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Waterfall Gully, Mount Lofty Ranges,
South Australia

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USING LIDAR TO ASSESS THE EFFECT OF FIRE AND FLOODS ON UPLAND PEAT BOGS, WATERFALL GULLY, MOUNT LOFTY RANGES, SOUTH AUSTRALIA

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ABSTRACT

A flood exceeding the 100 year average recurrence interval in November 2005 led to the failure of an upland peat bog in Waterfall Gully. The area is prone to severe bushfire and flood events and the control dam at the base of First Falls was filled with sediment sourced from Wilson Bog. A resistant quartzite bar at Fourth Falls has formed a natural constriction point against which burnt logs and debris have collected following previous fire events forming a natural dam resulting in sediment/peat accumulation upstream. The failure of the bog was inevitable as the vegetative material in the log-jam progressively weakened and rotted. Intense flooding triggered the failure but it was augmented by the build up of a critical mass of sediment upstream of the restriction point. The downstream force of the flood waters and the weight of the saturated bog sediments was enough to overcome the basal frictional forces resulting in slumping and headward erosion. LiDAR data clearly shows an erosion channel scoured out by the flood. Approximately 5000 m³ of sediment (~10,100 tonnes) was washed downstream. LiDAR coupled with a tri-spectral scanner has the capacity to identify other upland peat bogs due to their high NDVI value and assess their stability on steep slopes or narrow valleys. Fire is another risk to the stability of these bogs as it has the potential to remove binding vegetation and expose unconsolidated sediments to erosion during subsequent rain events. Groundsurface and vegetation surface DEM's generated from LiDAR combined with NDVI maps derived from a tri-spectral scanner provide an ideal tool to monitor and assess the risk of slumping in other upland peat bogs.

INTRODUCTION

Widespread flooding occurred in the greater Adelaide region between 7-10th November 2005 producing localised flash flooding and river flooding. Flooding was exacerbated by already wet catchments and near capacity reservoirs and dams (Johnston et al. 2007). This led to the breaching and failure of an elevated valley-fill peat bog (Wilson Bog) in the upland regions of First Creek. A slurry of water, boulders, sediment and vegetation flowed down from Wilson Bog across several waterfalls before eventually being trapped in the reservoir at the base of First Waterfall in Waterfall Gully. Although much of the debris was trapped in this reservoir, roadways and houses situated along First Creek were flooded, causing significant damage. There is little doubt that had the debris flow sediment (~10,000 tonnes) not been trapped, houses could have been destroyed and lives may have been lost. Some of the boulders involved in the debris flow were up to 1 m in diameter.

The flood event provided the opportunity to assess the effects of flooding on upland peat bogs by combining our ground mapping with LiDAR flown soon after the event. This type of survey can provide important baseline data on ecologically sensitive upland bogs and swamps to monitor the effects of fire and/or flood in the future. We suspect that fire and flood events have been major contributors to long-term landscape evolution in the Mount Lofty Ranges.

STUDY AREA

The Mount Lofty Ranges form a natural drainage divide which separates the westward flowing streams that exit onto the Adelaide plains from the eastward flowing streams which drain into the River Murray and Lake Alexandrina (Figure 1). Proterozoic basement rocks are mantled by shallow to moderately deep, acidic soils with high erosion potential (Soil and Land Program, 2007). Elevated valley-fill bogs occur in the vegetated areas of the Mount Lofty Ranges surrounding Adelaide and have generally formed over the last 10,000 years (Bickford and Gell, 2005; Brownlie, 2007; Buckman et al., 2009). Prior to European settlement valley fill bogs were most likely common throughout the region. However, as a result of extensive land clearance, draining and stock grazing, many have either been degraded or have failed (Loffler 2006; Department of Environment and Planning 1983). There are several peat bogs located within Cleland Conservation Park including Wilson Bog (Seaman, 2002).

