VCAT Ref No: P2429/2014

Expert Evidence Report

for

Victorian Civil & Administrative Tribunal

relating to

Seymour Quarry

Lot 12, TP134132, SEYMOUR VIC 3660

Report prepared by:	Dr Dean Judd
Site inspected:	15th July 2013
	9th August 2013
	6th February 2015
Report prepared for:	Goulburn Broken Catchment Management Authority
Instructed by:	Mr Ian Pridgeon, Mr Guy Tierney

April 2016

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Glossary

Term	Definition
Average recurrence interval (ARI)	The average period of time between the occurrence or exceedance of an event (e.g. flood, fatality, emergency).
Annual exceedance probability (AEP)	The probability that an event (e.g. flood, fatality, emergency) will occur or be exceeded in any one year. AEP is often expressed as a percentage.
Anabranch	An anabranch is another channel of the river that branches from the parent channel and re-joins it some distance downstream.
Avulsion	Anabranching rivers form new channels via a process called avulsion, the scouring of a new river channel through the floodplain. When a new channel (anabranch) forms it may fully capture (take all the regular flow) or co-exist with the parent river channel.
Knickpoint	A locally steep, often vertical, section of stream bed that causes sediment transport discontinuities that in turn cause erosion. Such features typically migrate rapidly upstream, deepening and widening the stream, otherwise known as stream degradation or incision.
Palaeochannel	The remnant of an inactive river channel partially filled with more contemporary sediment.
Subcritical flow	Deep, slow flow where the velocity of flow is below the wave velocity.
Supercritical flow	Fast, shallow flow where the velocity of flow exceeds the wave velocity. Supercritical flow ends with an abrupt rise in the water surface (hydraulic jump) as kinetic energy suddenly converts to depth (potential energy). The rapid slowing of the flow creates turbulence and energy loss.

1 FULL NAME AND ADDRESS

Dr Dean Andrew Judd

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2 QUALIFICATIONS, EXPERIENCE AND AREA OF EXPERTISE

2.1 Qualifications

- Ph.D. (Fluvial Geomorphology and Hydraulics), Monash University, 2005.
- Masters (Environmental Studies), University of New South Wales, 1993.
- B.E. (Hons 1, Civil), University of Melbourne, 1990.

2.2 Experience

The professional experience of the author is detailed in Appendix B of this report.

2.3 Expertise

- Fluvial geomorphic investigations and process based studies including the analysis of sediment transport, stream degradation and aggradation and the initiation and propagation of avulsions.
- Hydraulic analysis applying both one and two-dimensional hydraulic models to river management, geomorphological and floodplain management investigations.

3 EXPERTISE TO MAKE THIS REPORT

The author has a degree in civil engineering, a Masters degree, a Ph.D. and 25 years of experience as a professional engineer. Of particular relevance to this report is the author's research specialisation, the initiation and propagation of avulsions across the floodplain.

This specialisation has led to Dr Judd undertaking a number of investigations into the anthropogenic and natural causes of avulsion development and the management of these processes. For example, to assist in managing the 50 kilometre long developing avulsion of the lower Goulburn River, Dr Judd was contracted from the University of Melbourne, Earth Tech and Water Technology to undertake consecutive studies over a number of years, including a study of the fluvial geomorphology, associated field testing of floodplain sediments for erosion potential, the subsequent risk based prioritisation of management intervention and the detailed design of structural works to delay an avulsion.

Dr Judd has also undertaken numerous investigations into the diversion of rivers and creeks around open cut mines, the management of risks associated with flood flows and pit capture around mines and the stabilisation of diverted waterways.

Dr Judd has substantial experience in the application of risk assessment frameworks as these are the primary basis for investment and management strategies in the natural resource management industry.

4 PRIVATE OR BUSINESS RELATIONSHIP WITH GBCMA

The author is employed by the Goulburn Broken Catchment Management Authority as a Floodplain and River Health Project Co-ordinator.

5 THE INSTRUCTIONS THAT DEFINE THE SCOPE OF THIS REPORT

My instructions concerning the preparation of this report were provided by Guy Tierney, Statutory Planning and Floodplain Manager, Goulburn Broken CMA and Ian Pridgeon, Principal, Russell Kennedy Lawyers.

I was requested to prepare an objective report that provides an expert opinion within my expertise as may be relevant to the grounds of review of the Goulburn Broken CMA.

6 APPROACH TO THIS INVESTIGATION

This study is framed within the risk assessment method described in the National Emergency Risk Assessment Guidelines, NERAG (AGD, 2015a, 2015b; NEMC, 2010). The Extractive Industries Guidelines for a risk-based work plan were also used where appropriate (DEDJTR, 2015). NERAG is relevant as the primary external driver of incident likelihood examined at Seymour Quarry is the emergency management issue of flooding. The consequences at Seymour Quarry also need to be considered in an emergency management framework. NERAG is consistent with the Australian/New Zealand Standard *AS/NZS ISO 31000:2009 Risk management – Principles and guidelines* (Standards Australia, 2013, 2009) but focuses on risk assessment rather than the broader issue of risk management (AGD, 2015a).

7 ESTABLISH THE CONTEXT

The context for this investigation is established by providing:

1. Context of the risk assessment (Section 7.1)
2. Site context and an understanding of the approved operation and the expansion proposed (Section 7.2)

7.1 Context of the risk assessment

7.1.1 Objectives of the risk assessment

The objectives of this risk assessment are to determine the tolerability of the risk that Seymour Quarry poses to people and assets, including:

- critical and community infrastructure;
- property;
- the land and surrounding environment, including the Goulburn River; and
- water quality

7.1.2 Scope for the risk assessment

The risk management process is outlined in Figure 1. This report addresses the risk assessment aspects of the risk management process (in the referenced sections of this report):

- Establish the context (Section 7)
- Risk identification (Section 8)
- Risk analysis (Section 9)
- Risk evaluation (Section 10)
- Risk treatment (Section 10.5)

The results of the risk identification, analysis and evaluation are recorded in the risk register (Section 11).

This is detailed risk assessment that largely takes a hazard-specific approach (AGD, 2015a, p. 85), focussing on the hazard of riverine flooding. Further, risk assessment methods range from asset-centric ("risks to") e.g. "risks to a sewage treatment plant" through to hazard/event-centric ("risks from") (NEMC, 2010). This assessment takes the "risks to" approach, focusing on the risks to the assets identified in Section 8.3.

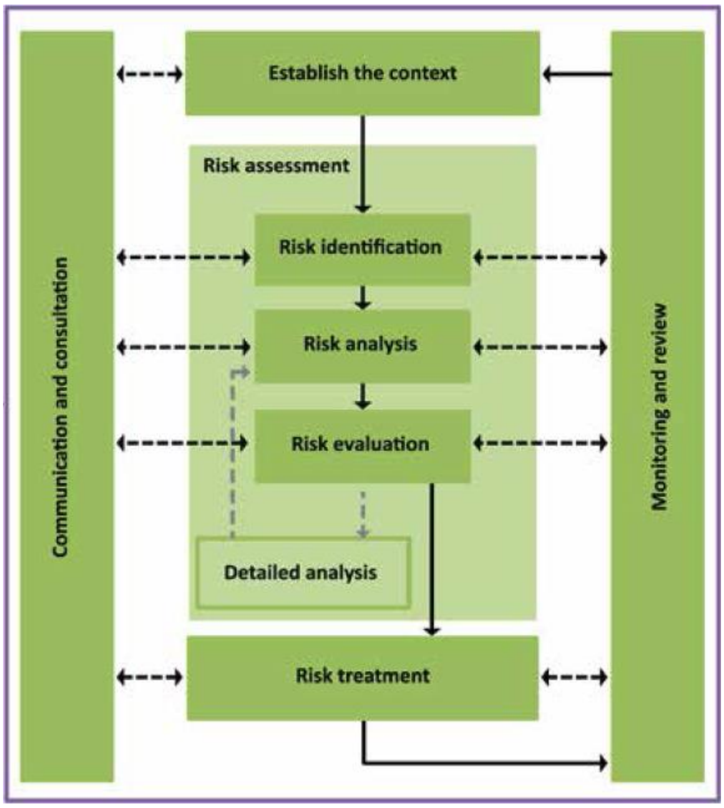

Figure 1 An overview of the risk management process (AGD, 2015a, extract of Figure 4).

From the legislative and planning framework it appeared clear to the author that this risk assessment should simply address the risk posed by the proposed quarry. However, the Applicant's grounds primarily relate to the change in risk due to the proposed quarry expansion. Addressing the grounds of the Applicant and the CMA has required an assessment of the risk posed by the approved quarry and the change in risk due to the proposed quarry expansion.

7.2 Site context and understanding of the proposal

7.2.1 The site and locality

The location of Seymour Quarry is shown in Figure 2 with the footprint of the approved northern and proposed southern pits. Seymour Quarry is located on the northern floodplain of the mid-Goulburn River, approximately 700 metres south of the main street of Seymour, 400 metres south of residences on Edward Street.

The southern pit of Seymour Quarry is located 100 metres north of the Goulburn River. When the pit is completed it will also connect with palaeochannels along its western side and Deep Creek, a substantial channel that runs north from the palaeochannels into the township of Seymour (Figure 2).

