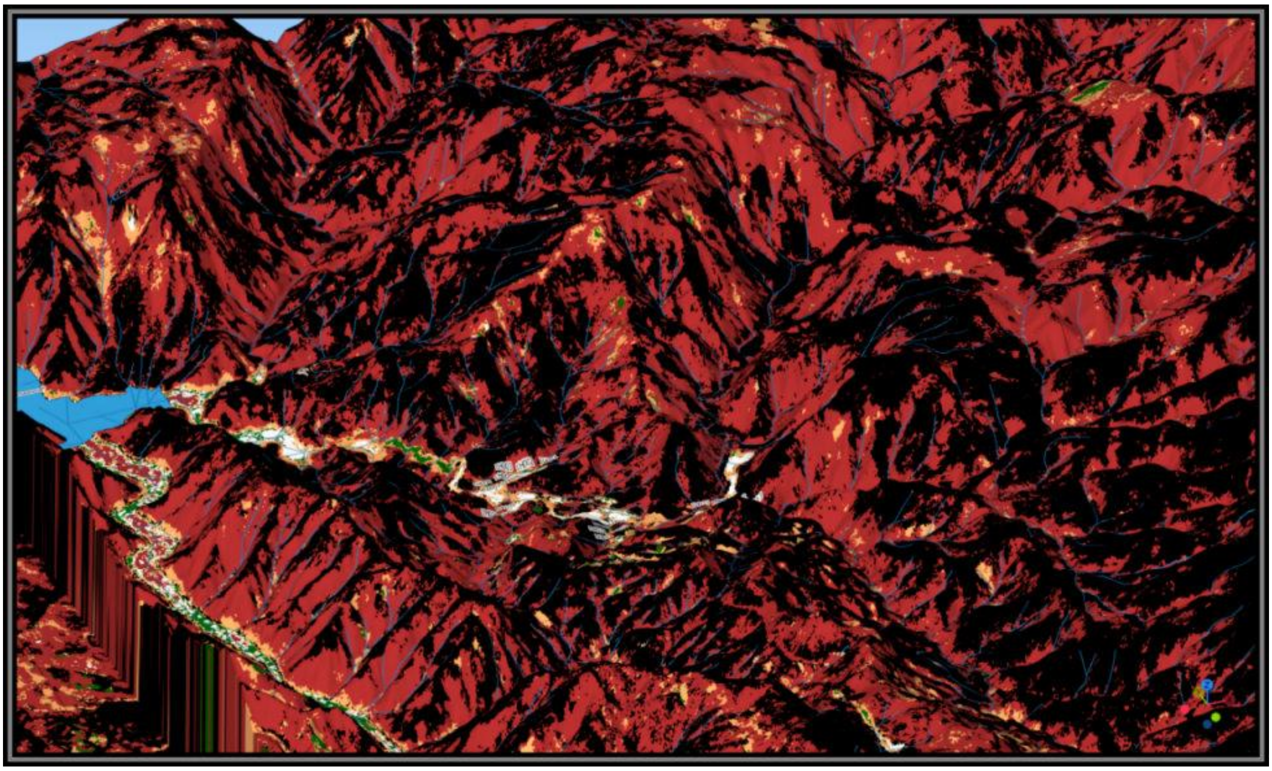

Figure 3 Three dimensional view of the FESM at Lobs Hole

Erosivity and Erodibility

The erosivity of a storm is the product of the storm's total energy, which is closely related to the storm's maximum 30-minute intensity (Dunkerley, 2019).

Many erosion processes, including rain splash dislodgment and surface sheet wash, that initiates the mobilisation and transport of surface material, is influenced strongly by short-lived peaks in rainfall intensity but is less well accounted for by longer-term average rates of rainfall. Rainfall intensities reached over periods of 10 – 30 min have greater accountability for initiating erosion than hourly or longer-period data (Dunkerley 2019; Lu et al. 2001).

The impact of fire on catchment properties has been shown to increase erosion rates throughout fire prone regions of Australia. The magnitude of the increase relative to the unburned state is highly variable, ranging from 10 - 1000 times the background levels. Factors such as the nature of the terrain, fire regimes and the frequency of post fire intense rainstorms all contribute to high variability of erosion rates from region to region. The largest documented erosion responses are those in steep terrain of southeast Australia where debris flow processes seem to operate regularly after bushfire (Rahman et al. 2018).

Rainfall and Turbidity Assessment

The Duns Road bushfire passed through Lobs Hole on the 5th of January 2020. The automated weather station at Lobs Hole recorded a maximum air temperature for that day of 81.7^{0}C. The previous day recorded a maximum temperature of 34.4^{0}C and the following day recorded 25.9^{0}C. The first period of any precipitation at Lobs Hole post fire was 4.8 mm two days later on the 7th of January.

Data Range

The data from water quality monitoring was available from June 2019 up to and including November 2020. Critical inputs for this study were data on Turbidity and Total Suspended Solids (TSS).

The data from the automated weather station at Lobs Hole was available from 1st of January 2020 up to, and including, 13th of November 2020.

Limitations

There is no continuous, unbroken, record of water quality data for the catchments dealt with in this report. Wallaces Creek has the most complete record with the only data gap being January 2020 as the programmed sampling was to occur the day the fires swept through. The recurrence of water quality sampling appears to be irregular but usually occurs in the first week of the month. However, not all monitoring sites were revisited every month (Table 2) and no sites were visited in January 2020 because of the proximity of the fire. In some instances the lack of base flow prohibited the collection of water quality samples.

There is a continuous daily record for weather observations available for the Lobs Hole automated weather station. This record includes total precipitation in millimetres nominally recorded at 09:00 each day.

While this data is very useful it also has its own inherent limitations. The issue here is related to rainfall intensity. e.g. On January 20, 2020 the rain gauge recorded the total rainfall for the previous 24 hours, up until 09:00, as being 30.4 mm. The information that is missing is whether this total occurred over a short period of intense rainfall, or an extended period of lighter rainfall.

Infiltration and runoff

Soils exposed to high temperatures during a bushfire become hydrophobic are slow to rewet during subsequent rainfall. Short periods of high intensity heavy rainfall lead to excessive runoff and erosion. Extended periods of low intensity rainfall allow for hydrophobic soils to rewet and enhance infiltration rates, decrease runoff and minimise erosion.

Rainfall

During the period immediately following the fires the regolith surface would have been at its most hydrophobic and vulnerable to erosion. The land surface would not have wetted up readily, infiltration would have been minimal in the short term, and runoff would have been at its greatest.

During the month subsequent to the fire there was minor rainfall on the 7th, 11th, 16th, 17th 19th, 22nd and the 24th of January that total 21.4 mm. The fall on the 17th accounted for more than half of this total with 12.2 mm recorded. There were three major falls on the 20th, 21st and 31st of January of 30.4 mm, 24.8 mm and 20.4 mm respectively (Figure 4). The next sample collection for water quality monitoring occurred on the 5th of February, 5 days after the last significant rain and 15 days after the two days of significant rain on the 21st and 22nd. Samples were only taken from EPL6 and EPL7 on Wallaces Creek. None of the other catchments addressed in this study were sampled (Table 1).

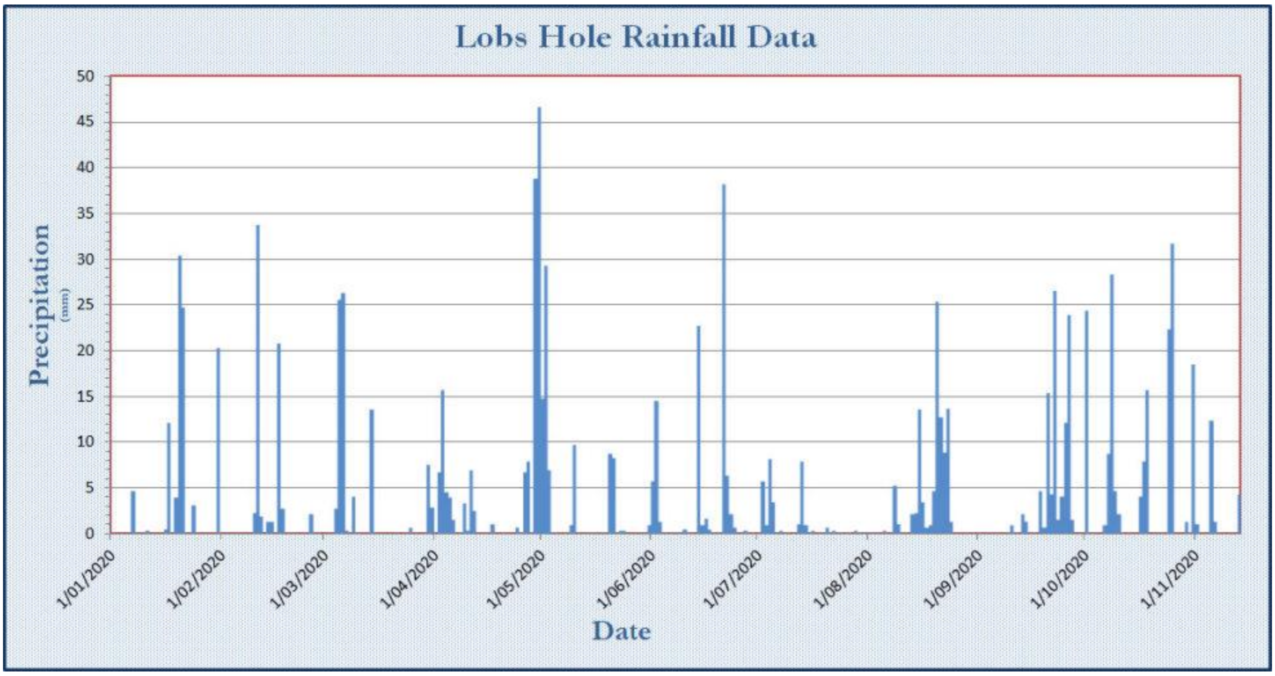

Figure 4 Rainfall data for Lobs Hole. January 1 to November 13, 2020

Analysis of the data for TSS and Turbidity (Figure 5 and Figure 6) show that there is a loose correlation between periods of rainfall and an associated rise in values for TSS and Turbidity. For most readings there appears to be a lag in the response of the data to reflect a rise in values as a response to rainfall in the catchment. This may be an artefact of the data being collected monthly, or it may be related to catchment size and discharge, and it could also be misleading. It may be something to do with the intensity of the rain fall. High intensity rainfall would produce immediate runoff and an attendant rise of turbidity and TSS. However, if the samples were not collected until some days following the period of rainfall then this would explain the lag and lower than expected values.

For example; the peaks for turbidity in Wallace's Creek and Watercourse 3 appear to be a direct reflection of the significant rainfall that was occurring on the day of collection, 6th of March, and had occurred the previous day. If the sample collection had been programmed to occur the following week the turbidity and TSS readings would have been much lower as there had only been a total of 4.8 mm in the seven days following.

The plots for Lick Hole Gully have a similar profile to the other catchments but generally return lesser values. This may be because the catchment is much smaller than the other tributaries or it may be because the lithology and sedimentology may be different and produce less suspended solids.

The interesting thing here is to look at the values for the 2nd of March. On that day there was rainfall in the catchments and it was also a day that sample collection occurred. The period of 24 hours to 09:00 on the 3rd of March produced only 15.8 mm of rainfall, much less than on other days, but the response of elevated TSS and turbidity was immediate and much greater than what would have been expected with this amount of rainfall.

An explanation may be that this rain had a short duration and high intensity and so produced more suspended solids than if it had occurred over a longer period of time.

In some instances high turbidity and TSS readings may be a legacy of sampling date. Some sampling dates occur immediately after rainfall and others have a much higher period between last significant rainfall and sampling date. There are other factors that may explain the variability of turbidity and TSS results. These may include;

- General rainfall that occurs in all of the catchments that feed into the Yarrangobilly River may not necessarily receive the same volume of rain.

- Some sub-catchments are some orders of magnitude larger than others. E.g. Wallaces and Stable Creek sub-catchments are by far the largest sub-catchments that combined are 6328 hectares. This is 42.5 times larger than Lick Hole Gully, 27.8 times larger than Watercourse 3 and 16.2 times larger than Sheep Station Creek (Table 3).
- The geology across the various sub-catchments is extremely variable. The lithology varies from igneous intrusive complexes, flysch sequence metasediments, metabasalts and calcareous limestones and marls. This variable lithology will produce weathering products that vary widely in their susceptibility to erosion. They will also produce different quantities of dissolved and suspended load in the streams.