Wilson Bog is situated on First Creek, which extends from the slopes of Mount Lofty to the Adelaide Plains where it enters the River Torrens. First Creek is laterally confined as a result of the steep hillslopes, shallow bedrock and narrow valley floor width, which limit lateral migration. The upper section of First Creek is divided into two branches, which converge adjacent to the Chinaman Hut Ruins in Cleland Conservation Park (Figure 15). Wilson Bog is located on the northern branch of First Creek, locally referred to as the Cleland Branch while the southern branch of First Creek is identified as the

Crafers Branch. The main watercourse length of the Cleland Branch is approximately 1.7 km with a catchment area covering a mere 1.5 km². It extends from an elevation of 710 m asl at Mount Lofty to 360 m at the Cleland and Crafers Branch confluence. The hillslope gradient of the Cleland Branch catchment varies from 0-10° to > 30°. Approximately half of the catchment falls between 11° and 20° (Loffler 2006).

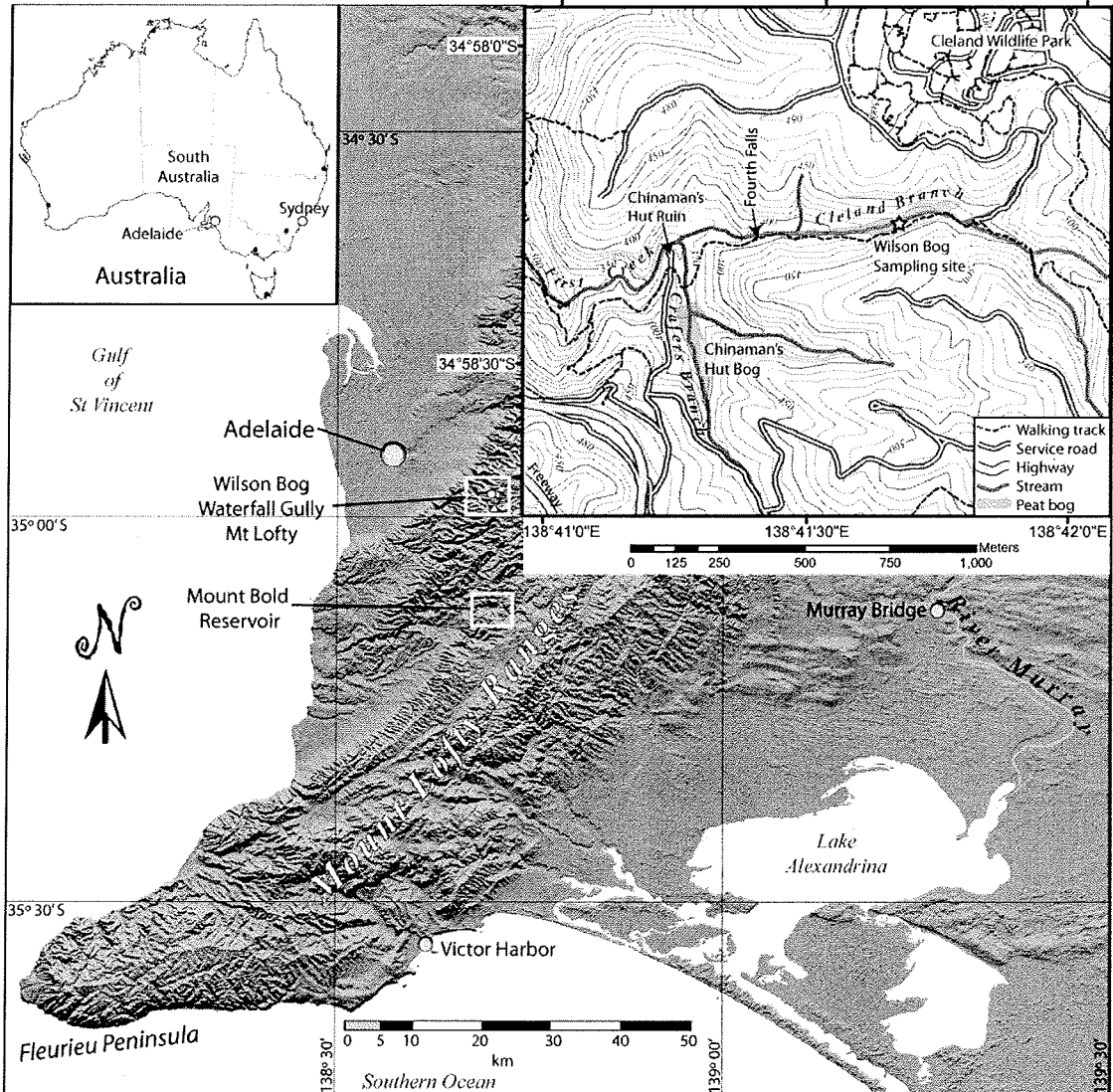


Figure 15 Location map of Wilson Bog in the Mount Lofty Ranges, South Australia (DEM sourced from SRTM data). Inset showing the topography of the Wilson Bog site (Data supplied by Department for Environment and Heritage, South Australia).