The mid-Goulburn River at Seymour is an anabranching river with a tendency to meander and migrate laterally. The catchment area of the Goulburn River at Seymour Quarry is approximately 8,600 square kilometres. According to the previous flood study (Walden et al., 2001), and the smallest flood they mapped, the quarry site is inundated in a 6 year ARI (average recurrence interval) event (WBM, 2001a). Flood inundation mapping at the quarry for the 100 year ARI flood is shown in Figure 3 (based on the topography in March 2000).

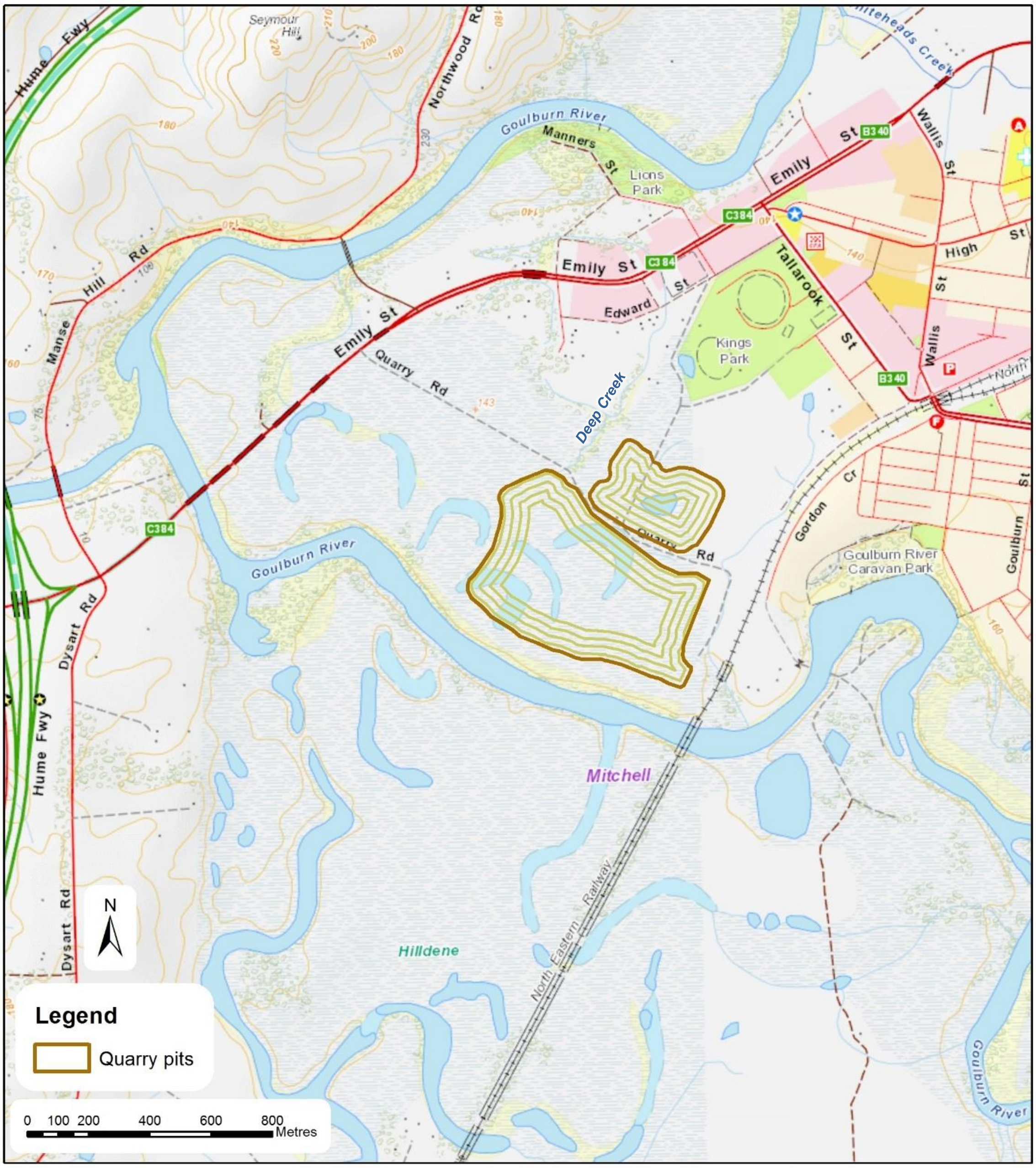

Figure 2 Map showing the approved northern pit and proposed southern pit at Seymour Quarry.

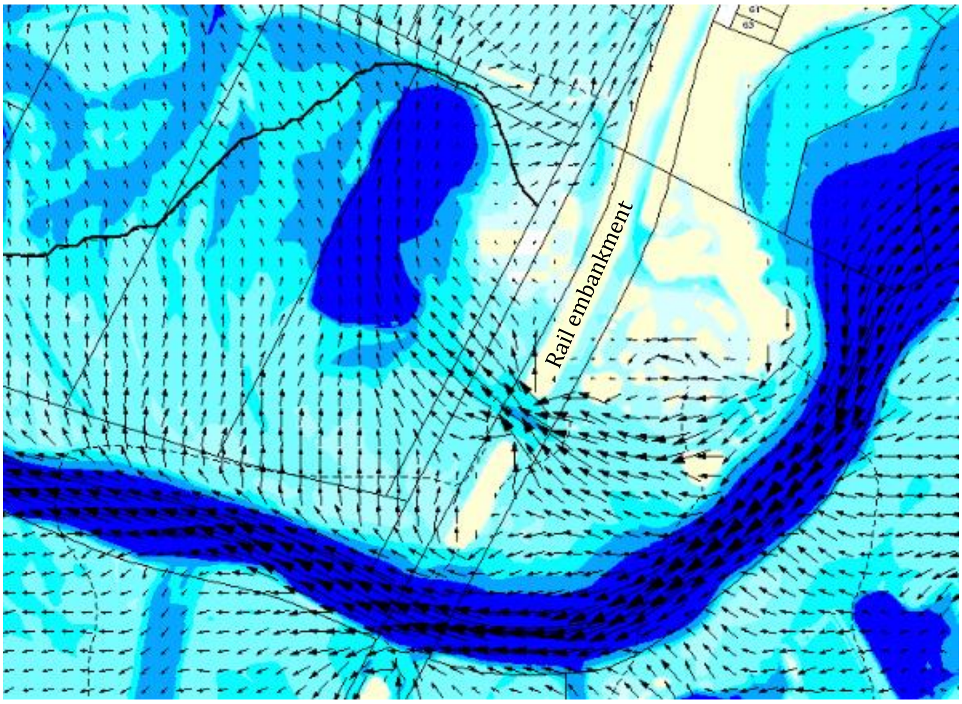

Figure 3 **The 100 year ARI flood flow spilling north from the Goulburn River and west through the rail embankment into the Seymour Quarry. Extract of WBM drawing number 540209-3 (WBM, 2001b).**

The depth of the Goulburn River directly adjacent Seymour Quarry can be drawn from the following cross section surveys of the river:

1. The State Rivers and Water Supply Commission (SR&WSC) surveyed two cross-sections of the Goulburn River directly adjacent Seymour Quarry. These cross-sections, labelled in Figure 4, show the river to be 7.5 and 10.2 metres deep at river distances 313.1 and 313.5 kilometres respectively (SR&WSC, 1980a)

2. Checking the SR&WSC cross-sections for the 2001 flood study, WBM repeated the section at 313.5 kilometres finding the river to be 13.5 deep (Walden et al., 2001).

The average depth of the Goulburn River adjacent Seymour Quarry, based on the survey in 1980 at 313.1 kms and in 2001 at 313.5 kms, is 10.5 metres, which is the depth value used for the Goulburn River in the remainder of this report.

Depth here is defined as the vertical height from the invert or thalweg of the channel to the top of bank at a particular cross-section. Average depth is defined as the average of the depths at the two cross-sections.

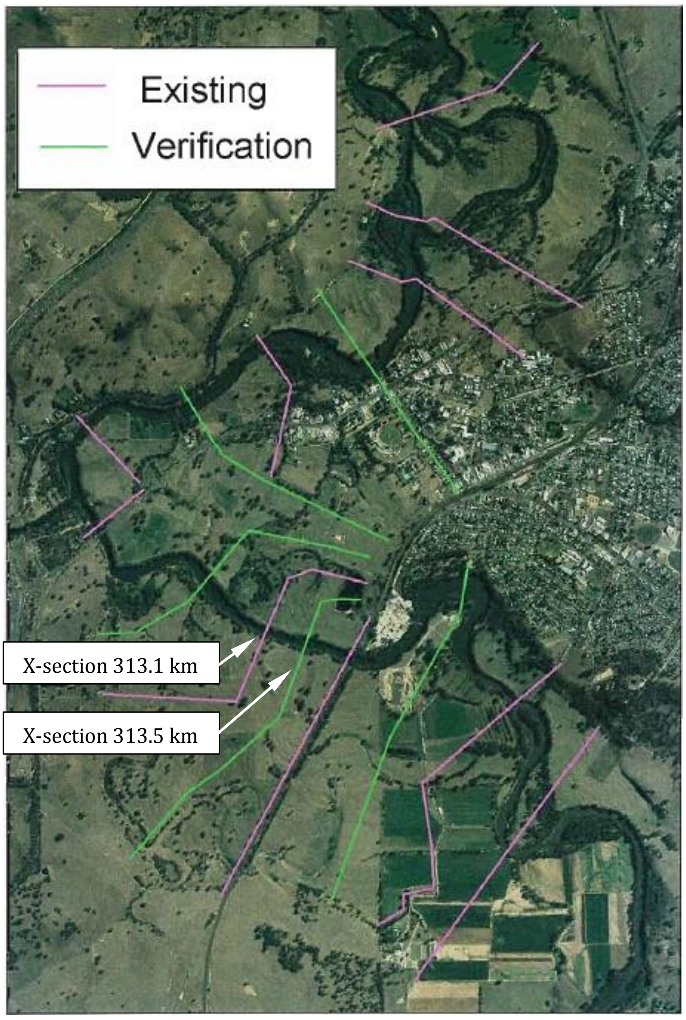

Figure 4 **Cross sections of the Goulburn River; Figure 4.2 of the Seymour Floodplain Mapping Study (Walden et al., 2001) annotated with cross-section labels at river distances 313.1 and 313.5 kms. Note all the cross-sections shown here were surveyed in 1980, and the repeat surveys for the 2001 flood study are shown as *"Verification"*.**