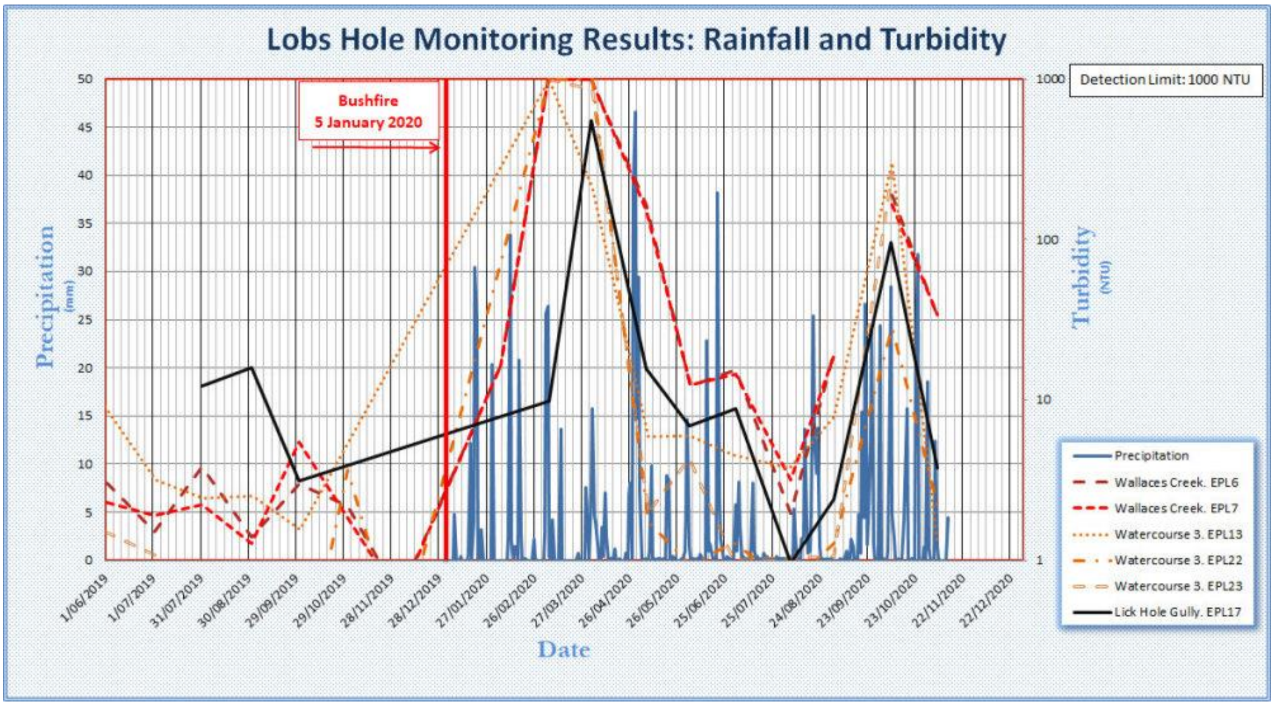

Figure 5 Rainfall and turbidity data for Lobs Hole

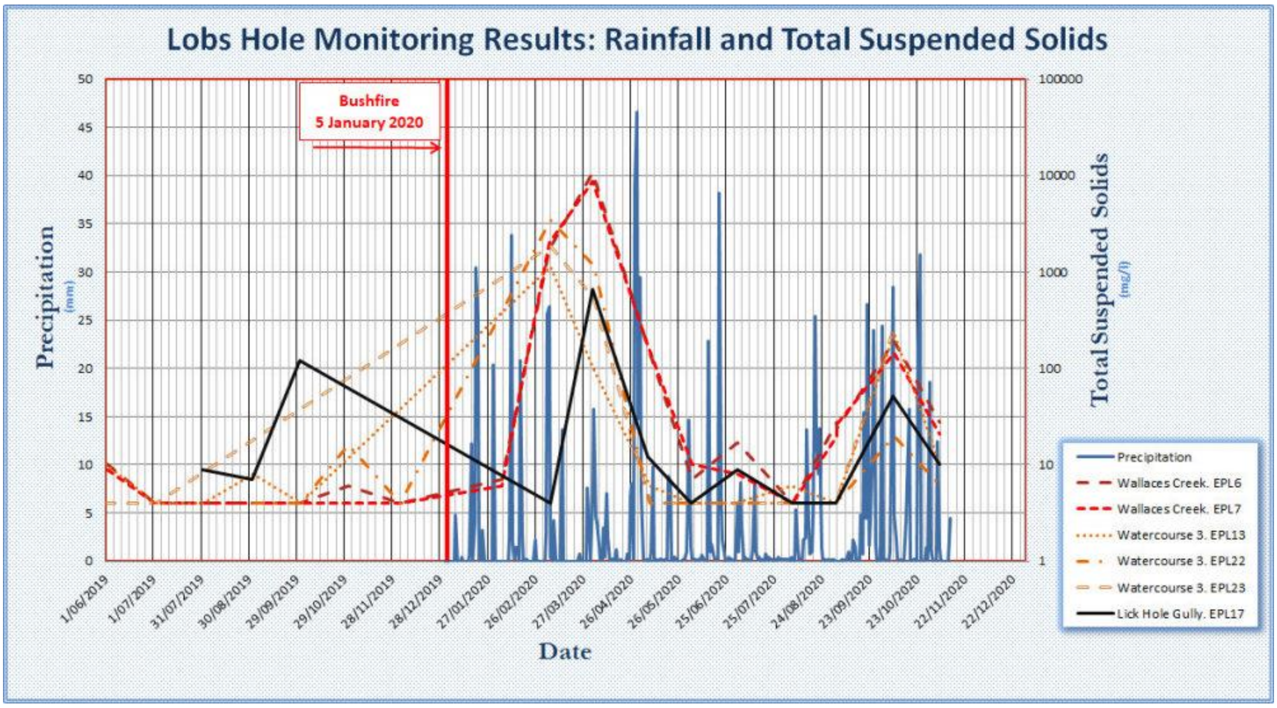

Figure 6 Rainfall and TSS data for Lobs Hole

	Wallaces Creek	Wallaces Creek	Lick Hole Gully	Watercourse 3 EPL13	Watercourse 3 EPL22	Watercourse 3 EPL23
Jun. 2019	Yes	Yes	Dry	Yes	Dry	Yes
Jul. 2019	Yes	Yes	Dry	Yes	Dry	Yes
Aug. 2019	Yes	Yes	Yes	Yes	Dry	Dry
Sep. 2019	Yes	Yes	Yes	Yes	Yes	Dry
Oct. 2019	Yes	Yes	Yes	Yes	Yes	Dry
Nov. 2019	Yes	Yes	Dry	Dry	Yes	Dry
Dec. 2019	Yes	Yes	Dry	Dry	Yes	Dry
Jan. 2020	No sampling due to fire proximity					
Feb. 2020	Yes	Yes	Dry	Dry	Dry	Dry
Mar. 2020	Yes	Yes	Yes	Yes	Yes	Yes
Apr. 2020	Yes	Yes	Yes	Yes	Yes	Yes
May. 2020	Yes	Yes	Yes	Yes	Yes	Yes
Jun. 2020	Yes	Yes	Yes	Yes	Yes	Yes
Jul. 2020	Yes	Yes	Yes	Yes	Yes	Yes
Aug. 2020	Yes	Yes	Yes	Yes	Yes	Dry
Sep. 2020	Yes	Yes	Yes	Yes	Yes	Yes
Oct. 2020	Yes	Yes	Yes	Yes	Yes	Yes
Nov. 2020	Yes	Yes	Yes	Yes	Yes	Dry

Table 1 Data availability for water quality monitoring stations at Lobs Hole

Date of rainfall	Rainfall (mm)	Next Sample Date	Days between rainfall and sample date
07/01/2020	4.8		29
17/01/2020	12.2		19
20/01/2020	30.4		16
21/01/2020	24.8		15
31/01/2020	20.4	05/02/2020	5
11/02/2020	33.8		23
17/02/2020	20.8		17
05/03/2020	25.6		1
06/03/2020	26.4	06/03/2020	0
29/04/2020	38.8		7
30/04/2020	46.6		6
01/05/2020	14.8		5
02/05/2020	29.4	07/05/2020	4
14/06/2020	22.8		17
21/06/2020	38.2	02/07/2020	11
20/08/2020	25.4	03/09/2020	14
22/09/2020	26.6		17
26/09/2020	24.0		13
01/10/2020	24.4		8
08/10/2020	28.4	09/10/2020	1
24/10/2020	22.4		13
25/10/2020	31.8	06/11/2020	12
13/11/2020	End of Data		

Table 2 Recurrence of sampling dates and relationship to significant rainfall

Aerial Photography

Monday October 21 2019

This imagery was captured 76 days before the fires passed through Lobs Hole. The channel and riparian zones of all tributaries are primarily obscured by ubiquitous and luxuriant blackberry growth. Intact canopy and mid story cover also obscures the channel zone of some tributaries. Flow pathways in this imagery are primarily defined by changes in vegetation cover. There are indistinct discontinuous flow paths elsewhere, especially Lick Hole Gully. Lick Hole Gully exits from bedrock confinement and passes onto the gravel lags of the ancient and manifestly underfit (*sensu* Dury 1964) Yarrangobilly River. This morphology was described in the geomorphology section of the EIS.

Nothing else could be interpreted from this photography regarding channel length and morphology. However, morphological changes at the floodplain/footslope boundary are evident and sediment stores can be interpreted from this photography. Geomorphological mapping of sediment stores and sediment fans was completed for the EIS.

Sunday January 26 2020

This imagery was captured 21 days after the fires passed through Lobs Hole and 97 days since the October 2019 imagery.

There has been an almost total loss of canopy cover in each study area. Additionally, the groundcover (including blackberries) has also been totally removed. The broad, distinct, and in some instances unchannelised, flow paths evident on the October 2019 imagery are manifest here. This is because these flow paths were primarily defined by changes in vegetation, not variations of morphology, and this masking vegetation has now been removed.

Tuesday October 13 2020

This imagery was captured 282 days after the fires passed through Lobs Hole and 261 days since the January 2020 imagery.

The luxuriant ground cover that is evident in 2019 photography has not returned here. While ground cover is gradually returning the vegetation ground cover is still sufficiently sparse such that more drainage depressions are evident as indistinct channels.

Tuesday December 1 2020

This imagery was captured 331 days after the fires passed through Lobs Hole and 49 days since the October 2019 imagery.

Only 49 days has passed since the previous photography was captured on October 13 and there are only minor changes to ground cover evident in this imagery since the last photography. The greening of the valley floors is still in contrast to the valley sides but there has been some recovery on the surrounding slopes.

Study Sites

Overview

A geomorphic assessment of the Yarrangobilly River at Lobs Hole, and its tributaries (Figure 1), was completed for the EIS from the location of the upstream access tunnel portal to the backwaters of the Talbingo Reservoir impoundment. There was very little variability of the morphology and form process associations of the Yarrangobilly River through the study area. In the lower reaches, downstream of the Wallaces Creek confluence, the character of the Yarrangobilly River 'floodplain' was unusual.

The tributaries exhibited characteristics of steep headwater streams until they exited from bedrock confinement and debouched on to the Yarrangobilly River floodplain. However, most of the tributaries do not reach the main trunk of the river. Upon exit from confinement the minor tributaries, e.g. Cave Creek and Lick Hole Gully, lose channel capacity and low angle sediment fans extend out from the floodplain margin. The decrease in channel capacity and attendant decrease in bank height are like floodouts in Central Australia (*sensu* Tooth 1999). The channels decrease of capacity occurs because of high infiltration rates into the 'floodplain'. However, the planar surface adjacent to the main channel is underlain by cobbles and boulders of a remnant paleo drainage system that has a meandering planform and is manifestly underfit (*sensu* Dury 1964). It is not really a floodplain at all. It is a deposit of basal lag boulders and cobbles that has been interred by recent deposition.

The Lobs Hole streams were again visited for this report on Tuesday the 10th and Wednesday the 11th of November 2020. Not all of the tributary streams that debouch into the Yarrangobilly trunk at Lobs Hole could be visited during the time available. Similarly, the main Yarrangobilly trunk was not assessed during the field visit. A detailed site investigation was completed for Watercourse 3, Sheep Station Creek, Lick Hole Gully and Wallace's Creek. These catchments were chosen because each had elevated levels of TSS and turbidity and each had been assessed during fieldwork completed for the EIS.

Watercourse 3

Watercourse 3 (Figure 1) can be divided into two distinct zones based on morphology and process association and the assemblage of geomorphic units that determine these zones character. These two zones are the steep headwater zone and the Yarrangobilly River floodplain zone. These zones are characterised by bedrock confinement and a steep channel slope in the headwater zone and low channel slope, reducing channel capacity and the complete absence of bedrock in the floodplain zone.

- The steep headwater zone is characterised by partial bedrock confinement and a steep channel. There are minor, narrow pockets of floodplain that alternate from one side of the channel to the other and opportunistically store sediment in the medium to long term. The channel has a low sinuosity and low to medium bank heights that are generally less than two metres high.

  The channel consists of a gravel and cobble bed creek with bedrock in base of plunge pools less than 25 cm below bed armouring. There are common cross channel bedrock bars that restrict channel incision.

  The channel appears to be partially infilled with recent deposition with what appears to be a debris flow. The sediment is very poorly sorted pebbly and gravelly, coarse and granular sand (Figure 7). The sediment is clast supported, for the most part, and consists of primarily lithic fragments that have most categories of sphericity from sub angular to well rounded; the degree of sorting, or lack thereof, combined with the range of angularity of the clasts indicate that this sediment was a debris flow at time of deposition.

  Exposures of the recently deposited sediment proximal to banktop indicate multiple phases of deposition and varying stream power (Figure 8). Note the difference in grainsize between bedload and overbank deposits. Since deposition there has been four stages of channel incision where the channel bed is no longer is covered by fine gravel. There is minor opportunistic deposition of finer grained material in the lee of boulders or as bank attached bars. Otherwise the high slope of the channel gives high stream power that moves finer sediment through this section.

- Watercourse 3 exits from bedrock control at a cross a bedrock bar, with a 0.75 m step in the long profile at site 6 (Figure 10). From this point the channel is low angle. Bedrock is still exposed in the right bank for a short distance downstream ad the channel parallels the floodplain margin of the Yarrangobilly River.

  The channel widens out to greater than 8 m on exit from confinement and left bank is undercut and susceptible to block falls. The channel bed is fundamentally a gravel bed river but there are no cobbles or boulders in evidence.

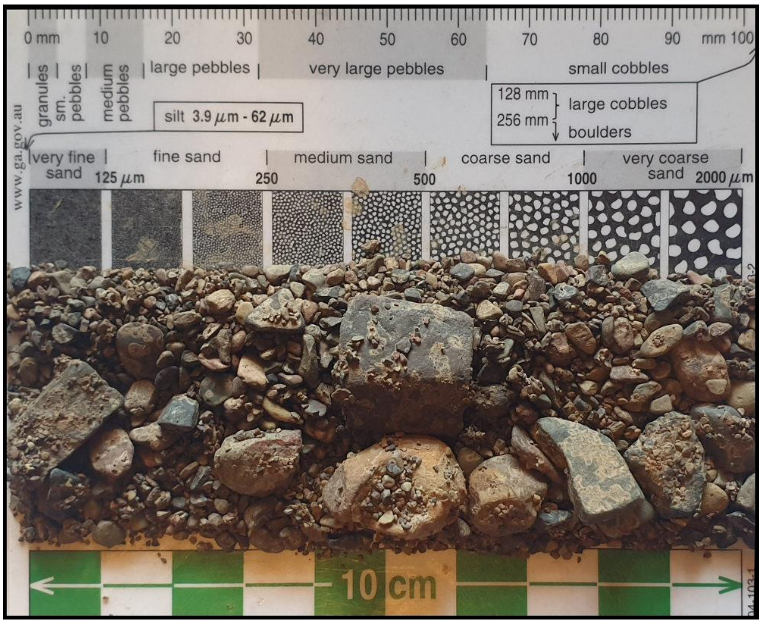

Figure 7 Grainsize distribution of poorly sorted sediment in channel at Watercourse 3, Site 1.

At exit from confinement the bank heights are in excess of two metres but bank height and channel capacity rapidly decrease downstream. Both banks show evidence of a sediment fan that the contemporary channel is now incising through.

The base flows that are evident when flowing across bedrock (Figure 9 and Figure 10) rapidly infiltrate into the floodplain sediments that are the remnant lag deposits of the paleo Yarrangobilly River.

❖ Channel definition is completely lost at recent deposition of a sediment fan (Figure 11) that has interred the channel that was in evidence in 2019 during the previous field inspections here (Figure 12). This morphology is analogous to floodouts of central Australia (*sensu* Tooth, 1999).