Wilson Bog begins at the Fourth Falls where a prominent quartzite bar forms a natural constriction point against which fallen vegetation and debris has created a dam and promoted the buildup of sediment upstream (Figure 16). The bog extends 350 m upstream and is 30 m at its widest, comprising between 1-5 m of valley-fill sediment and peat deposits. The average stream gradient from above the bog down to the top of the waterfall at Waterfall Gully is 6.36° while the average slope of the section at Wilson Bog is 5°.

Bogs occurring in and adjacent to Cleland Conservation Park have characteristic vegetation usually consisting of a dense cover of silky tea-tree (*Leptospermum lanigerum*) and other species including hop goodenia (*Goodenia ovata*), pink swamp-heath (*Sprengelia incarnate*), Mount Lofty ground-berry (*Acrotriche fasciculiflora*), red-fruit cutting grass (*Gahnia sieberiana*), coral fern (*Gleichenia microphylla*) and slender clubmoss (*Lycopodium laterale*) (Department of Environment and Planning 1983). Swamp wattle (*Acacia retinodes*) is also common in the bogs and generally occurs in areas where there has been recent disturbance (Loffler 2006). Since the failure of Wilson Bog, swamp wattles have recolonised the disturbed areas as shown in Figure 16 C, D. The thick vegetation occurring at Wilson Bog corresponds with the high NDVI values obtained from the tri-spectral scanner (Figure 20).



Figure 16 A) Failed section of Wilson's Bog 12 days after the event (photo courtesy of Roscoe Shelton); B) Debris deposited at the base of First Falls (photo courtesy of Roscoe Shelton); C) the failed upper region of Wilson Bog revealing large angular boulders and gravel that underlie the peat bog and the beginnings of regrowth ; D) Prominent quartzite bar at Fourth Falls marking the downstream beginning of

Wilson Bog – note the vegetation debris wrapped around the tree from the flood event and the regrowth of swamp wattle in the disturbed channel floor downstream.

FLOOD EVENT

The climate of the Mount Lofty Ranges is temperate, with cool wet winters and distinctly warm to hot, dry summers. Annual mean rainfall is variable across the Mount Lofty Ranges with some parts receiving as little as 400 mm and others as much as 1100 mm. The study area is located below Mount Lofty Summit on the western scarp of the ranges. Mean monthly maximum temperatures recorded at Mount Lofty Summit range from approximately 9 °C in winter to 22 °C in summer. Average annual rainfall recorded below the summit in Cleland Conservation Park is 992.1 mm, with most rain falling from May to August (B.O.M. 2007).

Rainfall for the month of October 2005 exceeded 100 mm in the Mount Lofty Ranges which was well above average. This antecedent rainfall created near saturated catchments leading up to the November floods and minor flooding occurred in the Onkaparinga and Para rivers and around Mt Lofty on the 23-24th October.

The November flood event was a combination of an active cold front passing through South Australia on the 6th November and an occlusion rainband wrapping around from the south to produce a low pressure cell centered on Kangaroo Island on 7th November. High rainfall over the next 24 hours was concentrated over elevated regions such as Mt Lofty due to the effect of orographic uplift. The heaviest rainfalls for the seven days leading up to 0900 8th November were recorded in the higher parts of the Mount Lofty Ranges with over 150 mm recorded in areas near Mount Lofty. Both Mount Lofty and Uraidla recorded in excess of 100 mm in the 24 hours before 0900 8th November. This event fed the upper reaches of creeks draining westward onto the Adelaide plains resulting in flooding in the River Torrens and eastern suburbs of Adelaide (Johnston et al. 2007).