7.2.2 The proposal

Two pits are currently approved at Seymour Quarry and the proposal is to vary the work plan to expand the extraction area and hence the volume of the southern pit (Figure 5). The work plan variation does not propose to change the northern pit or increase the maximum depth of either pit.

To analyse aspects of the approved and proposed work plan and the impact on the floodplain, the Working Plan (Prowse and Castle, 2014a) and Rehabilitation Plan (Prowse and Castle, 2014b) were georeferenced into the geographic information system (GIS) ArcGIS 10.2. Various features shown on the plans were checked against aerial photos, confirming the accuracy of the georeferencing.

Comparing the Working Plan to the Rehabilitation Plan a number of discrepancies were noted, including:

1. On the northern side of the southern pit the Rehabilitation Plan shows groundwater north of the limit of extraction in the Working Plan. Based on batter slopes, groundwater should be at least 18 metres south of the limit of extraction;

2. The shape of the northern and western sides of the southern pit are different in the Rehabilitation and Working Plans; and

3. The northern pit is larger in the Rehabilitation Plan with the groundwater along the western batter shown to essentially match the limit of extraction in the Working Plan.

The discrepancies between the Working and Rehabilitation Plans were dealt with by adopting the limit of extraction and shape of the pits described in the Working Plan (Prowse and Castle, 2014a). Although these discrepancies are minor relative to the issues dealt with in this risk assessment, the extent of extraction on the western side of the southern and northern pits (points 2 & 3 above) may influence the risk.

The Work Plan refers to pit areas of 25 and 8 hectares for what is assumed to be the approved southern and northern pits (Prowse and Castle, 2012, Section 7.6). Based on the Working Plan (Prowse and Castle, 2014a), the surface areas of the approved and proposed southern pits are 25.7 and 31.0 hectares respectively and the area of the northern pit is 9.3 hectares, for a total proposed pit area of 40.3 hectares (100 acres). These areas were calculated in ArcGIS 10.2 and the areas of the proposed southern and approved northern pits were checked manually. The approved southern and northern pits on the Working Plan are respectively 3% and 16% larger than those described in the Work Plan and 43% and 50% larger than the 18 and 6.2 hectares described in the approval (VCAT, 2011, pp. 3–4).

Note, condition 18 of the approval also states *"To ensure the structural integrity of the levee bank, no extraction shall occur within 100m of the alignment of the toe of the proposed town levee"* (VCAT, 2011, p. 21). The northern pit (Figure 5) extends up to 28 metres north of the centreline of the proposed Seymour town levee (Figure 15). Allowing for the width of the levee crest and batters, a 100 metre setback from the levee requires that the limit of extraction for the northern pit be up to 140 metres further south. So whilst the geometry of the northern pit (Figure 5) has been adopted for this risk assessment, and it is referred to as the approved pit, the northern pit does not comply with the VCAT condition referenced above.

Note the alignment of the Seymour town levee (labelled *"Proposed GBCMA levee bank"*) in Figure 5 is not accurate. The centreline of the levee is 15-30 metres, and up to 60 metres, further south. The levee alignment shown in Figure 15 was provided as a GIS file by Jon Herbert of Mitchell Shire Council on the 10th March 2015.

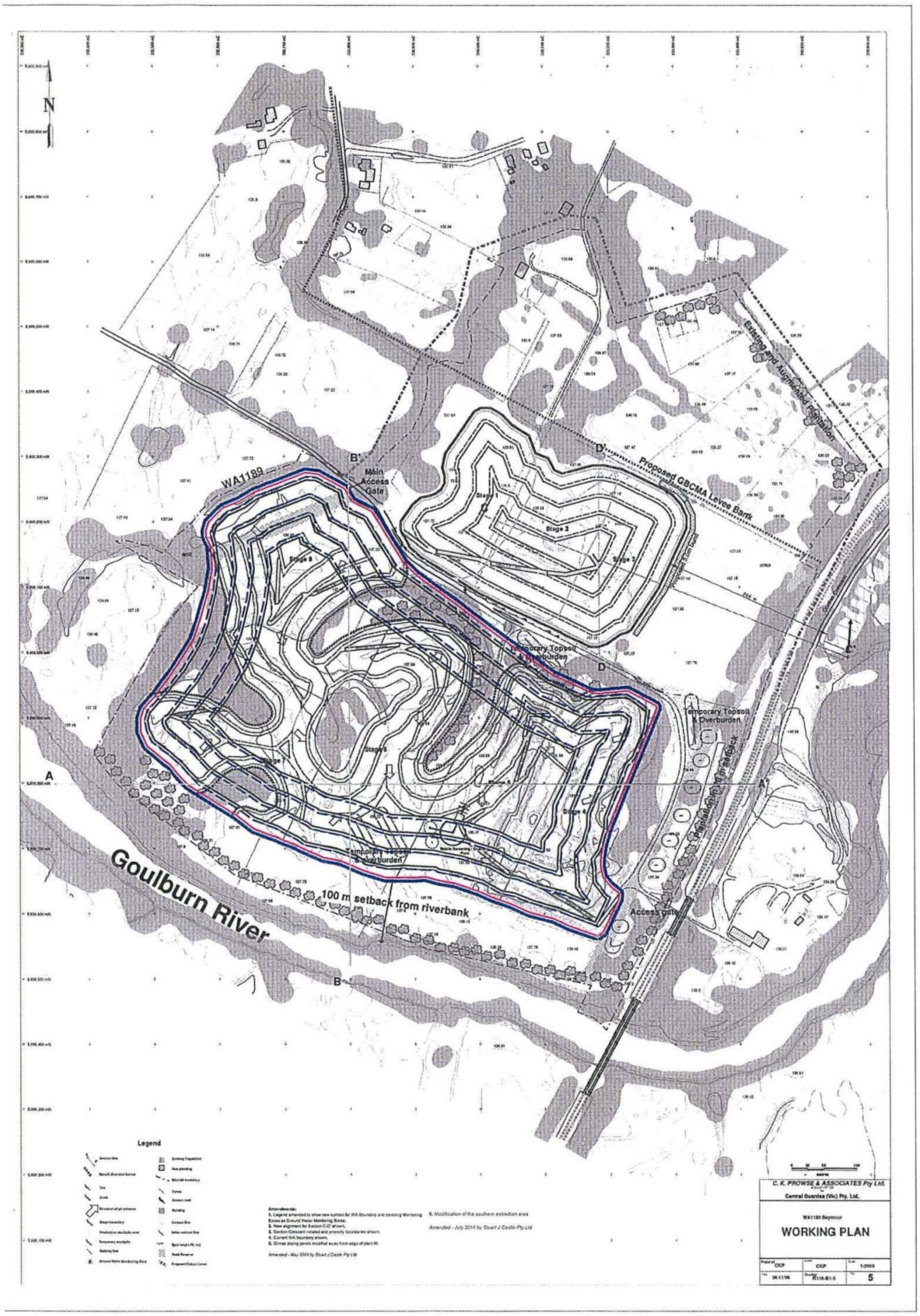

Figure 5 The Working Plan (Prowse and Castle, 2014a) showing the approved northern and southern extraction pits and the proposed variation to the southern pit.

7.2.3 Review of the pit geometry and local topography

In February 2015, Seymour Quarry was extracting sand and gravel from the eastern end of the southern pit (Figure 6), reaching an estimated depth of 20 metres in this area. Comparing the limit of extraction in the Working Plan (Figure 5) to the November 2013 aerial laser survey* some differences were noted:

1. Locally extraction is 13-14 metres past the limit of extraction at the feature labelled *"most easterly feature to be removed under the variation to the Work Plan"* in Figure 6;
2. Locally extraction is 18 metres past the limit of extraction on the eastern batter of the southern pit, to the left of the foreground in Figure 6; and
3. The south east corner of the southern pit is approved to extend 30 metres closer to the rail corridor than is currently the case, to within 90 metres of the nearest railway bridge or 80 metres from the corresponding rail corridor embankment.