Figure 8 Sediment stack proximal to banktop on Watercourse 3. Multiple stages of deposition are indicated by changes in grainsize due to changes in available stream power.

Figure 9 Watercourse 3 shows evidence of recent incision and is scoured to bedrock and has large cobbles and boulders exposed in the base. Proximal overbank deposits shows multiple stages of deposition and incision

Figure 10 Watercourse 3 exits from confinement across the last cross channel bedrock bar. Site 6

Sheep Station Creek

Sheep station Creek (Figure 1) is characterised as a gravel bed river with a riffle-run sequence. The length of the run sequences decrease upstream as channel slope increases. There are small patches of opportunistic deposition within the channel, at left bank, in the lee of gravel lag deposits armouring the bed of the channel. The lower energy run sequence decreases upstream and fine deposits of granular lithic fragments in the channel have a low resident time. The low flow channel migrates across macro channel base and is undercutting right bank where upward fining floodplain fill sediment is exposed.

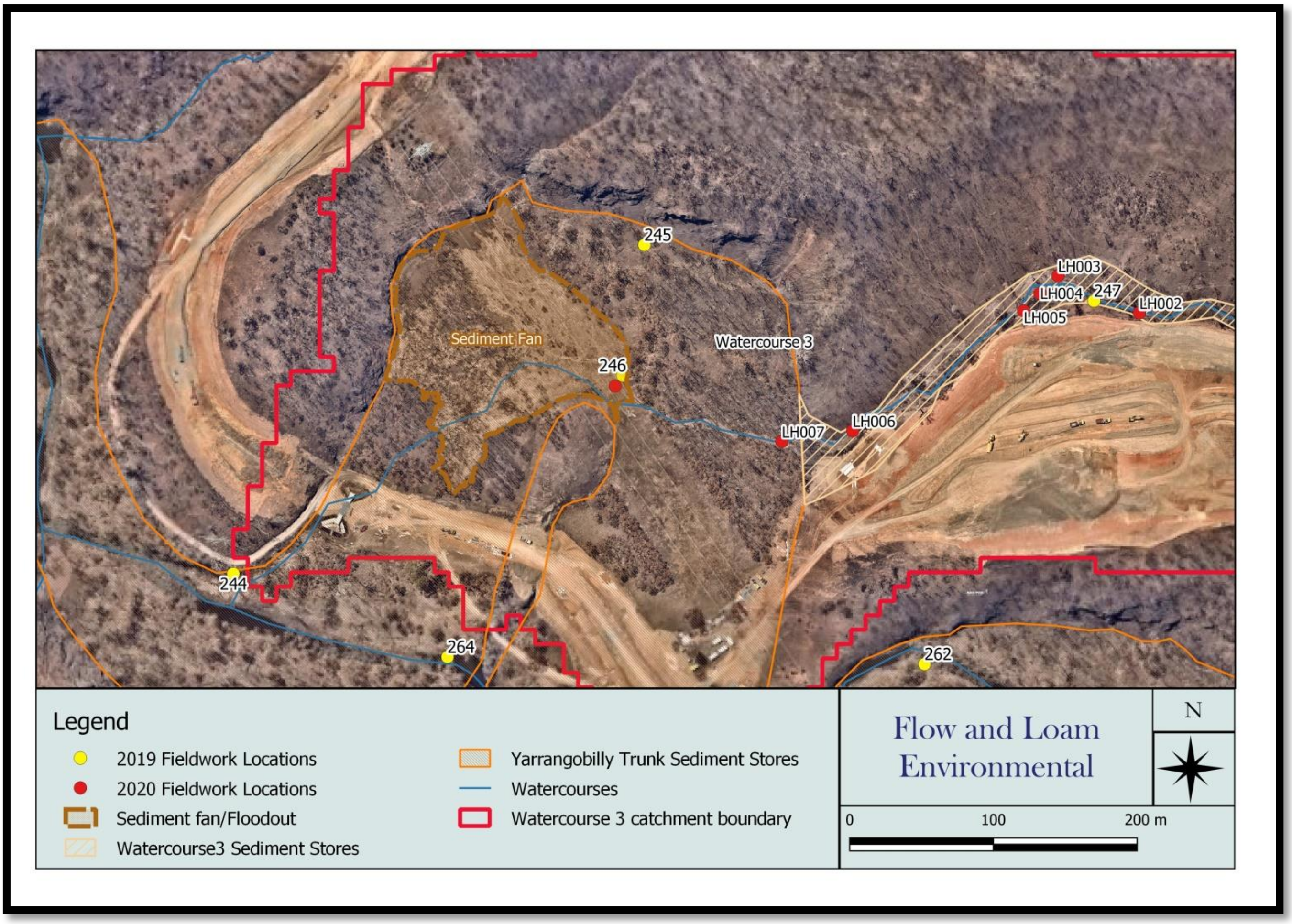

Figure 11 Watercourse 3 exits from bedrock control at LH007 and channel capacity decreases downstream to LH008/246 where channel definition is lost in a floodout.

Figure 12 Images looking upstream from the beginnings of the distributary fan at location LH008/246

At exit from bedrock confinement the base flow partially disappears into floodplain-saprolite interface. Channel capacity and bank height at first increases at exit from bedrock control but then decrease downstream. There is no evidence of recent deposition of proximal overbank deposits at bank top downstream of this point. Upstream of the exit from bedrock control there is evidence of recent overbank deposits of fine to medium, well sorted, sediment that consists mainly of angular and sub-angular lithic fragments (Figure 13). This indicates very juvenile sediment that has not been extensively worked by fluvial processes.

Figure 13 Poorly sorted proximal overbank deposition on small tributary of Sheep Station Creek.

Figure 14 Multi phase proximal overbank sediments near to confluence of Sheep station Creek and small tributary.

Upstream of the valley margin interface there are discontinuous pockets of sediment storage that are not floodplain pockets but are channelised valley fill. Channel migration is exhuming both colluvial and alluvial sediments that are exposed in both banks. Exposed clasts are sub rounded to rounded alluvial sediments and angular to sub angular colluvial sediments.

Multiple phases of deposition are evident in the sediment that has been deposited proximal to bank top (Figure 14). These multiple phases are characterised by varied amounts of sorting and grainsize. Each variation of grainsize indicates a variation of stream power and this change of stream power reflects variations of intensity of rainfall and catchment discharge.

Lick Hole Gully

The Lick Hole Gully channel (Figure 1) is characterised as having a laterally unconfined valley setting. The channel is planform controlled and has a low sinuosity with a discontinuous channel where it crosses the floodplain of the Yarrangobilly River. This lower reach, down slope of the road crossing, was not assessed during the last field work because of the extensive works. A full description of Lick Hole Gully channel is included in the EIS. Upslope, where the channel becomes partly confined, there is a continuous channel that decreases in capacity upstream.

Figure 15. Grainsize of poorly sorted sediment filling detention basin at Lick Hole Gully Site 1

Lick Hole Gully upstream of road crossing (site 234/LH016) occupies a broad channel zone with an inset floodplain 35-50 m wide. There has recently been a sediment trap constructed upstream of the new road alignment. This trap is completely filled with recent deposition of very poorly sorted, very fine to coarse and pebbly sandy gravel (Figure 15). The larger clasts are sub rounded to sub angular that indicates a mixture of alluvial sediment that has been mobilised and colluvial material that has not been subject to fluvial processes.

Upstream of the road crossing the colluvial footslope extends to both channel margins and the channel zone is decreasing in width. The channel upstream becomes poorly defined with common pools extending into a swampy channel zone.

At the time of the previous inspection in January 2019 the valley floor of Lick Hole Gully was colonised by luxuriant growth of blackberries that completely masked the channel zone in most instances. At the time of the latest inspection the fire had completely removed the blackberries and exposed the passage of multiple nickpoints incised into the valley fill. The nickpoints had present as steps in the longitudinal profile to a maximum of 3.5 m.

The valley floor narrows upstream to less than 15 m at both banks and bedrock is exposed in the plunge pool at the base of the 3.5 m falls. Bedrock is also exposed in both banks where there has been a knickpoint pass through.

There is a group of falls at Site 4 where there are five steps totalling 4 - 5 m of relief. Each step is hardened with cross channel bedrock bars that may equally be some sort of precipitate in terrace deposits. At the head of the cascades the channel bifurcates and has a low capacity with bank heights generally less than 0.20 m. The channel floor is covered in biofilm over very fine silty and clayey substrate with surface armouring of angular lithic clasts to 2 cm B_{max}. This section represents an intact valley fill.

Wallaces Creek

Wallaces Creek (Figure 1) is laterally confined and planform controlled where it debouches onto the floodplain of the Yarrangobilly River. It has a continuous channel that is incised into the floodplain and is armoured by cobbles and boulders (Figure 16). The combined catchment area of Wallaces Creek and Stable creek is sufficient to maintain a significant base flow and there are discontinuous pockets of floodplain at both banks. Wallaces is a boulder and cobble bed river and boulders and cobbles are exposed in the base of both banks.

Wallaces Creek is a high angle and high energy stream (Figure 17) characterised by turbulent flows of rapids and small cascades over boulders and cobbles. The flow exhibited moderate turbidity at the time of inspection.

Figure 16 Wallaces Creek (right) at the confluence with the Yarrangobilly River (left)

The left bank is low to moderate angle and two-stage that indicates bed lowering and channel incision. The right bank is partially undercut and is sub-vertical. The right bank and channel bed consist of matrix supported cobbles and boulders while the left bank has cobbles at base but is fine gravel floodplain fill.

The channel here is incised to bedrock as a cross channel bedrock bar and shows recent evidence of minor incision to 40 cm.

The riffle – rapid sequence is high energy with greater than 90 cm riffles (no broken water surface) and 10% broken water as rapids. There is a single cross channel boulder bar upstream that forms a single cascade sequence.

There is minor opportunistic deposition of granular and pebbly lithic fragments at channel margin behind boulders and as bank attached bars at backwaters.

There is evidence of fire scorching of surface sediment and rock at banktop but there is no evidence of recent deposition.

Figure 17 High energy turbulent flow over cobbles and boulders in the base of Wallaces Creek

Sediment Flux

The character of weathering and erosion has been discussed by many researchers, some of whom invoked catastrophism, or diastrophism, where development of landforms is a product of series of 'catastrophic' events, much like the fire that has passed through Lobs Hole and initiated the significant erosion and sediment flux through the system. Other authors adhered to the tenets of uniformitarianism where processes acting over long periods of time brought gradual change and were used to explain surface morphology.

Schumm and Lichty (1965) investigated erosion processes over geologic time periods and described fluvial systems as being in dynamic equilibrium. i.e. landscapes appear to be in equilibrium when interpreted over short time periods but are in a state of constant change (dynamic) when interpreted over geologic time periods. An extension of the investigation of these erosion processes led Schumm (1977) to divide landscapes into sediment production, sediment transfer, and sediment deposition zones (i.e. Source, Transfer and Sink zones). This was a process driven interpretation of the movement of sediment through river systems over geologic time periods.

Process based domains in fluvial systems takes a constructivist approach to interpreting the assemblage of geomorphic units extant within a river reach to determine the character, behaviour and processes that combine to shape current morphology. Process domains are fundamental to riverine classification systems that seek to classify fluvial landscapes and gain insights into channel variation and behaviour (e.g. Church. 1992; Nanson and Croke, 1992; Knighton 1998, Brierley and Fryirs, 2005).

The fluvial system that encompasses the Yarrangobilly River, and its tributaries, at Lobs Hole can be divided into these process based domains. These are;

1. Source Zone. Where sediment is mobilised during periods of rainfall from the valley slopes and washed into tributaries.
2. Transfer Zone. Where these mobilised sediments are moved through the fluvial system. Residence times for these sediments are generally short to medium length.
3. Sink Zones. Where sediments are deposited and residence times are long.

Lobs Hole

Sediments that have been liberated from the valley sides at Lobs Hole, and delivered to the various tributaries of the Yarrangobilly River, will eventually be deposited into the Talbingo Reservoir impoundment where residence times will be exceedingly long. The movement of these sediments through the system will depend on available stream power to move the sediments and also the connectivity of the tributaries with the Yarrangobilly River. Opportunistic deposition of sediments within the transfer zones will generally have low residence times and be remobilised during the next peak flow. The exception is where the channel is still coupled with the floodplain and overbank deposits occur during peak flow. These overbank deposits will have long residence times and will not be transferred to a 'sink' zone downstream until remobilised by channel migration or avulsion.

Stream power is a function of slope and discharge (e.g. Nanson and Croke 1992). Discharge is a function of runoff which in turn is a function of rainfall intensity, duration and infiltration. Slope is variable throughout the system but is static at any specific location and changes in slope can be used as a proxy for changes in available stream power. Insights into zones of potential deposition can be gained by constructing longitudinal profiles to determine changes in channel slope. For any specific discharge, lower slope will mean lower stream power and the potential for sediment deposition is increased. By identifying these zones of low slope, where deposition is most likely to occur, future assessments of riverine health can effectively target zones that are most susceptible to deposition.

Of the four tributaries that are studied in the report, two have channels that debouch into the Yarrangobilly River (Wallaces Creek and Sheep Station Creek) and two lose their stream power because the flow infiltrates into the coarse bed load lag deposits that underlay what has been interpreted as the Yarrangobilly River flood plain (Watercourse 3 and Lick Hole Gully). The Yarrangobilly River at Lobs Hole is manifestly underfit (*sensu* Dury 1964) and the cobbles and boulders that underlie the 'floodplain' represent bedload of the paleo Yarrangobilly River. These deposits are highly permeable and have a high hydraulic connectivity.

Catchment Areas

Catchment areas for each tributary have been calculated and are presented in Table 3.

	Watercourse 3	Sheep Station Creek	Lick Hole Gully	Wallace and Stable Creeks	Watercourse 6	Watercourse 7
Area in Hectares	228	390	149	6328	43	215

Table 3 Catchment areas for selected tributaries in Los Hole

Sediment Fans and Sheet Deposits

Sediment fans have been deposited on the Yarrangobilly River floodplain where tributaries exit from bedrock confinement. These sediment fans for all tributaries at Lobs Hole were mapped and presented in the EIS. For the current report analysis of the post fires aerial photography revealed recent deposition of sediment as fan deposits on Watercourse 3 (Figure 18), 6 and 7. Also, on Watercourse 3 there was a reach that had an overbank sheet flow across the valley floor. Geomorphic mapping of these deposits are presented in Appendix 1. The thickness of the deposits on Watercourse 3 were tested with a sediment spear at multiple locations and were found to have an average thickness of 0.45 m for the lower fans and 0.35 m for the sheet flow. The deposits on Watercourse 6 and 7 were not visited during the field component and the depth of recent sediment deposits was not tested. So the lesser value for an average thickness of 0.35 m has been used to calculate volume is indicative only. There are two quite distinct sediment fans on Watercourse 3 but there was insufficient information to determine the volume of each and so they are presented as one feature. The area and volume of these deposits was calculated using QGIS and is presented in Table 4.