The November 2005 flood event resulted in several river systems reaching major flood levels with maximum flow intensities exceeding the 100 year Average Return Interval (ARI) for First Creek (Waterfall Gully), Third Creek (River Torrens), Aldgate Creek and Cox Creek (Onkaparinga River). The River Torrens exceeded the 50 year ARI but flows were contained within its banks (Johnston et al. 2007).

FAILURE OF WILSON BOG

The major flood event over the 7th and 8th of November 2005 led to the headward erosion of Wilson Bog beginning at Fourth Falls. Once initiated the 1-5 m of unconsolidated boulders, gravel, peat and vegetation that make up the valley fill at Wilson Bog were rapidly eroded downstream as a muddy slurry. The increased density of this slurry aids in the transportation of large boulders downstream.

Although much of the debris was trapped in a reservoir at the base of the First Falls in Waterfall Gully (**Figure 16**), roadways and houses situated along First Creek were flooded. A review of the occurrence and impact of the erosion within the upper First

Creek catchment as a result of the 7th and 8th November rainfall event was undertaken by Loffler (2006). Loffler found that the initial incision and failure of Wilson Bog occurred at the downstream front (which was saturated) and had most likely reached a critical angle. Erosion progressed rapidly through the bog sediments and peat, with the formation of an erosion trench up the centre of the valley. The walls of the erosion trench were progressively undercut and failed by slumping and block failure of the non-cohesive sands. At the upstream end of the failed portion of the bog large blocks of soil remain *in situ* in the floor of the trench. In the downstream section, however, most of the block failure material was removed resulting in the significant expansion of the channel cross-section (Figure 19).

METHODS

Mapping of the Wilson Bog slump was undertaken in December 2005. LiDAR data was obtained for the Waterfall Gully catchment in June 2006 by Airborne Research Australia (ARA). The ARA aircraft was flown at low altitude along east-west transects of Waterfall Gully resulting in a dense terrain dataset with 5 cm average spacing. The LiDAR data table is shown in Table 1 and Global Mapper software was used to generate the DEM.

A tri-spectral “push-broom” scanner was mounted on the ARA aircraft and flown contemporaneously with the LiDAR. Resolution from the tri-spectral scanner is better than 1 m. The recorded wavelengths compared to other remote sensing data are shown in Figure 17. The difference in response between near infrared (shown as purple) and red by chlorophyll in vegetation is the basis of the Normalised Difference Vegetation Index (NDVI), which is calculated as:

$$\text{NDVI} = \frac{\text{NIR} - \text{Red}}{\text{NIR} + \text{Red}}$$

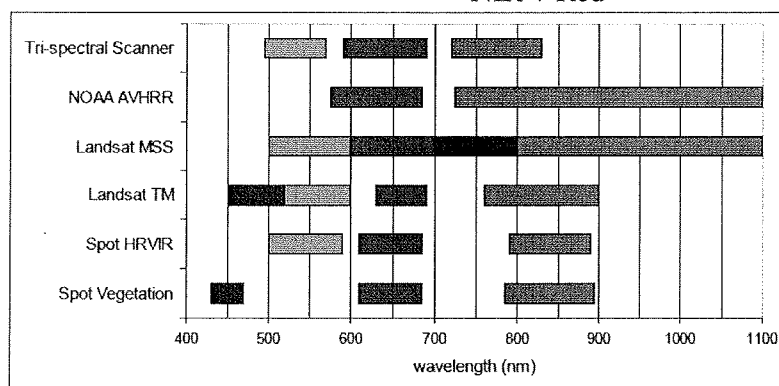


Figure 17 - Wavelengths recorded by the tri-spectral scanner compared to other remote sensing data.

RESULTS

A high resolution digital elevation model (DEM) was derived from the dense LiDAR terrain data set (Figure 3). The survey was flown without differential GPS correction so internal (point-to-point within flight lines) and horizontal accuracy are in the order of

meters. This can be remedied by post-processing given access to GPS base station data for the times of the flights. Vertical accuracy, however, remains below the typical 15 cm for the best conditions, varying with flying height and land cover (Hodgson et al. 2004).

The elevation and intensity (i.e. echo waveform) values from the LiDAR dataset were used to classify ground types using a supervised object-orientated approach (Antonarakis et al. 2008) (Table 2). The canopy can be separated from the bare surface using this simple, yet efficient approach, allowing the thickness and density of vegetation cover to be determined.