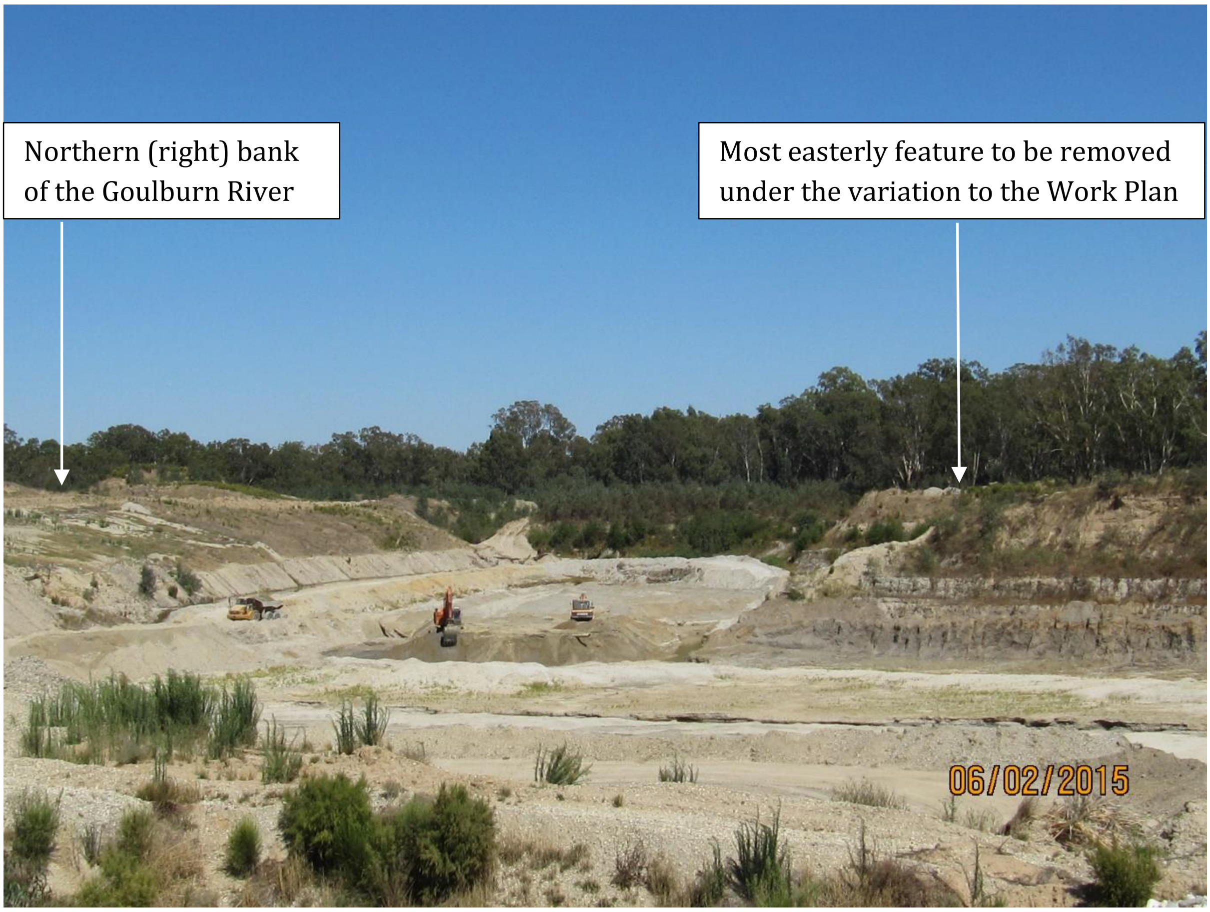

Figure 6 Looking west (downstream) across the southern pit on 6th February 2015.

* The November 2013 aerial laser survey is from the 2013-14 North East Towns Elevation Project, consisting of high accuracy elevation data. The data at Seymour was acquired on the 1st November 2013 and found to have a horizontal accuracy of 0.18 metres and a vertical accuracy of 0.10 metres at one sigma (68% confidence level) (DEPI, 2014).

7.2.3.1 Approved depth of the pits

The Work Plan states *"The minimum pit floor elevation will be ~RL 110m (AHD) in either pit"* (Prowse and Castle, 2012, p. 8). Despite this reference to an approximate level for the minimum pit elevation being repeated in the Work Plan, the author has assumed 110 metres AHD (Australian Height Datum) is proposed. The excavation of the approved and proposed quarry pits to a fixed elevation will yield a pit depth that varies slightly with floodplain level. The floodplain slopes from upstream, the rail corridor (eastern end), to downstream, the western and northern sides of the pits.

The aerial laser survey (November, 2013) of the site shows that the land around the southern pit is generally above 138 metres AHD at the upstream (eastern) end (Figure 7). The survey picks up a number of stockpile areas as higher than 138 metres AHD but also shows the floodplain around these areas to be in this elevation range. Notable exceptions are the scour feature under the floodplain railway bridges and the access ramp into the pit. As the pit is approved to be excavated to 110 metres AHD, surface levels exceeding 138 metres AHD indicate a pit depth of at least 28 metres adjacent the rail corridor. Similar analysis indicates the northern pit and southern pit at the downstream or western end are approximately 27.5 metres deep.

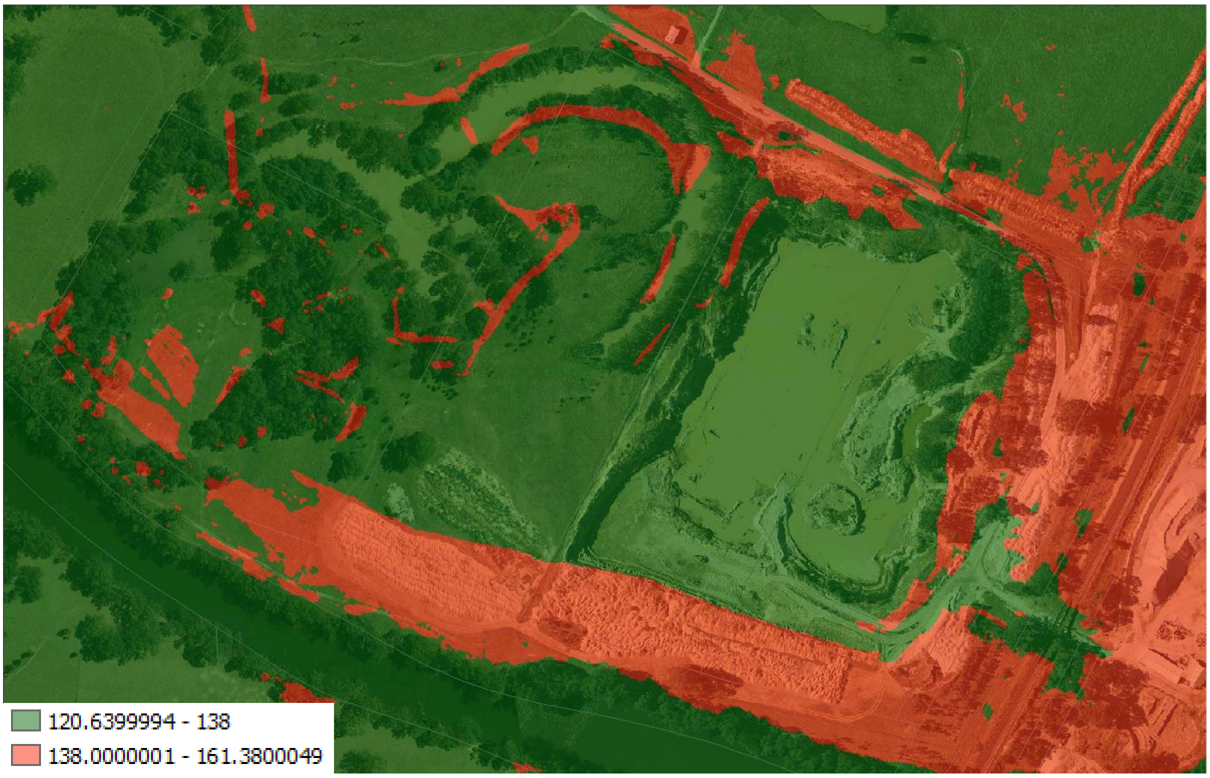

Figure 7 Aerial laser survey (November 2013) over the southern pit of Seymour Quarry with all areas higher than 138.0 metres classified red and shown as a transparency over the aerial photo.

The two Goulburn River cross-sections at river distance 313.1 and 313.5 kilometres (Figure 4) recorded top of bank levels of 137.73, 137.86, 138.04 and 138.09 metres AHD (SR&WSC, 1980a), 137.93 metres AHD on average, providing an independent check that a basement level of 110 metres AHD is 28 metres below the typical floodplain levels.

Whilst the depth of the pits varies with the elevation of the floodplain, a pit depth of 28 metres is used in other parts of this report as it is the depth of the southern pit adjacent key assets such as the Melbourne-Sydney rail corridor, telecommunications cables and much of the Goulburn River.