Watercourse	Geomorphic Feature	Area (m^2)	Average Cover (m)	Volume (m^3)
Watercourse 3	Sediment Fan	17,991.5	0.45	8,096.2
Watercourse 3	Sediment Sheet	5,202.0	0.35	1,850.7
Watercourse 6	Sediment Fan	8,553.7	0.35	2,993.8
Watercourse 7	Sediment Fan	14,477.5	0.35	5,067.1

Table 4 Estimated volumes of recent deposition on Yarrangobilly River floodplain.

Longitudinal Profiles

Longitudinal profiles have been constructed for each of the tributaries that have been assessed for this study. A synopsis of indicative channel slopes for each is presented in Table 4.

Reach	Sub Reach	Watercourse 3	Sheep Station Creek	Lick Hole Gully	Wallaces Creek	Watercourse 6	Watercourse 7
Reach 1		-0.5197	-0.3505	-0.2946	-0.4368	-0.6009	-0.0709
Reach 2		-0.1384	-0.1710	-0.1232	-0.1196	-1.5618	-0.3533
Reach 3		-0.0755	-0.0750	-0.2234	-0.0289	-0.4725	-0.1107
Reach 4		-0.0755	-0.0243	-0.1371	-0.1585	-0.1787	-2.2895
	Reach 4A	-0.0549					
	Reach 4B	-0.0396					
	Reach 4C	-0.0242					
	Reach 4D	-0.0026					
	Reach 4E	-0.0251					
	Reach 4F[1]	-0.0018					
	Reach 4G[1]	-0.0096					
Reach 5			-0.1745	-0.4225	-0.0379	-0.2393	-0.3234
Reach 6			-0.0453	-0.1975	-0.0408	-0..1266	-0.4776
	Reach 6A				-0.0518		
	Reach 6B				-0.0941		
	Reach 6C				-0.0396		
	Reach 6D				-0.0824		
	Reach 6E				-0.0099		
	Reach 6F				-0.0242		
	Reach 6G				-0.0125		
Reach 7			-0.0779	-0.5967			-0.1410
Reach 8			-0.0239	-0.1175			-0.0765
	Reach 8A						-0.0106
	Reach 8B						-0.0191
	Reach 8C						-0.0333
	Reach 8D						-0.0126
	Reach 8E						-0.0590
	Reach 8F						-0.0188
Reach 9			-0.0218	-0.0524			
Reach 10				-0.1231			
Reach 11				-0.0299			
Reach 12				-0.0834			

Note 1: Sub reaches 4F and 4G are not shown on Figure 20 due to restrictions of available space.

Table 5 Indicative channel slopes for tributaries dealt with in this study (m/m)

Watercourse 3

Most sediments that have been liberated from the surrounding catchment of Watercourse 3 do not reach the Yarrangobilly River. The coarser sediments are deposited as sediment fans atop the sediment in the paleo Yarrangobilly River that is underlain by coarse bedload of cobbles and boulders. As the discharge infiltrates the underlying permeable sediments it is only the dissolved load and finest suspended load that will be delivered to the Yarrangobilly River through the coarse substrate as it has a high hydraulic connectivity. There is also a dis-synchronicity between depositional processes upstream and downstream. When there is deposition upstream in Watercourse 3 there is very little, or no, sediment transferred to the downstream sink zones. Conversely, when sediment stored within the channel upstream is liberated during periods of peak discharge, this sediment is deposited as fan deposits downstream (Figure 18; See also Appendix 1).

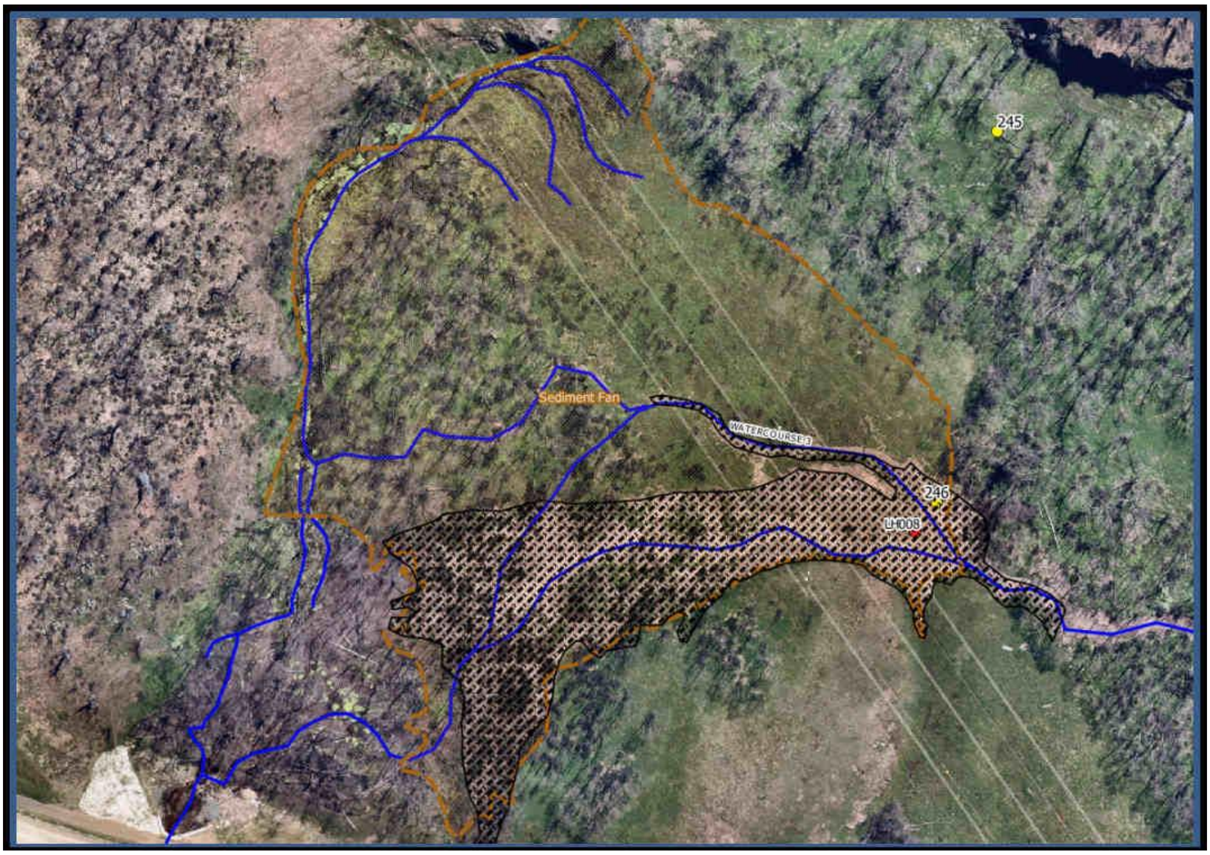

Figure 18 Sediment fans deposited on paleo Yarrangobilly River bedload at Watercourse 3

The upstream zone (Reach 1) of Watercourse 3 is steep and has a slope of -0.5197 (Figure 18, Table 3).

The slope of this reach is such that any discharge from the catchment that flowed into, or thorough, this reach would have very high stream power. Sediment liberated from the surrounding catchment would have low residence times in this reach and would quickly transit down slope.

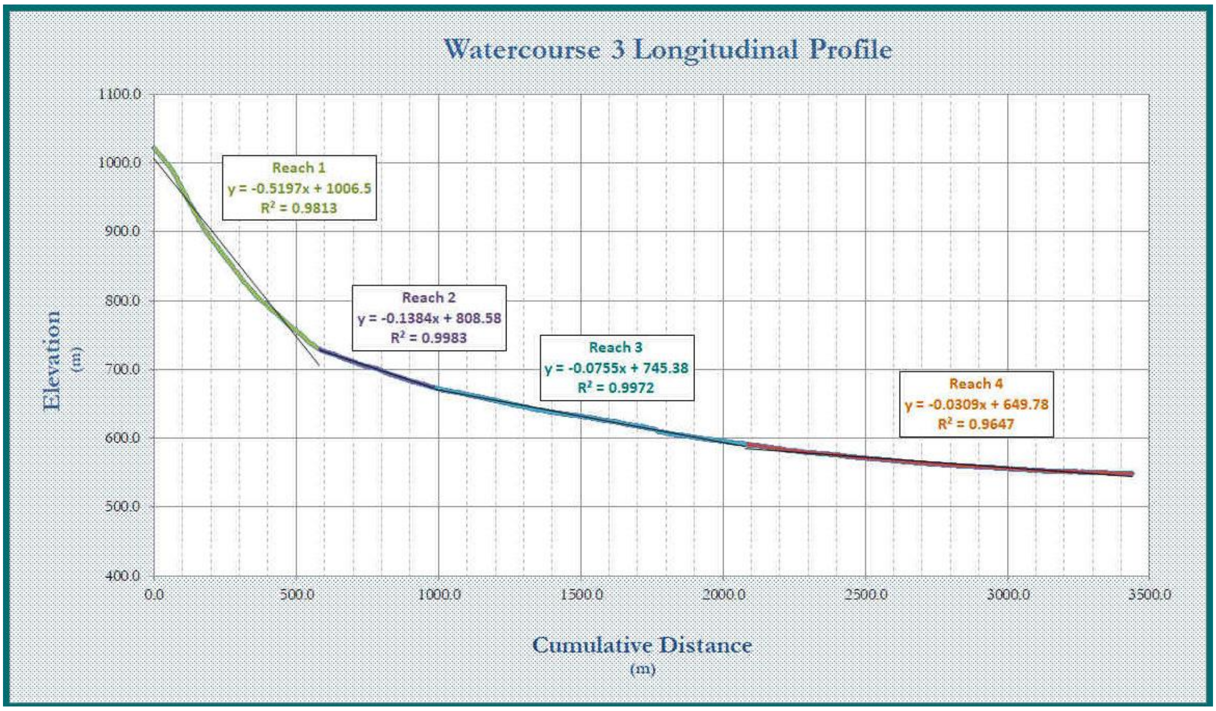

Figure 19; Watercourse 3 longitudinal profile

Figure two shows that channel slope decreases downstream but remains high through Reach 2. The channel slope in Reach 3 would allow for more opportunistic deposition of short term sediment stores, however, it is not until Reach 4 that channel slope decreases sufficiently to allow longer residence time deposition.

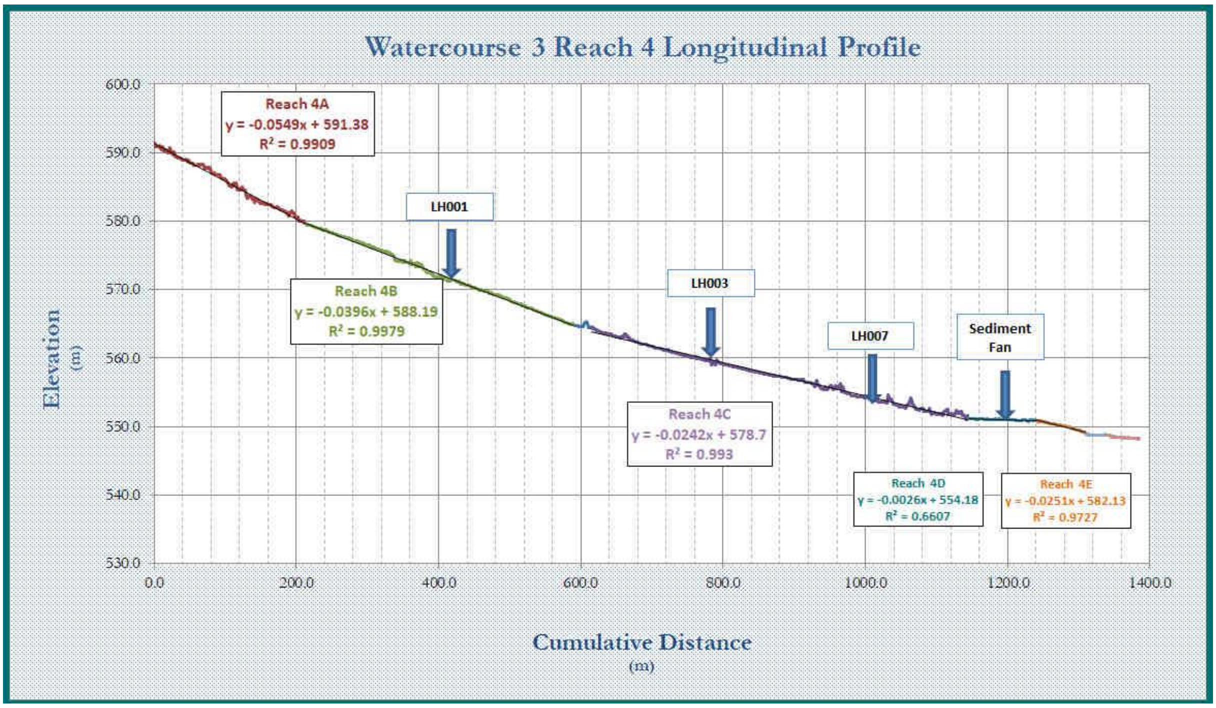

Figure 20; Watercourse 3, Reach 4 longitudinal profile

Greater insight can be gained by a closer examination of Reach 4 (Figure 20) Channel slope is moderately constant throughout Reach 4 until Reach 4D is reached. At Reach 4D the channel slope is very low at -0.0026 and this is the location of the sediment fan. This sediment fan is prograding over a previously deposited sediment fan which is Reach 4F. Reach 4E represents the frontal lobe of the current fan and Reach 4G is the old surface of the paleo Yarrangobilly bedload.

Upon exit from bedrock confinement (Figure 10) the flows that are contained within the channel infiltrate the underlying coarse sediment, boulders, and cobbles, thereby progressively diminishing stream discharge and stream power as the flow becomes subterranean. This process is very similar to a 'floodout' (*sensu* Tooth 1999) and only the largest flows extend to, or beyond, the sediment fans.

Sheep Station Creek

Sheep Station Creek at first inspection in January 2020 maintained a small base flow that was evident before the rains came. In the lower reaches that were inspected post fires there was evidence of minor deposition of sediment proximal to banktop upstream of a log jam that was partially blocking the channel. Otherwise the channel of Sheep Station Creek appears to be decoupled from the small floodplains that alternate at either side and stream power is concentrated within the channel. Consequently, there is very little sediment that is temporarily stored within the channel. Small tributaries entering from the valley margin have smaller channel capacities and have deposited sediment on the small floodplains of the trunk (Figure 13; Figure 14).