The NDVI values are generally between 0 and 1 with higher values correlating with higher photosynthetic activity (chlorophyll) and denser vegetation. The NDVI shown in **Figure 20** identifies thick/wet pockets of vegetation correlating with peat bogs and clearly shows that slopes with a northerly aspect are more sparsely vegetated than slopes with a southerly aspect.

Table 1 – LiDAR data columns

Column	Description	Units
1	Longitude	Degrees
2	Latitude	Degrees
3	Elevation	Metres
4	Signal Amplitude	receiver units
5	Echo half peak width	1/10 ns
6	Class ID	see table 2
7	Total number of echos received from this laser shot	
8	Index of the current echo	

Table 2- Class IDs. The Class ID property contains an (experimental) estimate of the surface type hit by the laser pulse as deduced from the echo waveform.

Class	ID
0	Not classified (not attempted)
1	Not classified (attempted but did not work)
2	Ground
3	Low vegetation
4	Medium vegetation
5	High vegetation
6	Building
7	Noisy data
8	Model key point
9	Water

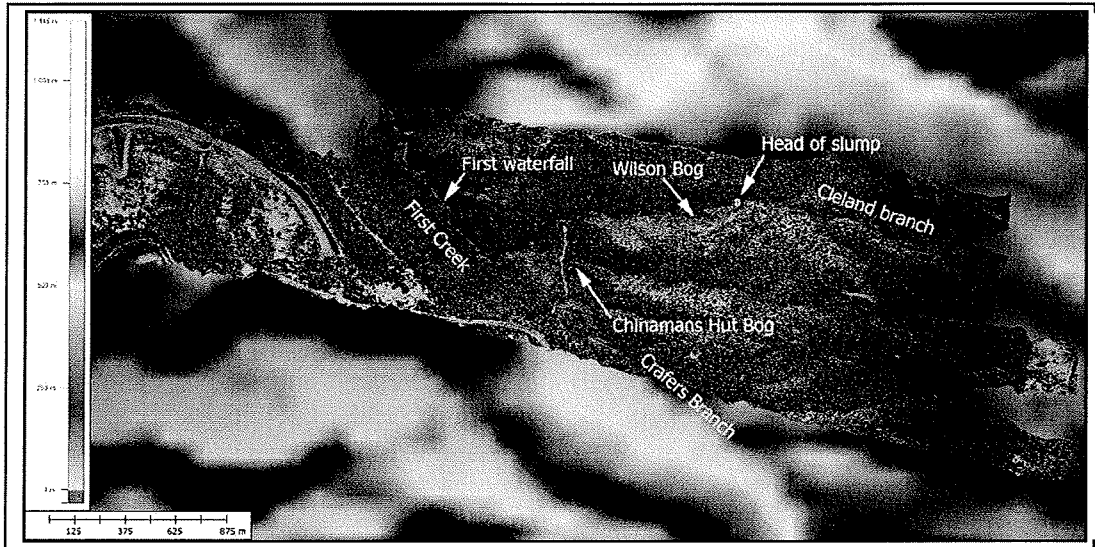


Figure 18 LiDAR strips superimposed on a SRTM DEM for the Waterfall Gully region.