7.2.3.2 Volumes to be excavated from pits

To determine the volume of material to be extracted from the proposed southern pit, relative to the approved work plan, the terrain (rasters of the aerial laser survey) was modified and volumes calculated using ArcGIS 10.2. In the first instance the geometry of the proposed and approved pits was generated based on the rehabilitation surface shown on the plans and sections (Prowse and Castle, 2014a, 2014c), as shown in Figure 8 and Figure 9. Where the proposed pit batter surface was below the existing terrain the surface was lowered. However, where excavation already (in November 2013) exceeded that approved in the work plan these areas were not filled. Such areas are small and would not impact significantly on the volumes calculated. These areas are also included in both the approved and proposed volumes and will, if anything, lead to an underestimate of the proposed volume of pit expansion.

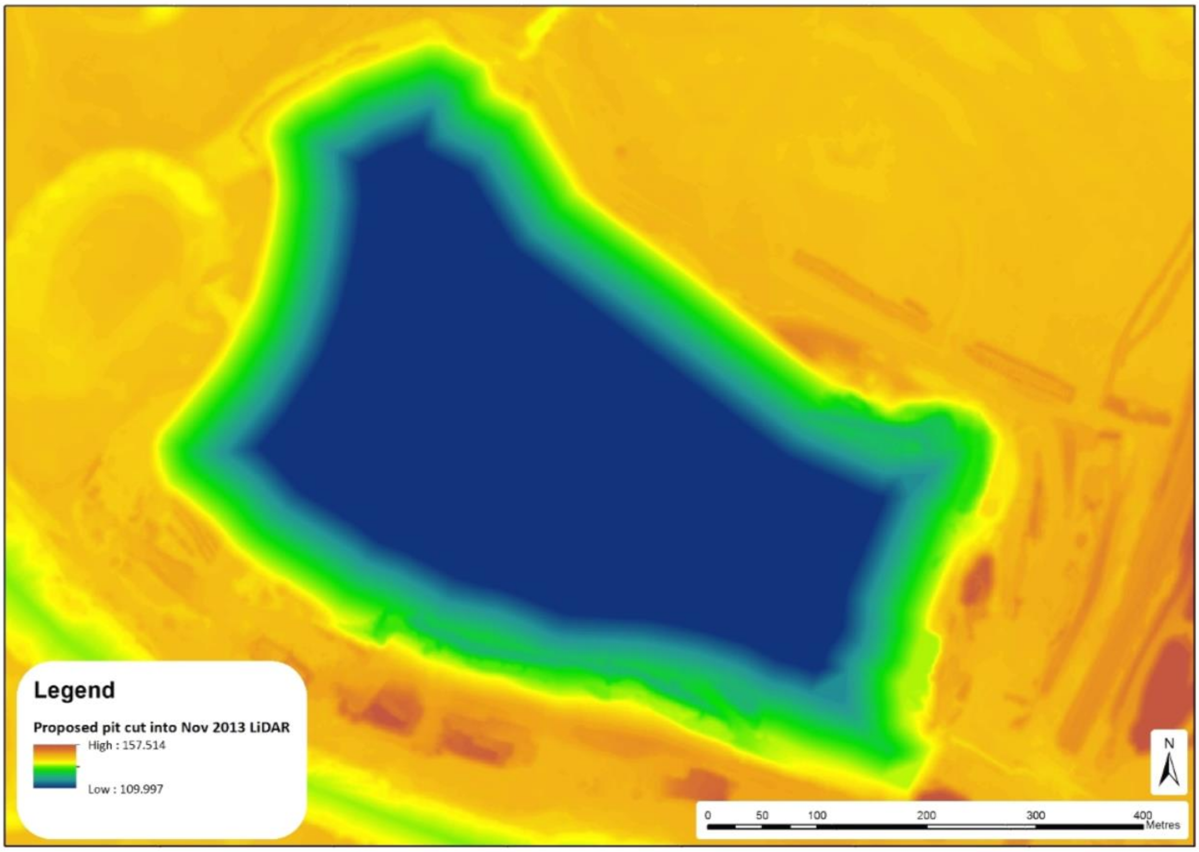

Figure 8 The geometry of the proposed southern pit cut into the November 2013 aerial laser survey.

Leaving areas in the terrain model that are lower than the batters shown on the Applicant's plans also provided an independent check of the georeferencing. The surface generated for the approved southern pit (Figure 9) shows drains and minor excavations that locally exceed the batters on the Applicant's plans on the northern, eastern, southern and western sides of the pit.

If the georeferencing were incorrect these features would only tend to show up on one or two sides of the pit.

Excavation volumes were calculated using the 3D Analyst extension to ArcGIS 10.2 which analyses the volumetric difference between rasters. The volumes of the approved and proposed southern pit were generated as the difference between the original floodplain surface and the pits (Figure 8 and Figure 9). The floodplain surface was determined from the March 2000 photogrammetry that has an accuracy of ±114mm in this area (Walden et al., 2001). The volume of the 2.6 hectare pit shown in the March 2000 photogrammetry was also added to the volumes of the approved and proposed pits.

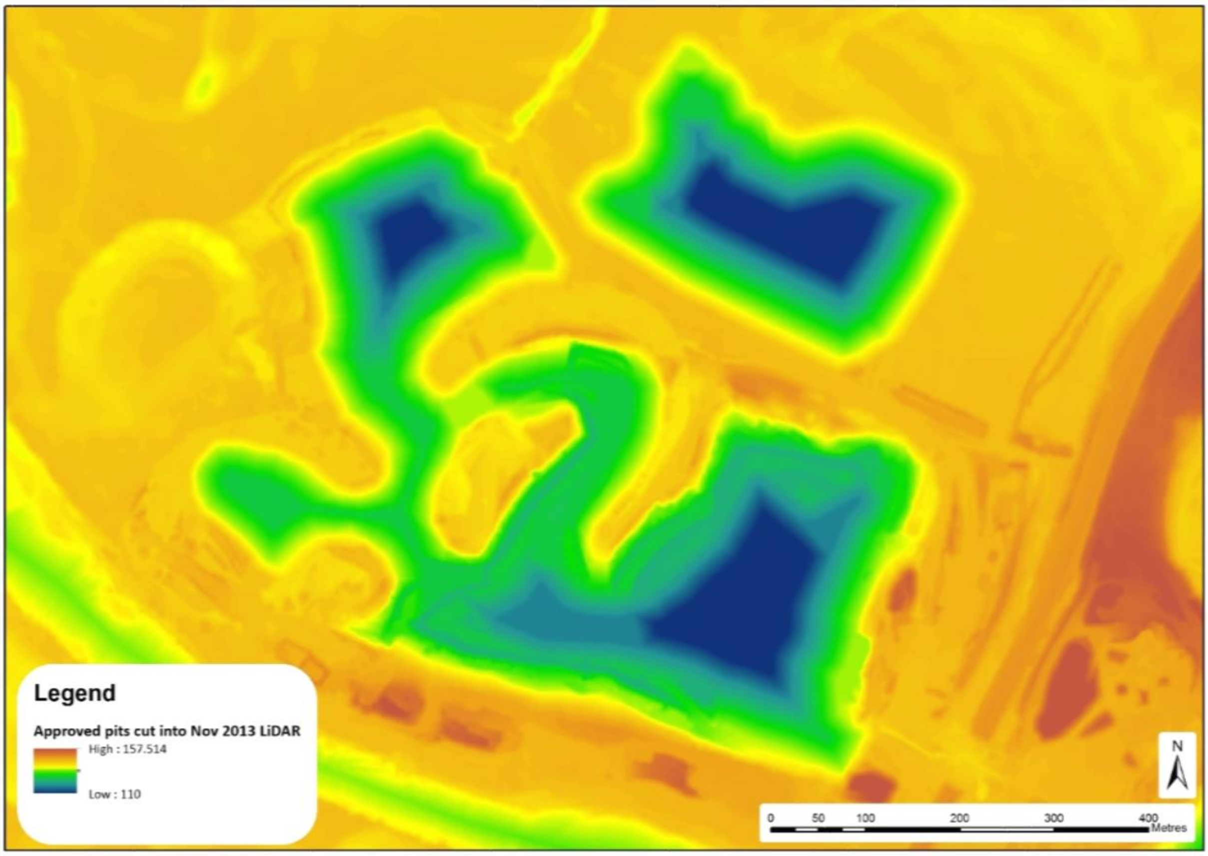

Figure 9 **The geometry of the approved northern and southern pits cut into the November 2013 aerial laser survey.**

The volume of the northern pit was calculated in 3D Analyst from the pit geometry (Figure 9) and the November 2013 aerial laser survey. The volumes of the proposed and approved pits are shown in Table 1 and Figure 10.

The additional volume proposed under the variation to the work plan is the arithmetic difference between the approved and proposed southern pit volumes in Table 1; 2,821,000 m^3 or a 97% increase in the volume. As a check, the volumetric difference between the rasters of the approved and proposed southern pits was also determined using 3D Analyst. This computation found that the work plan variation represented a 98.5% increase in pit volume.

Table 1 Pit volumes calculated using 3D Analyst.

Variable measured	Approved Volume# (m^3)	Proposed Volume# (m^3)
Northern pit	1,155,000	1,155,000
Southern pit	2,920,000	5,741,000
Total	4,075,000	6,896,000

\# Volumes were rounded to the nearest 1,000 cubic metres.