Reaches 1 – 3 of Sheep Station Creek have a high slope and would have sufficiently high stream power sufficient to flush most sediment through these reaches. The residence time of sediment within the channel here would be very short (Figure 21). These Reaches represent a transfer zone for sediments passing through the system.

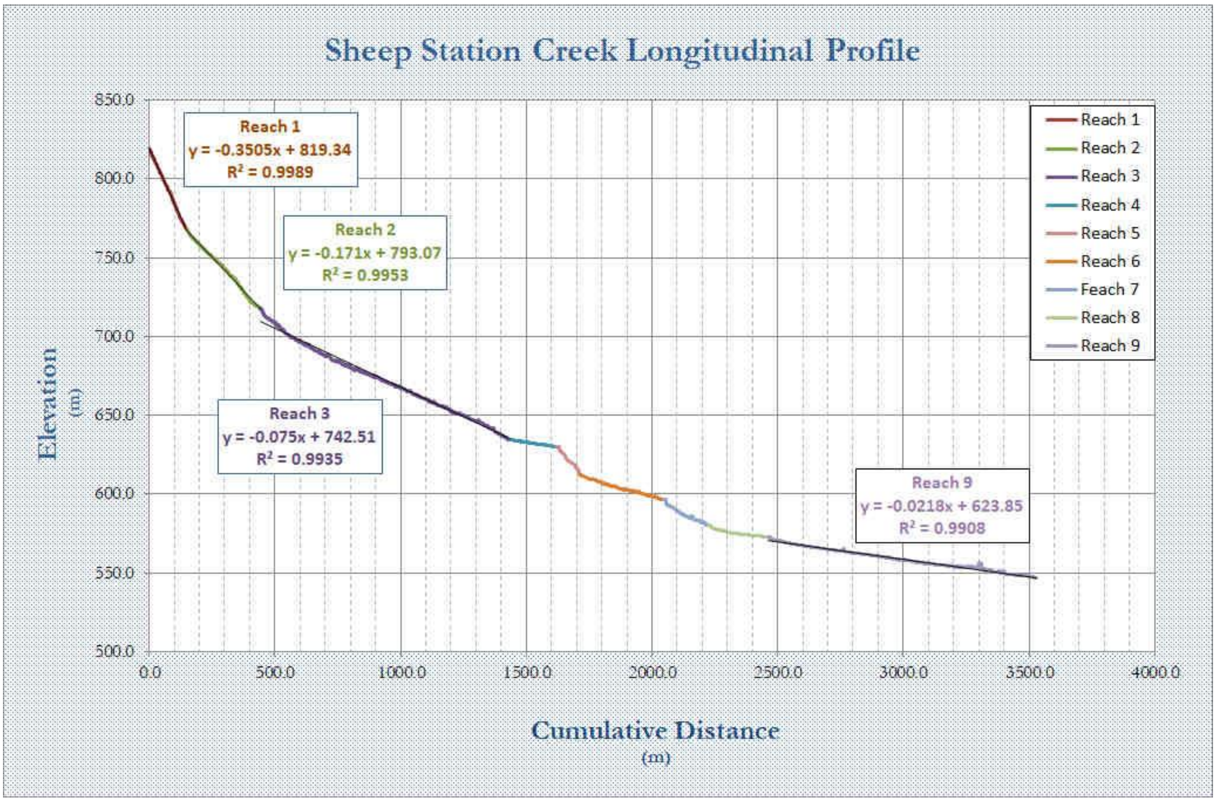

Figure 21 Sheep Station Creek longitudinal profile

From Reach 4 there are a series of steps in the longitudinal profile that would allow greater deposition of sediment while maintaining a short to medium term residence time (Figure 22) of sediment stores within the channel.

Reach 4, with a slope of -0.0243 m/m, and Reach 8, with a slope of -0.0239 m/m, would represent the greatest potential for sediment retention within these reaches. These reaches were not visited during the fieldwork for this study. Channel capacity cannot be determined from aerial photograph interpretation and so an assessment of the existence of any sediment pockets, or floodplains, and whether the channel is coupled with the floodplain cannot be determined.

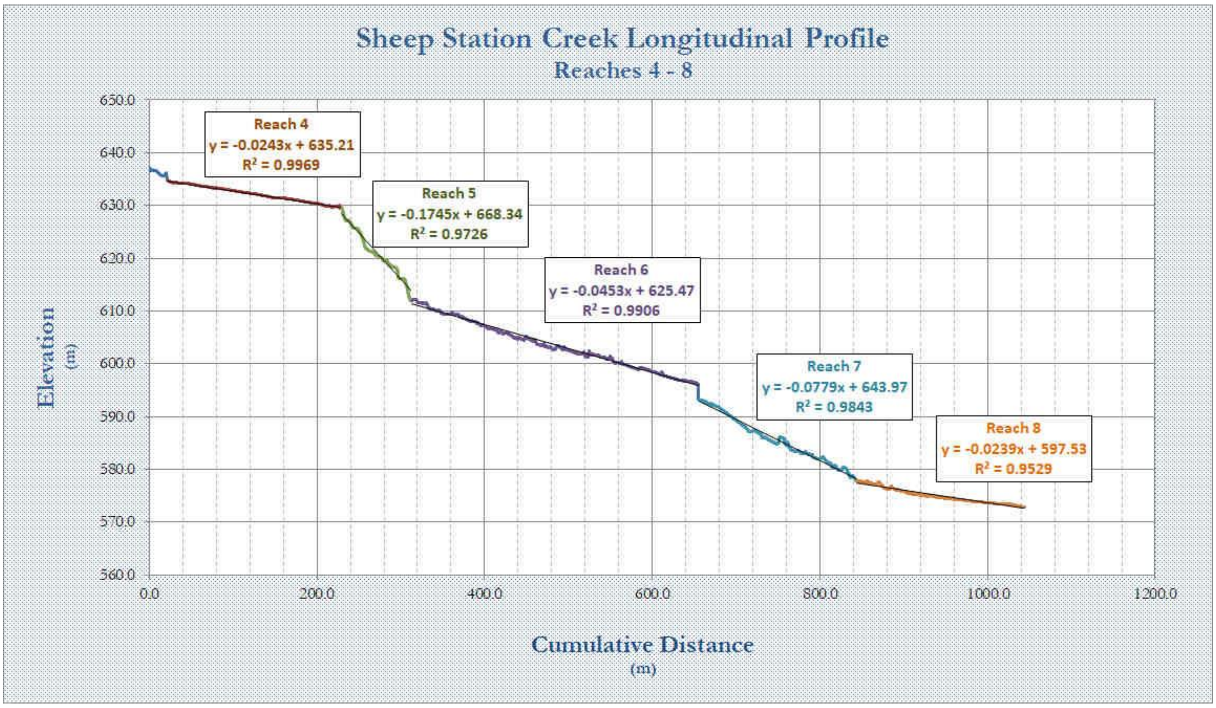

Figure 22 Sheep Station Creek Reaches 4 – 8

The channel of Sheep Station Creek continues across the Yarrangobilly River 'floodplain' and empties directly into the Yarrangobilly River trunk. Sediment that has been washed into Sheep Station Creek would generally have a low residence time and pass into the Yarrangobilly River very quickly.

Lick Hole Gully

For this study the assessment of Lick Hole Gully ends at the construction roadway. The assessment that was completed for the EIS continued down slope until the channel exited from bedrock confinement. As with Watercourse 3, and other unnamed tributaries that were assessed for the EIS, the channel capacity of Lick Hole Creek diminishes rapidly as discharge is able to infiltrate into the coarse grained substrate of the Yarrangobilly River floodplain.

There is a lot of variability of slope of Lick Hole Gully.

The upper reaches do not have the very steep slope that the other three tributaries do. For a full list of Reach slopes refer to Table 3. The central zones of reaches 3 – 7 have the greatest slope; especially Reach 5 and Reach 7. Reaches 9, 11 and 12 have the lowest slopes.

In this respect Lick Hole Gully is different from the other tributaries in that it does not present as a source-transfer-sink sequence. In Reach 9, and possibly in Reach 8, the channel is not incised into the valley fill and sediments deposited across the valley fill surface will have long residence times. At least until they become incised by knickpoints migrating upstream from lower reaches.

In Reach 9 the channel capacity is very low, bank heights are usually less than 20 cm and the channel is coupled with the floodplain. In this zone overbank deposition of sediment is common, exists as sediment sheets across the intact valley fill, and has long residence times.

Downstream the channel becomes incised into the valley fill and the channel is no longer coupled with the floodplain/valley fill surface. Sediment will pass through this zone rapidly.

Reach 11 is immediately upslope of the detention basin/sediment trap, upstream of the road crossing. Here the slope is very low and deposition will continue to occur here.

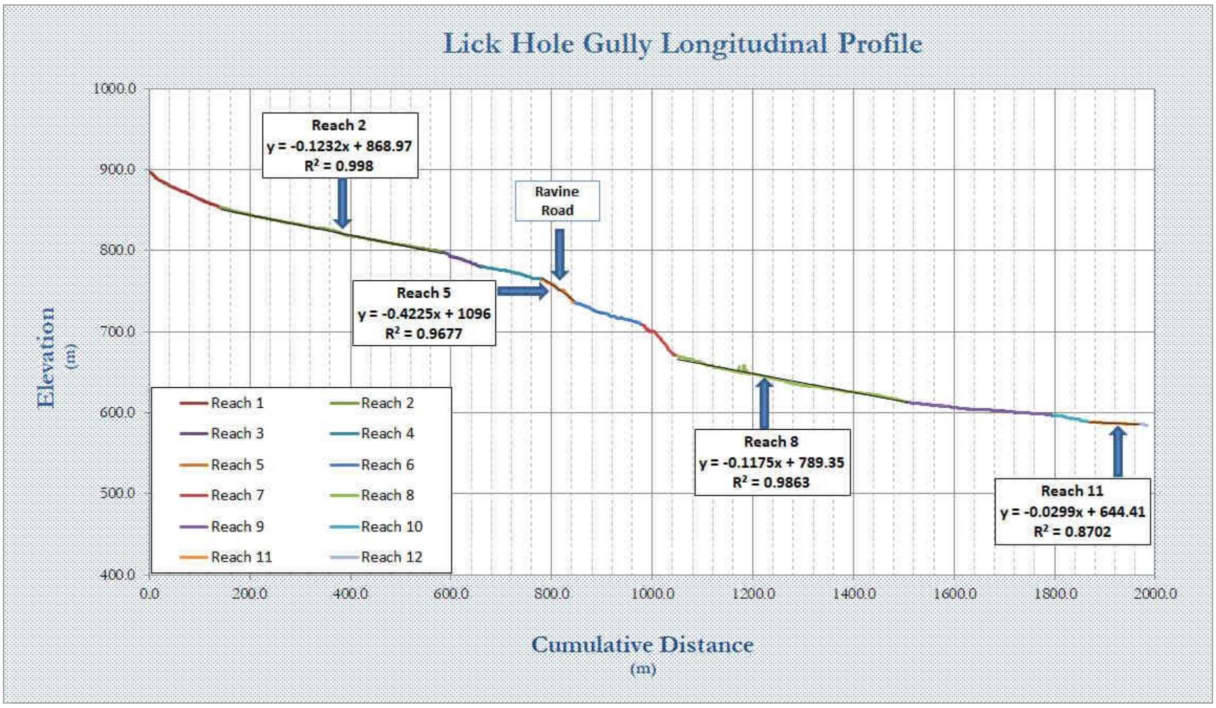

Figure 23 Lick Hole Gully longitudinal profile

Wallaces Creek and Stable Creek

The combined catchment area of Wallaces and Stable Creeks is more than eight times the size of the other tributaries combined (Table 3). The channel of Wallaces Creek at its confluence with the Yarrangobilly River, and the reaches immediately upstream, can be characterised as a high energy, cobble bed river that exists as a sequence of cascades, rapids and runs.

Inspection of the downstream reaches revealed that the channel is decoupled from the floodplain and there was no evidence of recent proximal overbank deposition. The channel capacity is such that all stream power is confined within the channel and there was evidence of recent channel incision and undercutting of the right bank downstream of the bridge crossing.

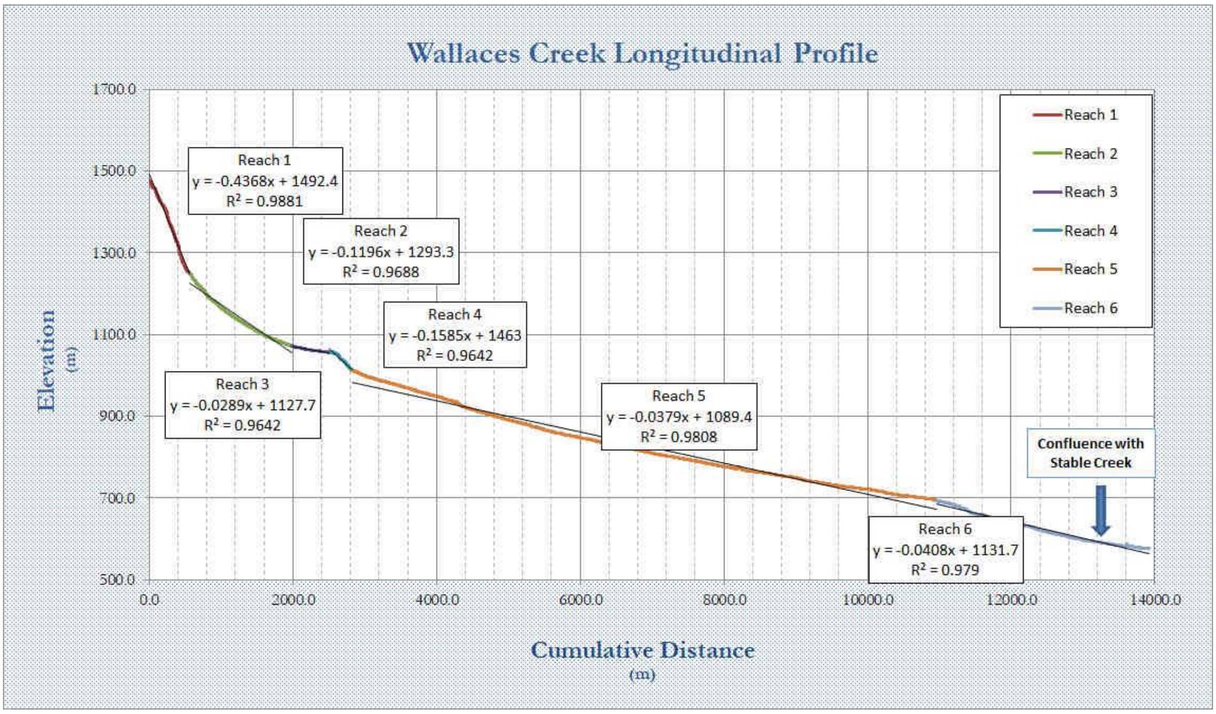

Figure 24 Wallaces Creek longitudinal profile

The upstream reaches of Wallaces Creek are high angle and would be characterised as having high stream power. Sediment that was delivered to these reaches from the surrounding catchment would have very short residence times and pass quickly to downstream reaches. Reach 3 has an anomalously low slope and there may be some short term deposition here. Reaches 5 and 6 have a more uniform and consistent slope and may, under other circumstances, represent zones of potential sediment storage. However, channel capacity is such that these would also be transfer reaches. Reach 6, where the two creeks merge, is worth further analysis.