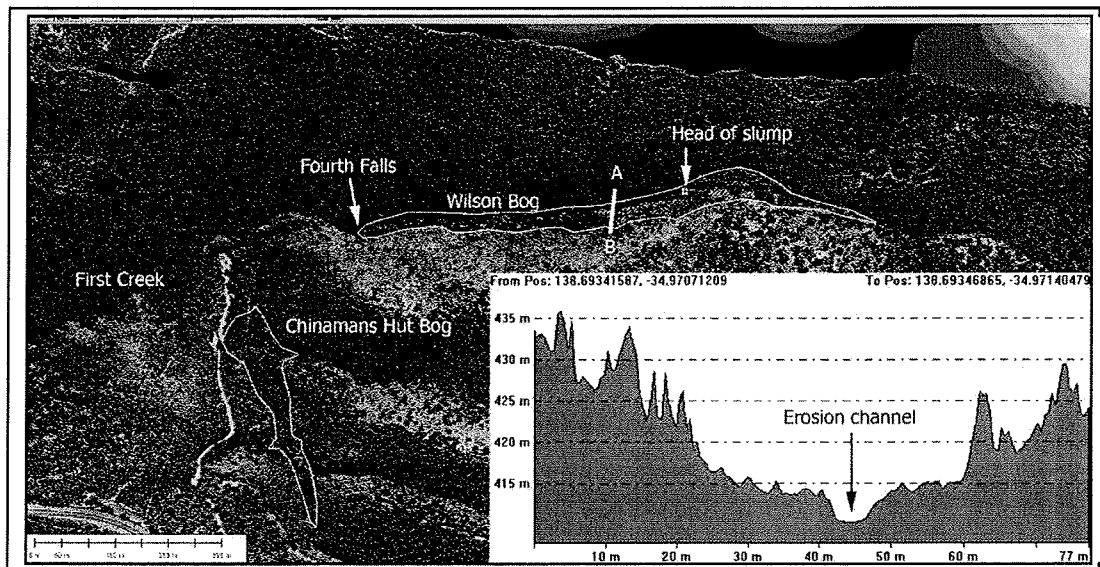


Figure 19 LiDAR image of the Wilson Bog area on the Cleland Branch of First Creek, Waterfall Gully. A cross-section through the bog shows the erosion channel scoured out by the November 2005 floods.

DISCUSSION

The Wilson Bog flooding event scoured an erosion channel initiated at Fourth Falls and extending some 500 m upstream. Field inspections combined with the LiDAR survey show that the channel is on average about 5 m wide and 1-5 m deep (average ~2 m). The volume of sediment calculated to have been eroded from Wilson Bog is equal to ~5000 m³. Given that wet gravel has a density of 2020 kg/m³, we estimate that approximately 10,100 tonnes of wet sediment was eroded and transported downstream of Wilson Bog. This correlates with reports from the local council that approximately 10,000 tonnes of material was excavated from the weir following this event.

Vegetation plays a significant role in the stabilisation of steep slopes and unconsolidated valley fill deposits. The tri-spectral data flown contemporaneously with the LiDAR is a useful tool for producing Normalized Difference Vegetation Index (NDVI) images to identify thick/wet pockets of vegetation correlating with peat bogs.