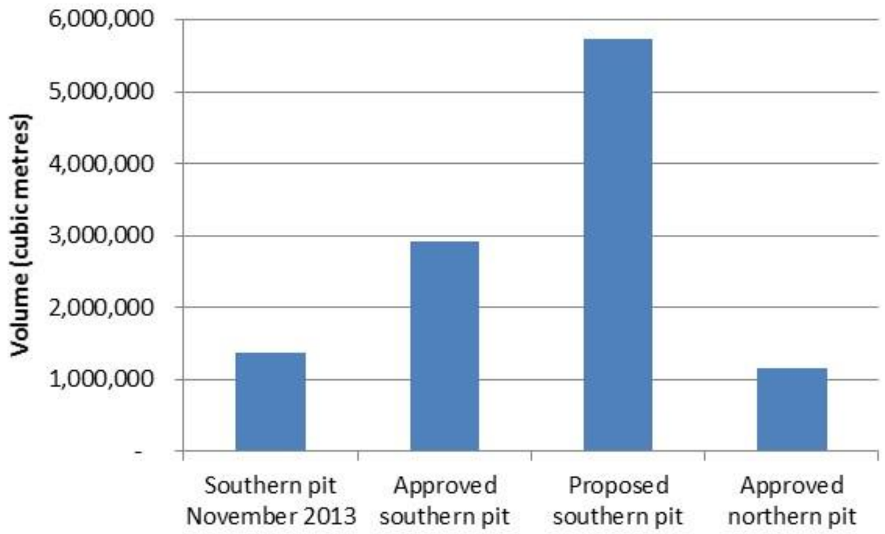

Figure 10 Pit volumes calculated using 3D Analyst.

The pit volumes calculated using 3D Analyst were checked by manual calculations. For each of the approved and proposed pits the surface area at various depths was measured and multiplied by the applicable depth. These manual calculations yielded pit volumes that were within 1-6% of the three volumes calculated by 3D Analyst and shown in Table 1.

7.2.3.3 Banks/fill constructed around Seymour Quarry

The aerial photography and site visits indicated constructed banks and fill around Seymour Quarry associated with a range of activities, including overburden and sand and gravel stockpiles and water storage/recycling ponds. To investigate the extent of modification of the floodplain and hence the potential for changes in flood behaviour, the 3D Analyst extension to ArcGIS 10.2 was used to calculate the elevation difference between the November 2013 aerial laser survey and the March 2000 photogrammetry (Figure 11).

Note, the elevation difference between the aerial laser survey and photogrammetry also shows differences in water levels. Figure 11 shows four wetlands where the water level was higher in 2013 relative to 2000. A probable cause of this difference is the quarry pumping water into the wetland system west at the southern pit.

Overall, Figure 11 shows an almost continuous bank of fill around 2-3 metres high has been constructed along the bank of the Goulburn River around the Seymour Quarry processing area and pit. Hence there is the potential for recent banks of fill on the floodplain to substantially influence flood behaviour. This issue and its impact on flood modelling and behaviour is discussed in more detail in Section 9.1.6.6.1. It is noted that the fill surrounding the quarry (Figure 11) does not appear to be in accordance with the Work Plan (Prowse and Castle, 2012, p. 7) for Seymour Quarry.

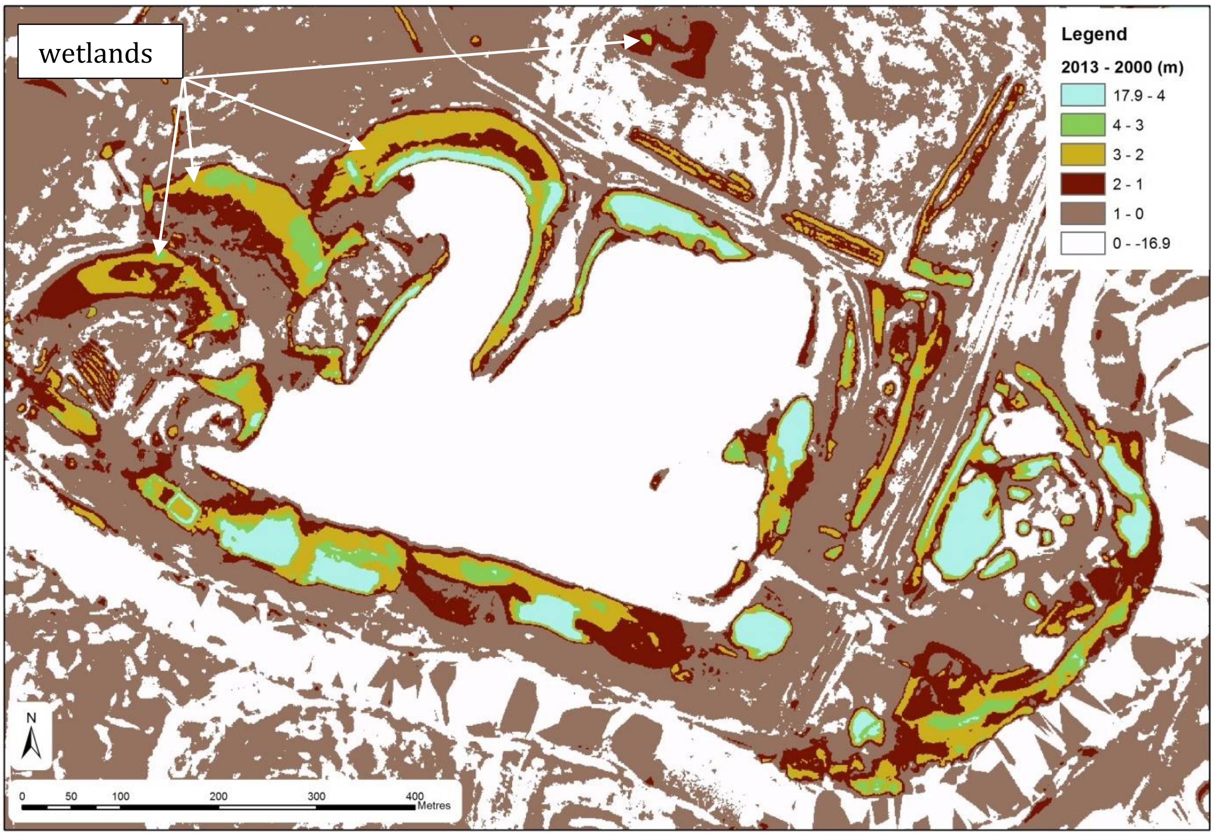

Figure 11 **The elevation in the November 2013 aerial laser survey minus the elevation in the 2000 photogrammetry.**

8 IDENTIFY RISKS

"Risk identification involves the identification of risk sources, events, their causes and their potential consequences" (Standards Australia, 2009). The source of risk is the hazard initiating the event, such as a landslide or earthquake. This risk assessment primarily deals with the hazard of riverine flooding and its interaction with Seymour Quarry.

The mechanisms that expose assets to the hazard are identified in Section 8.1. The pit capture events that these mechanisms cause are described in Section 8.2 and the assets that may be impacted are identified in Section 8.3.

8.1 Causes of risk - failure mechanisms

The causes of quarry pits destabilising the floodplain and adjacent river are the following failure mechanisms. A more detailed explanation of each process is provided in the referenced section.

- Flood flow through the pit and the subsequent erosion of the strip of land between the pit and the river (refer Section 8.1.1).
- The erosion of the bank of the river and the subsequent lateral migration of the river into the pit (refer Section 8.1.2).
- Failure of the pit walls due to a geotechnical instability caused by issues such as piping, suffusion or slope failure. The author is not an expert in geotechnical analysis and has hence not provided an explanation of this process.

8.1.1 Floodplain flow through the pit

The consideration of floodplain flow through the pit can be split into the initial spill of water into the pit (Section 8.1.1.1) and the ongoing flood flow through the pit once it fills (Section 8.1.1.2).

8.1.1.1 Initial spill

The initial spill of water into the pit refers to the cascade of floodwater during the initial part of the flood when the pit is filling from basement level to floodplain level. Whilst the quarry is operating, the erosion caused by the initial spill is exacerbated by the large volume of water required to fill the pit (Figure 10) and hence the duration for which water spills. Once pits are not dewatered the water level in the pit will be at the general groundwater level and the volume and duration for filling reduces.

The erosion caused by the cascade of floodwater during the initial filling of the pit is really just a sediment transport discontinuity, as discussed for flood flow through the pit (Section 8.1.1.2). However, it is highlighted here as the acceleration of flow down the steep slope of the pit batter causes the flow regime to transition to supercritical. Further, once the hydraulic slope flattens at an elevation just below groundwater level, or at the base of the pit, a hydraulic jump occurs.

A hydraulic jump is the violent transition in flow regime from supercritical to sub-critical flow that is associated with substantial turbulence and energy expenditure and will cause rapid erosion of floodplain sediments. Further, the supercritical flow found on the face of the batter is shallow, rapid flow. Shallow, rapid flow is associated with high bed shear stresses and such shear stresses are a reasonable measure of the erosive nature of hydraulic conditions (not considering issues such as turbulence).

8.1.1.2 Flood flow

Floodplain flow through quarry pits encourages pit capture through the physical processes of upstream and downstream progressing degradation due to sediment transport discontinuities. This process explanation is well established in the international literature since the seminal paper by Galay (1983); other examples include Erskine (1990) and Kondolf (1994).