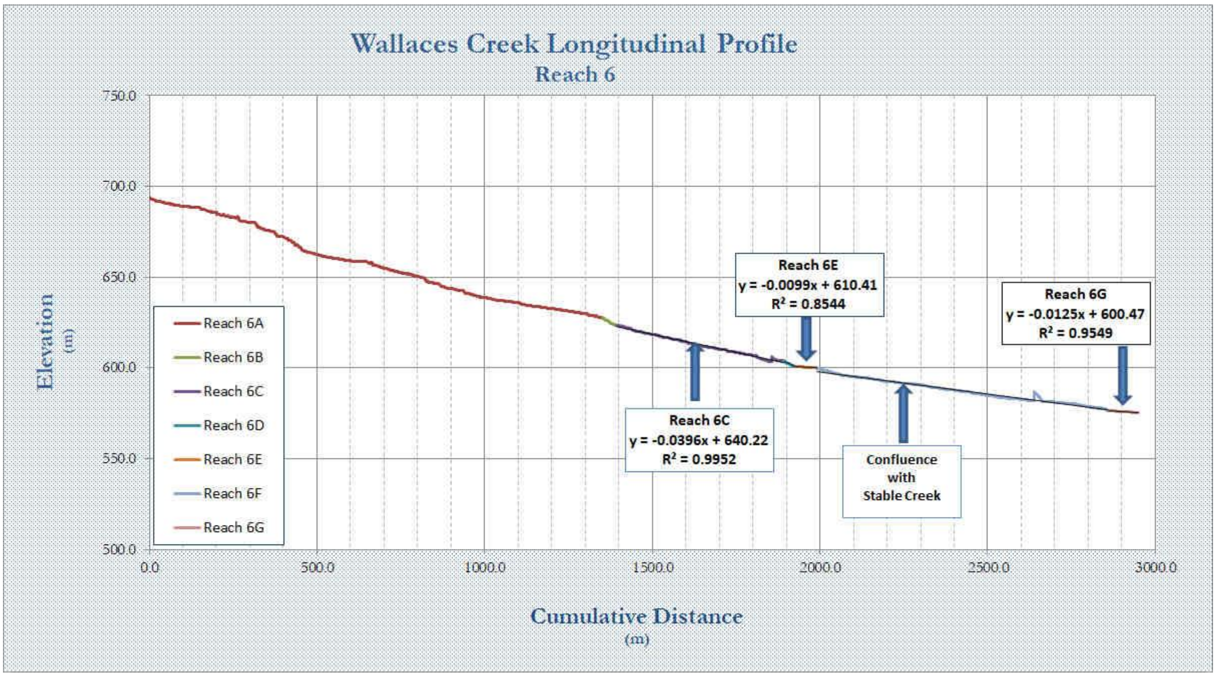

Figure 25 Wallaces Creek Reach 6

The slope through Reach 6 is moderately uniform, however, there are some instances where short to medium term sediment storage may occur; notably Reach 6E.

There appears to be very little variation of slope within Reach 6. The main issue here is that the channel is decoupled from the floodplain, all stream power is concentrated within the channel and most sediment would pass through rapidly and be delivered to the Yarrangobilly trunk. At the time of inspection there was very minor deposition of coarse and granular sand that had been deposited opportunistically in the lee of large cobbles on the bed of the channel.

Watercourses 6 and 7

Watercourses 6 and 7 were not visited during the fieldwork component of this study. However, during desk top analysis of the aerial photography for the 26th of January it was noted that sediment fans had been deposited on the Yarrangobilly River floodplain since the fires passed through Lobs Hole (Figure 26). Watercourses 6 and 7 are of particular interest as their confluence with the Yarrangobilly River is immediately upstream of the main works area for assembling the tunnel boring machine.

The sediment fans for Watercourses 6 and 7 were mapped from the respective channels exit from bedrock confinement to the channel margin of the Yarrangobilly River.

Watercourse 6

The longitudinal profile of Watercourse 6 is presented in Figure 27. The overall length of Watercourse 6 is 1315 m and shows very little variation of slope. The catchment area of Watercourse 6 is 43 hectares and is relatively small for the volume of sediment that has been deposited from it. There is no obvious channel length of sufficiently lesser slope to reduce stream power and induce deposition. Instead, there is a gradual decrease in slope throughout the profile of sufficiently high slope to move the sediment through the system quickly. The slope for all reaches in Watercourse 6 is presented in (Table 5).

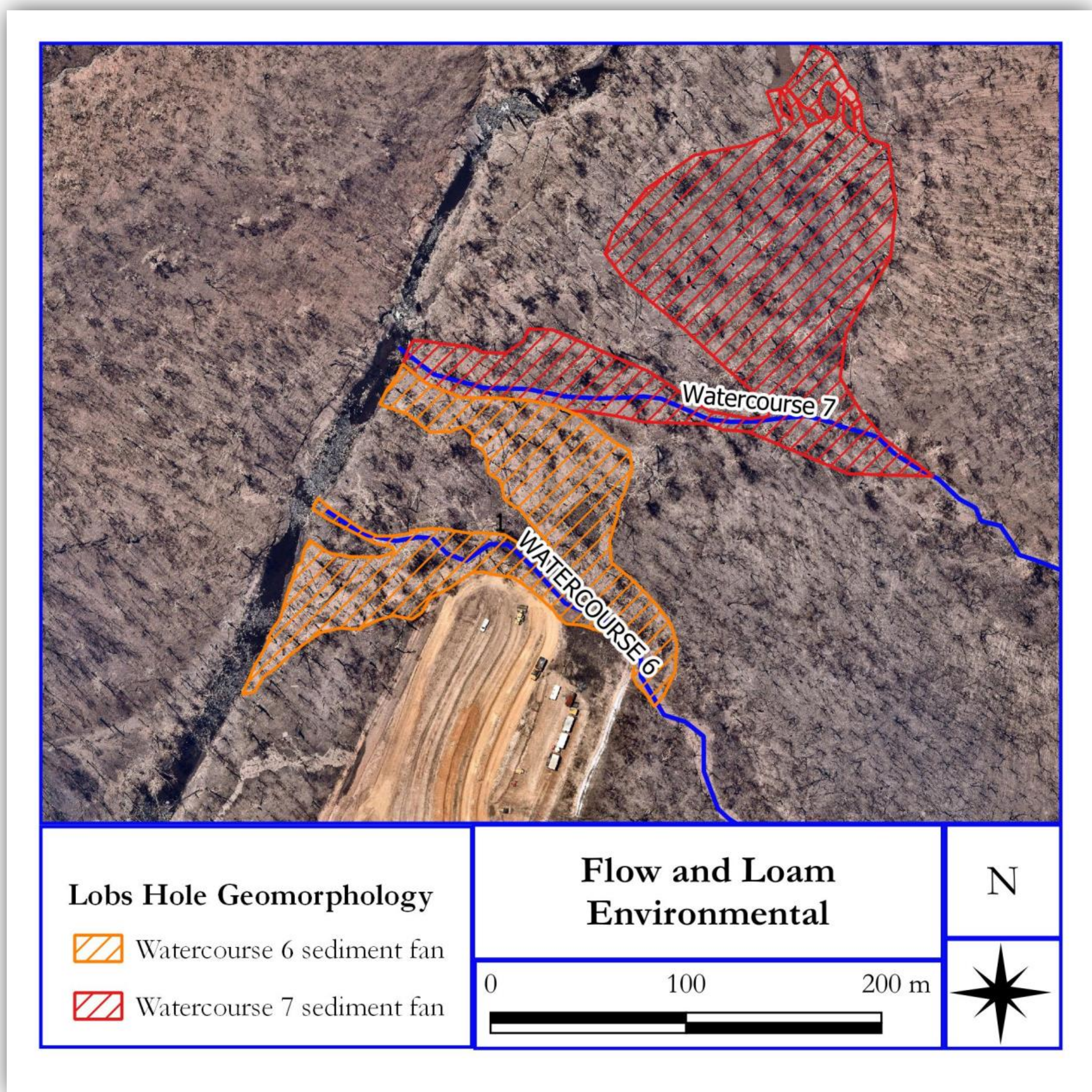

Figure 26 Recent deposition of sediment fans from Watercourses 6 and 7 onto the Yarrangobilly River floodplain.

Watercourse 7

The longitudinal profile for Watercourse 7 (Figure 28) shows marked variability of slope throughout its length 3097 m. It has a catchment area of 215 hectares (Table 4). While there are multiple variations of slope throughout the length of the longitudinal profile none of the reaches present a slope sufficiently low enough to maintain a depositional environment and induce sedimentation. Reach 8 has the least overall slope and a closer examination of this reach is insightful.

The overall slope of Reach 8 is -0.0765 m/m but closer examination of Reach 8 five reaches with sufficiently low slope so as to induce deposition within each sub reach. The longitudinal profile for Watercourse 7, Reach 8, is presented in Figure 29.

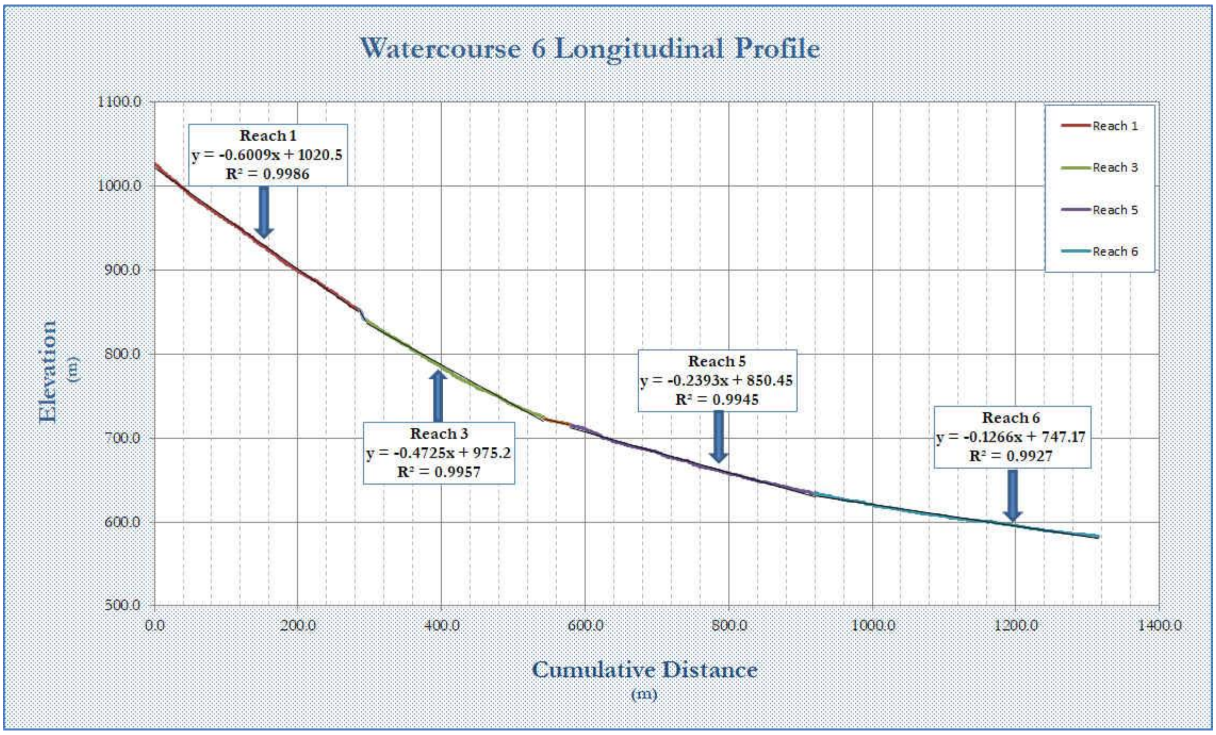

Figure 27 The longitudinal profile of Watercourse 6

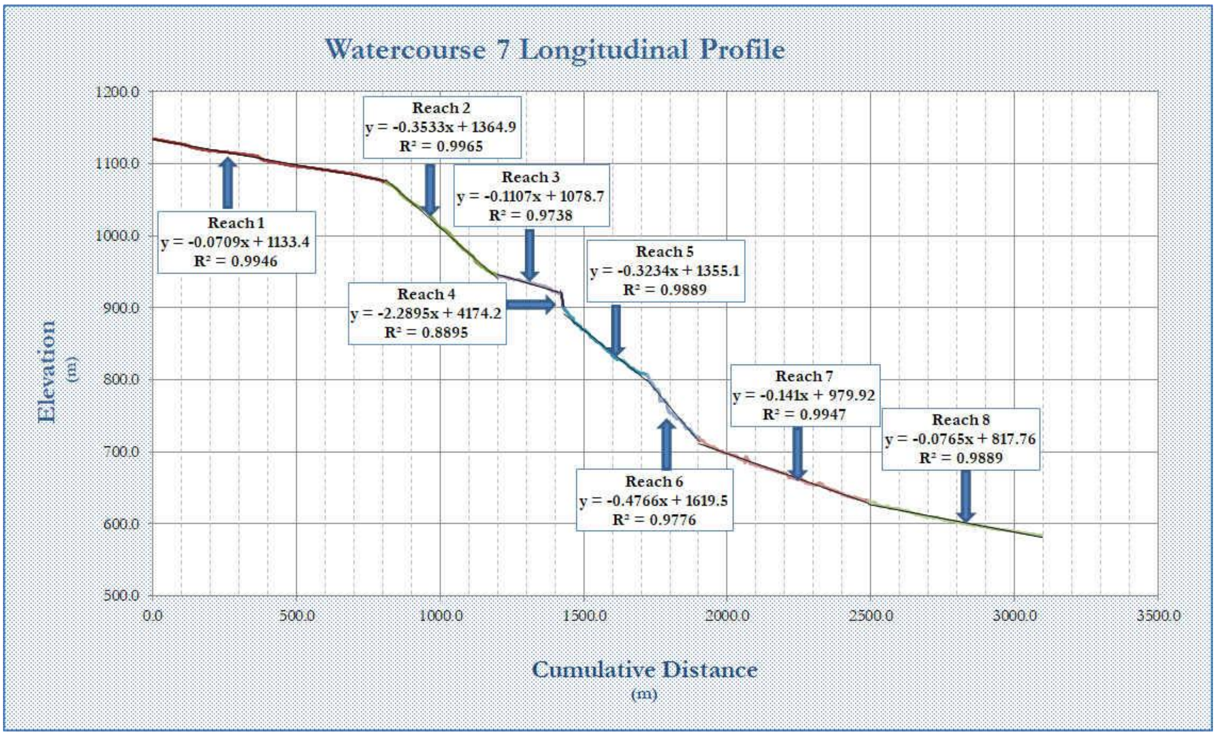

Figure 28 The longitudinal profile of Watercourse 7.