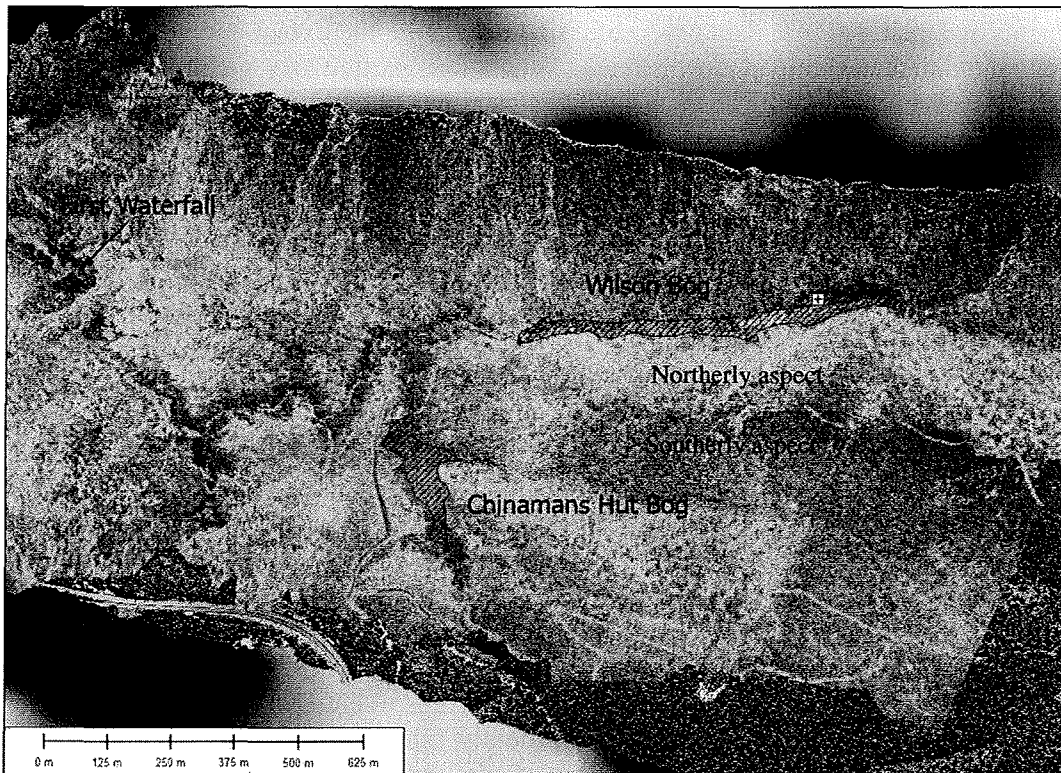


Figure 20 Normalized Difference Vegetation Index (NDVI) image produced by the tri-spectral scanner which was run contemporaneously with the LiDAR. Note the dark green colour of Wilson Bog and Chinamans Hut Bog and the pale yellow colour of the less vegetated slopes with a northerly aspect and the ridge tops.

NDVI differencing method also enables fire severity to be mapped remotely following a fire. These severely burnt areas are more prone to erosion due to the reduced vegetation cover particularly on steep slopes. In theory the combination of LiDAR and tri-spectral (NDVI) data would be a practical way to model the erosion potential of burnt areas allowing mitigation strategies to be better targeted on severely burnt, steep slopes.

CONCLUSIONS AND IMPLICATIONS

Wilson Bog formed at a constriction point created by a resistant quartzite bar at Fourth Falls. A natural dam consisting of logs and debris that had washed down during previous flood events. This allowed the gradual build up of sediment upstream beginning some 8000 years ago. This permeable sediment reservoir backed up against an impermeable quartzite bar created a semi-permanent, near-surface groundwater aquifer that would have encouraged the build up of riparian vegetation. As a result peat deposits have been accumulating for the past ~2000 years (Brownlie, 2007).

The failure of Wilson Bog was caused by a combination of meteoric and geomorphic processes. The saturated catchment leading up to the heavy rain from 6-8th November tipped the Wilson Bog catchment over a critical threshold that resulted in sudden erosion and scouring of the valley fill sediments. Collapse of the logjam that created the dam at Fourth Falls resulted in rapid erosion of the unconsolidated siliciclastic sediments and peat. LiDAR data was useful in determining the extent and volume (5000 m³) of material that slumped downstream. Vegetation, particularly the swamp wattle, has been quick to recolonise the disturbed areas and has effectively stabilised the creek walls from further erosion.

Several elevated bogs and wetlands occur in the vicinity of Mount Lofty. Just downstream of Wilson Bog on the Crafers Branch of First Creek is the Chainman's Hut Bog. It is larger in area than Wilson Bog and contains a significant volume of unconsolidated valley fill sediment and peat accumulations. It appears to be held in place by thick vegetation and a narrow constriction point just before the junction with the Cleland Branch. It would appear that this bog is relatively stable given that it survived the 2005 flood event. However, this is a fire prone region as documented by the paleofire history at Wilson Bog (Brownlie, 2007; Buckman et al, 2009) and the dry conditions prevailing since 2005 mean that much of the Mount Lofty bushland is under constant threat of being burnt. After fire the reduction in vegetation cover leaves slopes and swamps especially vulnerable to accelerated erosion from heavy rainfall. An example of accelerated erosion following a bushfire in 2007 was documented at a nearby reservoir located at Mount Bold (Morris et al., 2008). The last time the reservoir at Waterfall Gully filled up with sediment was after the Ash Wednesday fires in 1983. There was no catastrophic movement of debris after this event but large areas of burnt hillslopes were subject to erosion and consequently filled the reservoir with sediment during subsequent rains. The combination of fire and water has the potential to dramatically destabilize valley-fill and hillslope sediment reservoirs which can pose a significant risk to residents downstream.

The coupling of LiDAR, to produce detailed DEM's, with remote sensing, to assess vegetation cover (NDVI), is a powerful tool to assess the sensitivity of these upland sediment reservoirs to mass movements. LiDAR has the ability to penetrate vegetation cover and provide important information as to the ground surface profiles. It also has the potential to monitor long-term hillslope and stream erosion in sensitive regions if consecutive flights are flown over the same ground.

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