When flow passes through a pit it causes three bed load sediment transport discontinuities. Bed load comprises the materials found in the bed of a river, effectively the sands and gravels quarried at Seymour.

As floodwaters enter the pit there is an increase in the hydraulic conveyance due to the increase in the cross-sectional area of flow and the reduction in hydraulic roughness. These changes cause a hydraulic drawdown (an increase in the energy gradient) and hence an increase in shear stress and bed load transport capacity (Chang, 1988; Henderson, 1966). Bed load transport capacity then exceeds sediment supply, causing erosion of the upstream face of the pit (location I in Figure 12).

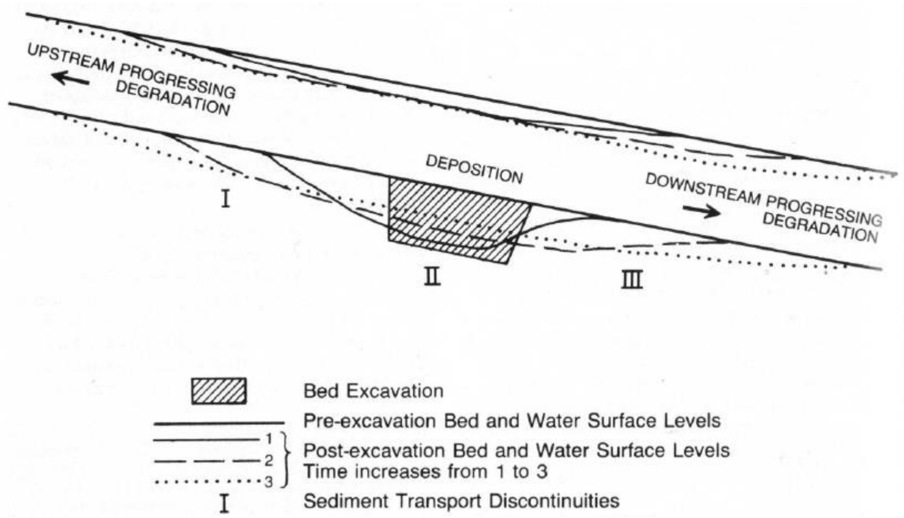

Figure 12 Degradation induced by sediment extraction and the subsequent channel recovery (Erskine, 1990, Figure 1).

As the flow continues downstream through the pit, little energy is required to convey flows through the large cross section of the pit. This reduction in the energy gradient causes a reduction in the bed load transport capacity below the rate of incoming sediment supply. Hence much of the sediment eroded from the upstream face of the pit is deposited in the pit (location II in Figure 12).

As flow spills back onto the floodplain from the downstream end of the pit, the cross sectional area of the flow decreases and the hydraulic roughness increases. These changes cause the energy gradient and the bed load transport capacity to increase. Bed load transport capacity then exceeds the supply of sediment causing downstream progressing degradation, commonly called clear water scour (location III in Figure 12).

8.1.2 Lateral migration

An alluvial waterway such as the Goulburn River migrates laterally across the floodplain through the erosion and deposition of sediment on and from the banks, benches and bars within the channel. One of the primary processes is the migration of a river bend where there is erosion from the outside or concave bank and concomitant deposition on the point bar on the convex bank.

Whilst erosion of the concave bank is a destructive process that does not leave evidence of migration, the construction and movement of the point bar creates scroll bar patterns across the floodplain. Prior lateral migration of the Goulburn River and the consequent scroll bar patterns on the floodplain are clearly evident in the aerial laser survey (Figure 13).

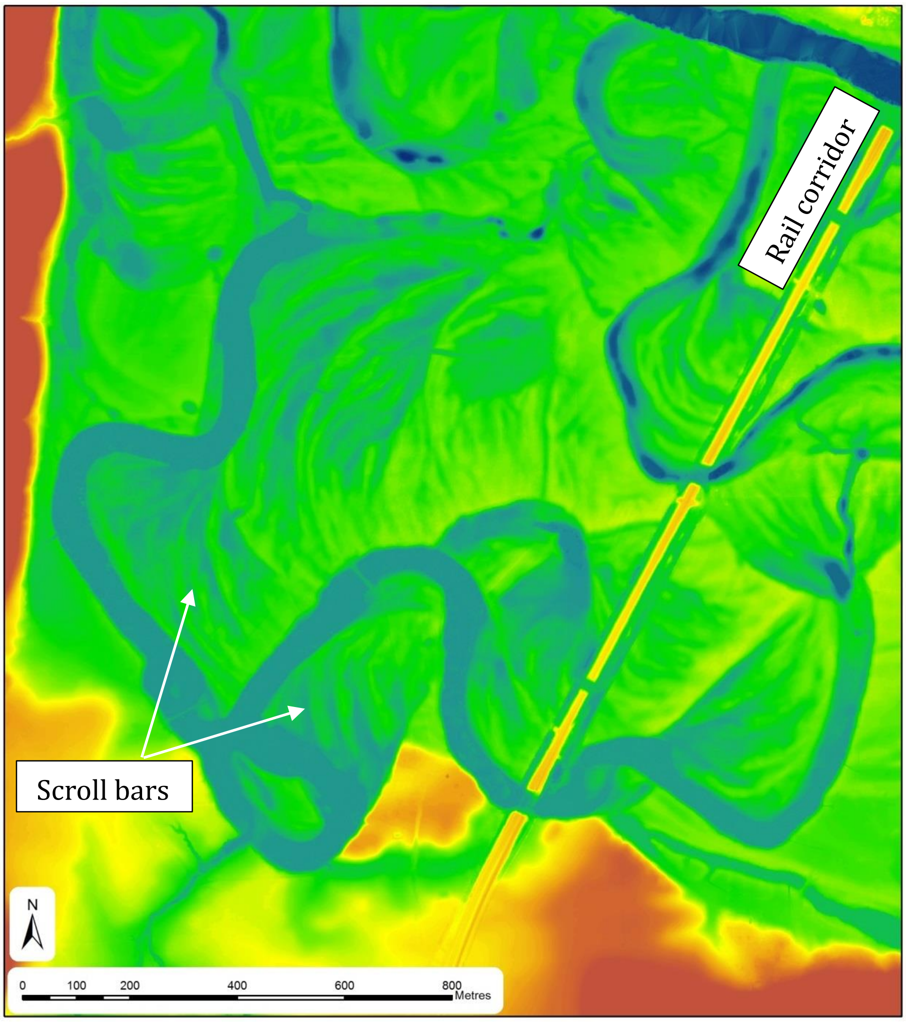

Figure 13 **Scroll bars on the southern floodplain of the Goulburn River opposite Seymour Quarry showing where the Goulburn River has migrated across the floodplain (November 2013 aerial laser survey).**

8.2 Pit capture events

The causes of risk (Section 8.1) facilitate pit capture events in the form of:

1. A diversion of the river. This is where a channel is scoured between the river and the quarry pit but a second channel out of the pit and connecting back to the river is not scoured.

2. A cut-off. This is where a channel is scoured both upstream and downstream of the quarry pit and the pit and the new river channel is within the meander belt of the river. This will generally involve the river cutting a new course across half a meander wavelength.

3. An avulsion. This is where a channel is scoured both upstream and downstream of the quarry pit but outside the meander belt of the river. The length of such an avulsion is likely to be multiple meander wavelengths and be measured in kilometres on a river as large as the Goulburn.

Figure 14 shows a potential river diversion (A or B), cut-off (A+B) and avulsion ((A or B)+C) at Seymour Quarry. These changes in river course are shown to illustrate the above definitions, they are not predictions.

Floodplain flow through the pit (Section 8.1.1) causes a pit capture event via erosion at the upstream face of the pit causing incision (deepening) to propagate upstream through the floodplain along the inflow path. This deepening may continue to the river, creating a river diversion (A or B in Figure 14) or, if erosion is occurring on two flow paths, a cut-off (A+B in Figure 14) and potentially deepening the bed of the river. Downstream progressing degradation will follow the dominant outflow path but progress substantially slower than the upstream erosion, potentially taking several floods to develop the outlet channel and hence an avulsion ((A or B)+C in Figure 14). Floodplain hydraulics may also dictate that flows do not exit the downstream side of the pit, or are insignificant, and a river avulsion does not develop.

Lateral migration (Section 8.1.2) causes pit capture at quarries via the river bank simply eroding into the pit to create a diversion (A or B in Figure 14). Lateral migration may also gradually compromise setbacks between the river and the pit that are needed for environmental reasons, geotechnical stability or to retain sufficient riparian vegetation to stabilise river banks.

8.3 Assets around Seymour Quarry

The event of pit capture can impact on infrastructure (e.g. Norman et al., 1998). The understanding of the failure mechanisms (Section 8.1) and the events they facilitate (Section 8.2) are important to identifying the assets at risk around Seymour Quarry.

Table 2 lists the infrastructure/assets around Seymour Quarry that may be exposed to the pit capture event. The location of these assets is shown in Figure 15. Table 2 also nominates which of the three types pit capture events listed in Section 8.2 could threaten the asset.

Note, Asset ID No.s 10, 11 and 12 are shown on an assumed course for the downstream reach of an avulsion channel (Figure 15), the course of Deep Creek. Alternate courses are possible but similar assets are likely to be found along or on these channels. The proposed Seymour levee has been included in Table 2 (Asset ID No. 13) as it is understood Mitchell Shire Council is in receipt of $7M of commonwealth and state funding on condition that the $9M project is complete by 2019.