Examining the profile for Reach 8 reveals that there are at least five reaches where the slope is sufficiently low enough to induce sedimentation with a mid to long term residence time. The slope of Reach 8E is presented because this reach is the last major reach, of uniform slope, before the Watercourse 7 exits from confinement onto the floodplain of the Yarrangobilly River. Within this reach there would only be opportunistic deposition of sediments within the channel that would have a short residence time.

Interpretation of the aerial photography did not reveal whether the channel was still coupled with the floodplain pockets.

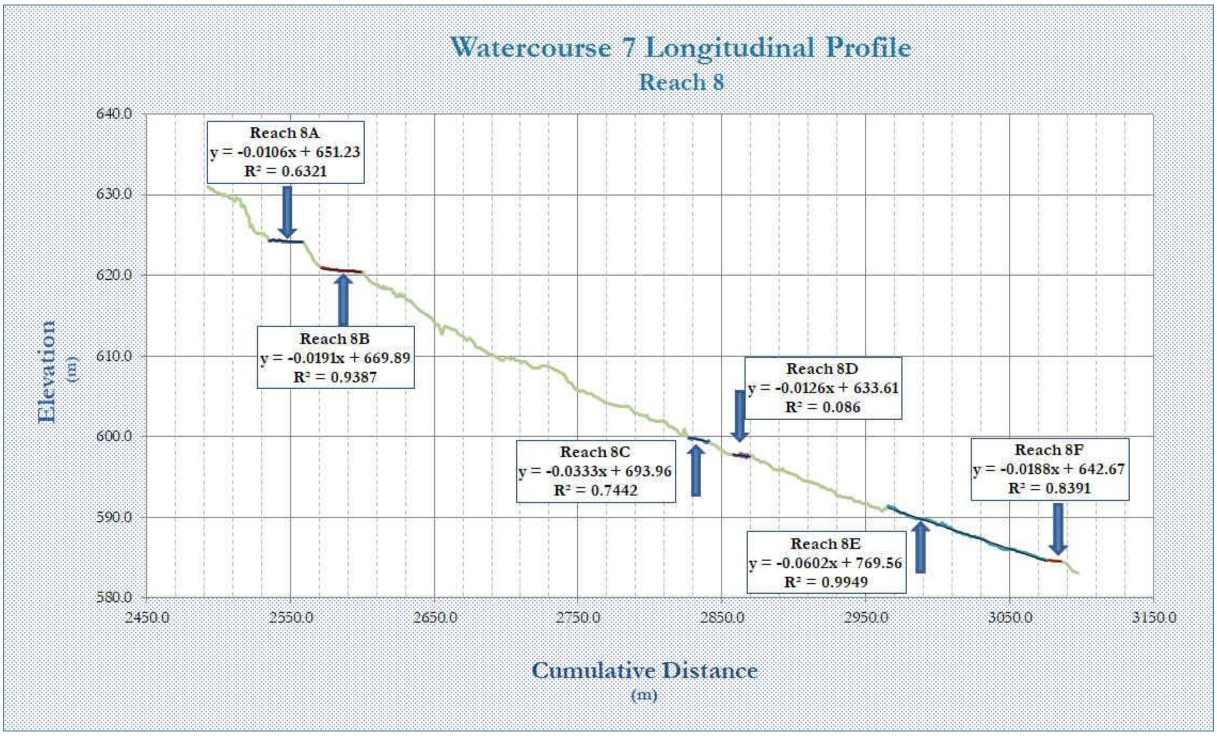

Figure 29 The longitudinal profile of Watercourse 7, Reach 8

Recovery Trajectory

Analysis of recovery potential and trajectory for this report is based upon the interpretation of aerial photography and rainfall data for the Bureau of Meteorology (BoM) Automatic Weather Station (AWS), Cabramurra. The assessment of recovery potential and trajectory is an assessment of the landscape returning to geomorphic stability after the catastrophic fires of the 5th of January 2020.

The recovery trajectory to a relatively stable and less erosional state is dependent upon vegetation returning to provide ground cover and also vegetation detritus availability that can be washed into litter dams to reduce the velocity and available power of surface sheet flows. The return of vegetation ground cover is largely based on rainfall; however, this assertion should be qualified.

The surface soils after the passage of the fires are hydrophobic and will repel initial precipitation and the soil will take an extended period of time to 'wet up' such that runoff is maximised in the short term.

There are variables that will mitigate this state of potential erosion based on available (stream) power. Given a constant discharge the most important factor is slope. Areas of low slope, both on the surrounding valley margins and within the channel zone, will hydrate faster and retain more moisture further enhancing the return of vegetation cover. Until hydrophobic conditions abate high intensity rainfall will result in severe erosion and sedimentation in streams and overbank where the channels are still coupled with the floodplain or the riparian zone.

Rainfall data was sourced from BoM for Cabramurra AWS for the period January 2020 to March 2021 and is shown in Figure 30.

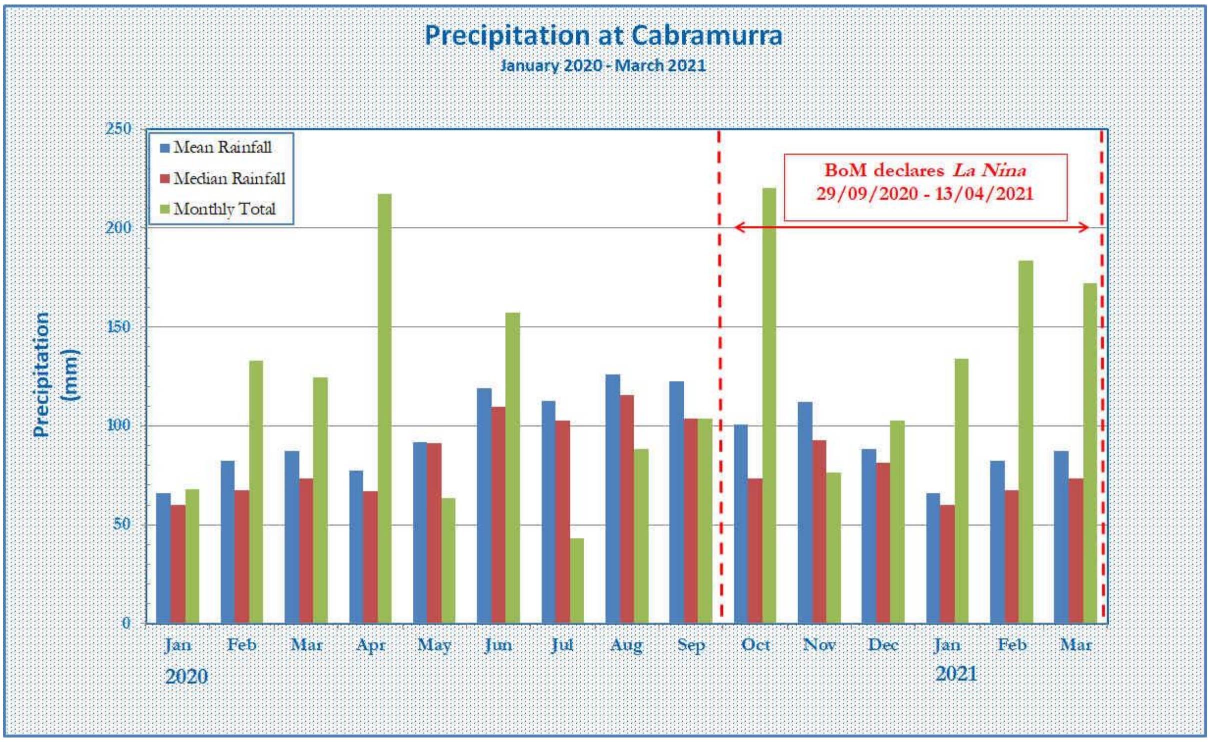

Figure 30 Rainfall Data from BoM AWS, Cabramurra.

The El Niño–Southern Oscillation (ENSO) had a strongly positive Southern Oscillation Index (SOI) and *La Nina* conditions were declared by Bureau of Meteorology on 29 September 2020 signalling a wet spring and summer likely for northern and eastern Australia. Subsequent rainfall data confirmed that Cabramurra experienced above average rainfall for 5 months out of 6 during the declared *La Nina* event (Figure 30). Above average rainfall was experienced at Cabramurra for the periods February to March, June, October and December 2020 and also for the period January to March 2021.

On 13 April 2021 the BoM has declared an inactive, or neutral, ENSO. Modelling by BoM indicates that the SOI will remain neutral until September 2021.

Aerial photography was available for 21 October 2019, 26 January 2020, 13 October 2020 and 01 December 2020 and is described on Page 16. For five locations (two locations on Watercourse 3 and one each on Sheep Station Creek, Lick Hole Creek and Wallaces Creek) excerpts from the aerials are presented as time slices and are presented in Appendix 1.

Each of the groups of aerial time slices shows the same results, impacts and recovery.

The image shown for 21 October 2019 shows intact vegetation prior to the passage of the fires through Lobs Hole on the 5th of January 2020. The image was captured 76 days prior to the fire.

The image shown for 26 January 2020 and is the first image captured 21 days after the fires. At each location the images show the same thing; total devastation and almost total consumption of vegetation. In each image the ground is easily visible and is blackened and covered with ash in most instances. In appendix 1A and 1B are images of two locations referred to in Figure 8 and Figure 18. At these locations the ground can be seen as patchy and light in colour in some places. During field investigations these locations were assessed as recently deposited sediment fans and a sediment probe was used to take multiple readings for the thickness of the deposits. Similar deposition was identified for Watercourse 6 and 7.

During this period of 21 days after the fire there were 11 rainfall episodes between fire and capture of the aerial photography. The images for the 26th of January show no obvious recovery of vegetation cover. It is during this period that the soils are at their most hydrophobic and runoff would have been almost total. It is during these 21 days that the two deposition events that deposited the fans at the down slope end of Watercourse 3 occurred.

The second aerial after the fire was captured on the 13th of October 2020, some 282 days after fire and 262 days since last aerial. There were 94 rainfall episodes since last aerial and 105 since fire. However, it can be noted that after this much time has passed and with a significant number of rainfall episodes, there is very little 'greening' of the valley side slopes. This confirms that post fire the surface is largely hydrophobic and infiltration is minimal. By contrast the valley floors, tributaries included, are more in recovery mode more likely because of greater moisture retention. Certainly lower slope, smaller grainsize, greater percentage of organic matter within the soil profile will aid in water retention in the surface soils and also aid in infiltration.

Third aerial after the fire was captured on the 01st of December 2020, some 331 days after the fire and 49 days since the last aerial. Since the last aerial was captured there have been an additional 37 rainfall episodes and a total of 142 since the fire.

Comparison of the aerials shows that there is not a huge amount of change between these aerials but there is noticeably more greening of the valley margins. The valley floors, in each instance, show significantly more vegetation recovery than the surrounding valley slopes.

Conclusions

- Sediment flows from catchments affected by intense fires are a well-documented and are a completely natural occurrence.
- Increased sediment flow and turbidity of the streams in Lobs Hole would naturally follow a catastrophic fire event and are completely independent of construction activities being completed for the Snowy 2.0 project.
- Surface soil material becomes hydrophobic during intense wild fires and exacerbates the erodibility and erosivity of the regolith in the post fire recovery period.
- Assuming total loss of ground cover sediment mobilisation from the catchments is primarily a function of the lithology of regolith, slope and rainfall.
- The volume and scale of sediment flows delivered to the channel zone is dependent on intensity and volume of precipitation.
- Short duration, high intensity, rainfall is much more erosive than longer duration and less intense falls delivering the same volume to the catchment.
- The short term impacts include:
  - An increase of suspended sediment and turbidity that is largely dependent upon maintenance of base flow and the turbulence of that flow.
  - A temporary increase in bedload and saltating load during periods of increased flow volume.
  - Opportunistic mid-term storage of transitory sediment within the channel.
  - Longer term storage of sediment proximal to banktop where channel is still coupled with the floodplain.
- Long term impacts and recovery are largely climate driven.
  - Increased frequency of low intensity rainfall within the surrounding catchment will re-establish ground cover while limiting mobilisation of surface material and limiting erosion
  - High intensity rainfall episodes (high volume precipitation over short periods of time) will be extremely erosive until ground cover is re-established.
  - The re-establishment of ground cover will reduce the mobilisation of regolith and delivery of sediment to the channel zone.
- The recent *La Nina* conditions have delivered greater volumes of precipitation to the catchments and have aided in re-establishing ground cover.
- Significant erosion and depositional episodes have been recorded prior to *La Nina* conditions being declared.
- Strongly positive SOI conditions have been declared neutral by the Bureau of Meteorology and *La Nina* conditions have been declared as ended on 13 April 2021
- The recovery of the catchments surrounding Lobs Hole will be slow. The process has started and the return of vegetation to the valley floors has already commenced, blackberries included. Until the return of vegetation cover to the surrounding slopes high intensity rain will continue to cause erosion and negatively impact the water quality of the tributaries and trunk of the Yarrangobilly River at Lobs Hole.

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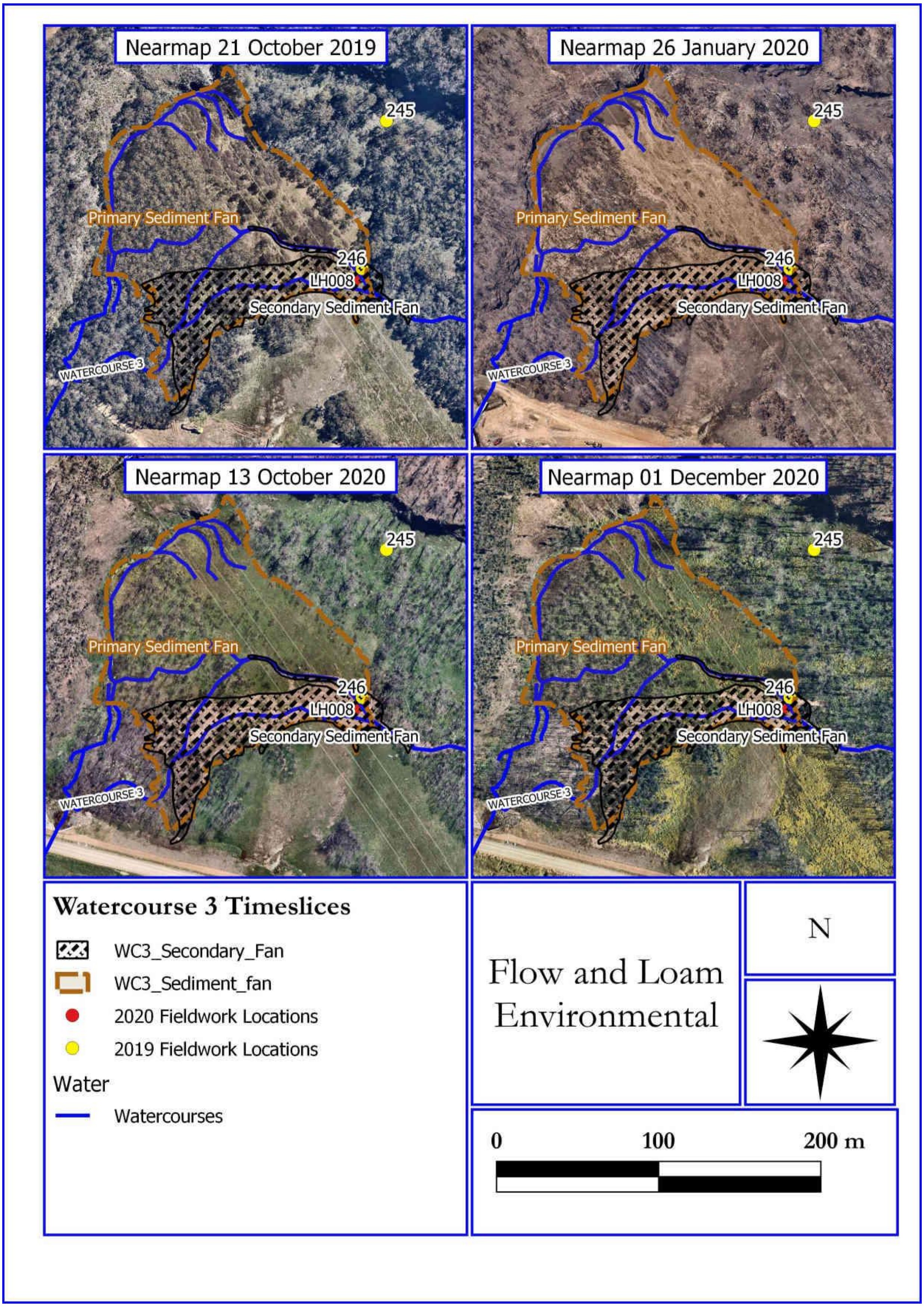
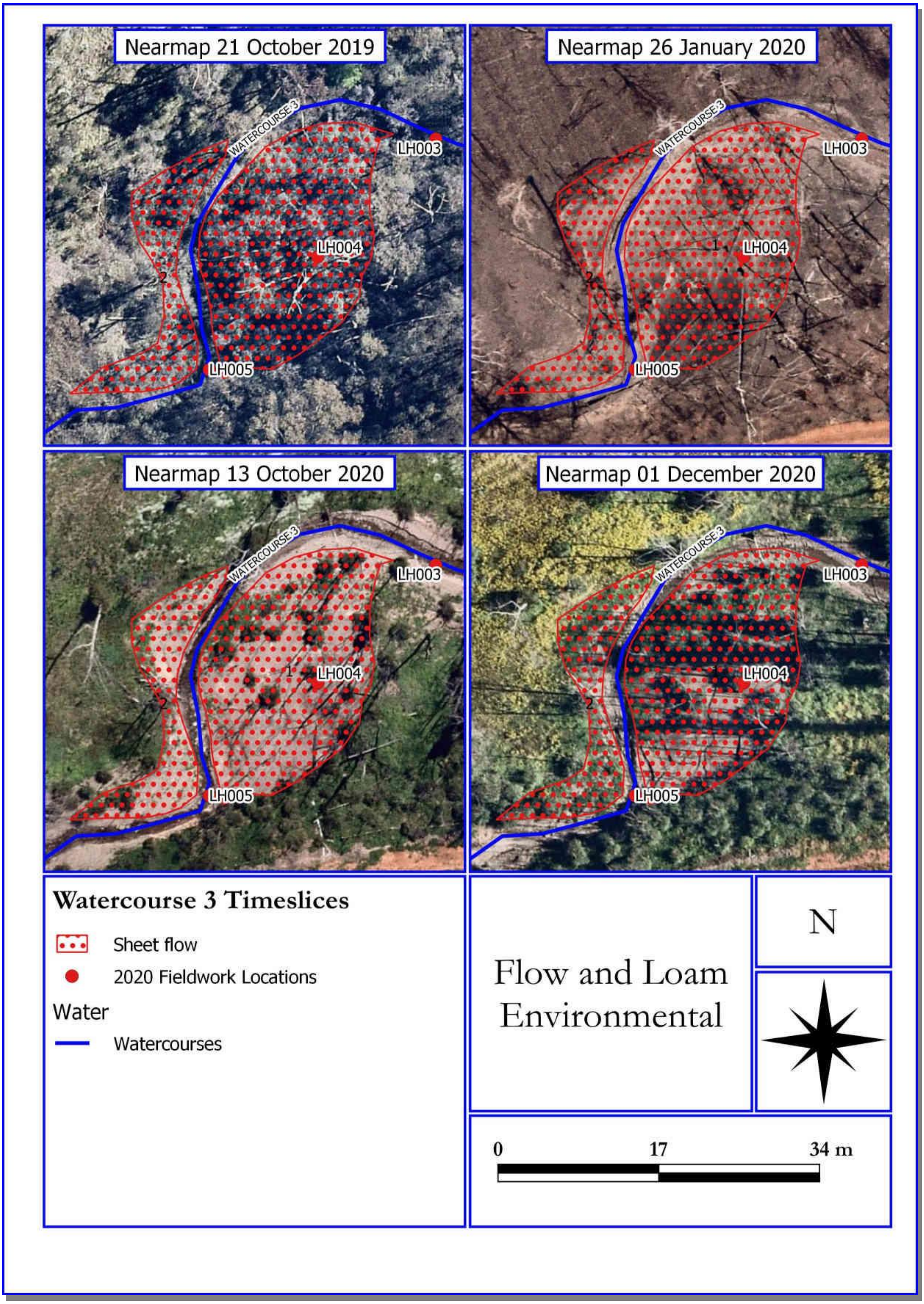
Appendix 1 - Time Slices

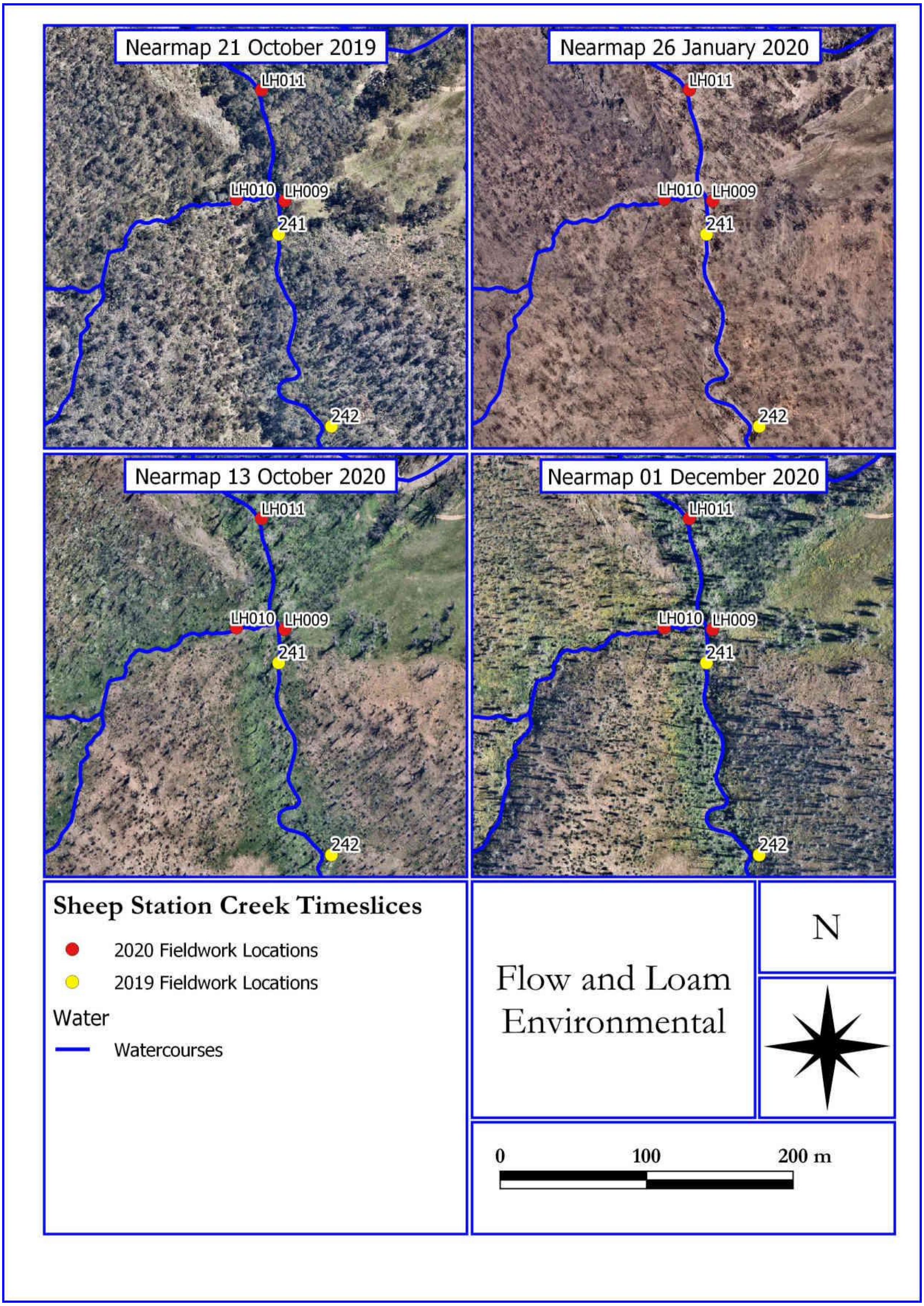
Appendix 1A; Watercourse 3 – Sediment Fans



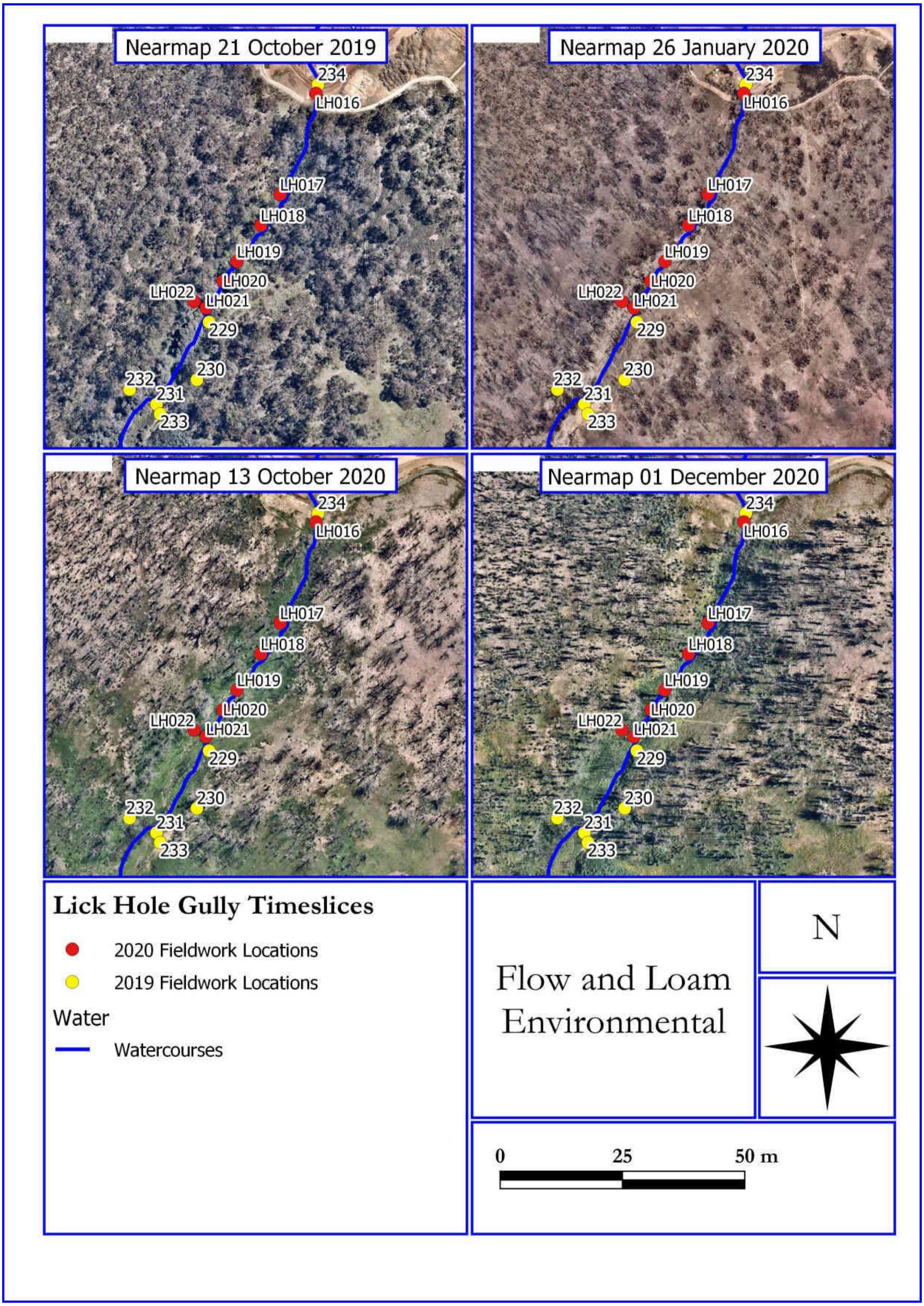
Appendix 1B; Watercourse 3 – Sheet Flow



Appendix 1C; Sheep Station Creek



Appendix 1D; Lick Hole Gully



Appendix 1E; Wallaces Creek