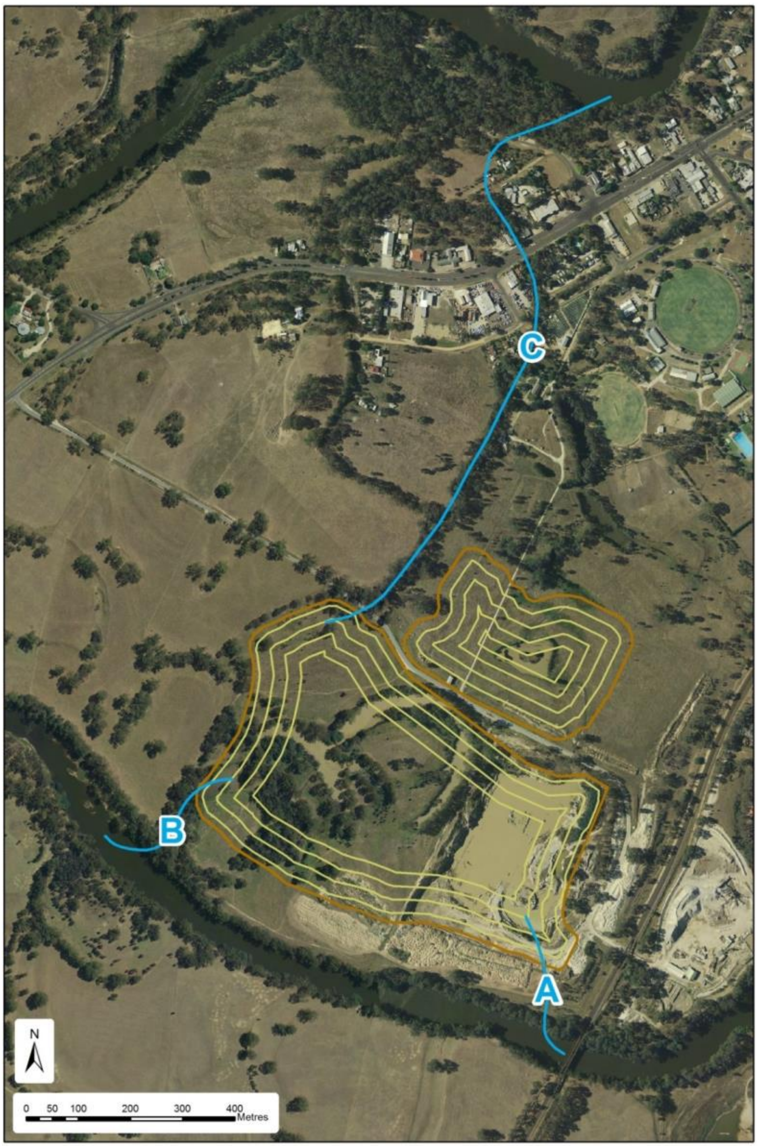

Figure 14 **A potential river diversion (A or B), cut-off (A+B) and avulsion ((A or B)+C) at the Seymour Quarry.**

Pit capture events will result in the loss of assets other than those listed here, including the public and private land eroded as the Goulburn River deepens and widens. However, the analysis of risk has been limited to the assets in Table 2. The consequences of pit capture will also extend beyond the physical impact on assets and impact on other aspects of the economy, environment, people, public administration and social setting (AGD, 2015a). Some of these consequences are discussed in more detail in Section 9.2.

Table 2 **The assets that may be impacted by physical changes at Seymour Quarry.**

Asset ID No. (Figure 15)	Asset	Pit capture event required to impact on the asset (Section 8.2)
1	Goulburn River	• Any
2	Railway bridges (x2) on the northern floodplain	• Any, but the course of the diversion channel would need to be through these bridges
3	Railway bridges (x2) over the Goulburn River (Figure 16)	• Any, except if the only diversion channel was through the floodplain bridges (Asset ID No. 2)
4	Nextgen optic fibre (Figure 17)	• Any
5	Telstra optic fibre (Figure 18)	• Any
6	Seymour caravan park	• Any
7	Seymour town water supply offtake	• Any
8	Emily Street bridge over the Goulburn River	• Diversion • Cut-off
9	Department of Defense pumping station	• Any
10	Emily Street	• Avulsion
11	Local roads in Seymour (Edward and Manners Streets)	• Avulsion
12	Homes and businesses	• Avulsion
13	Seymour levee (proposed)	• Avulsion
14	Seymour gauge (Site No. 405202)	• Any
15	Quality of potable and irrigation water supplied	• Any

To understand what additional major infrastructure is along the rail corridor the author used the "dial before you dig" service. In response, Nextgen sent the plan in Figure 17 and confirmed that the asset is the optic fibre connection between Melbourne and Sydney. Telstra also sent plans showing infrastructure in the area, an extract of which is Figure 18. Telstra confirmed that the alignment annotated with a star in Figure 18 is fibre optic cable and the remainder is local 14 pair copper infrastructure. The Telstra representative described the fibre optic cable as "major plant" but was unsure of whether it is Telstra's Melbourne-Sydney optic fibre connection.

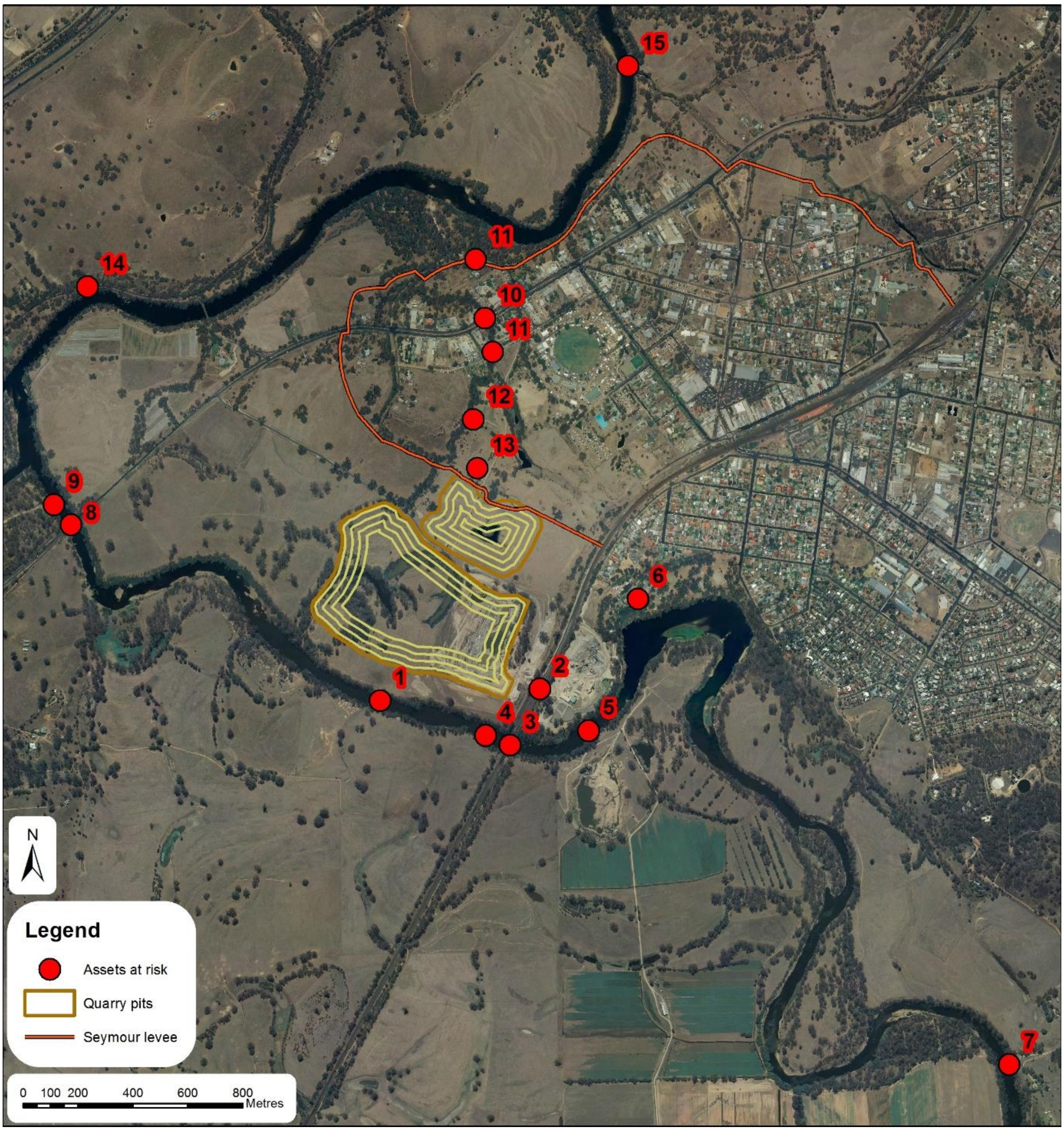

Figure 15 **The location of assets that Seymour Quarry may threaten based on the asset identification (ID) numbers in Table 2.**

Figure 16 Looking north at the bridges over the Goulburn River on the Melbourne-Sydney rail corridor.

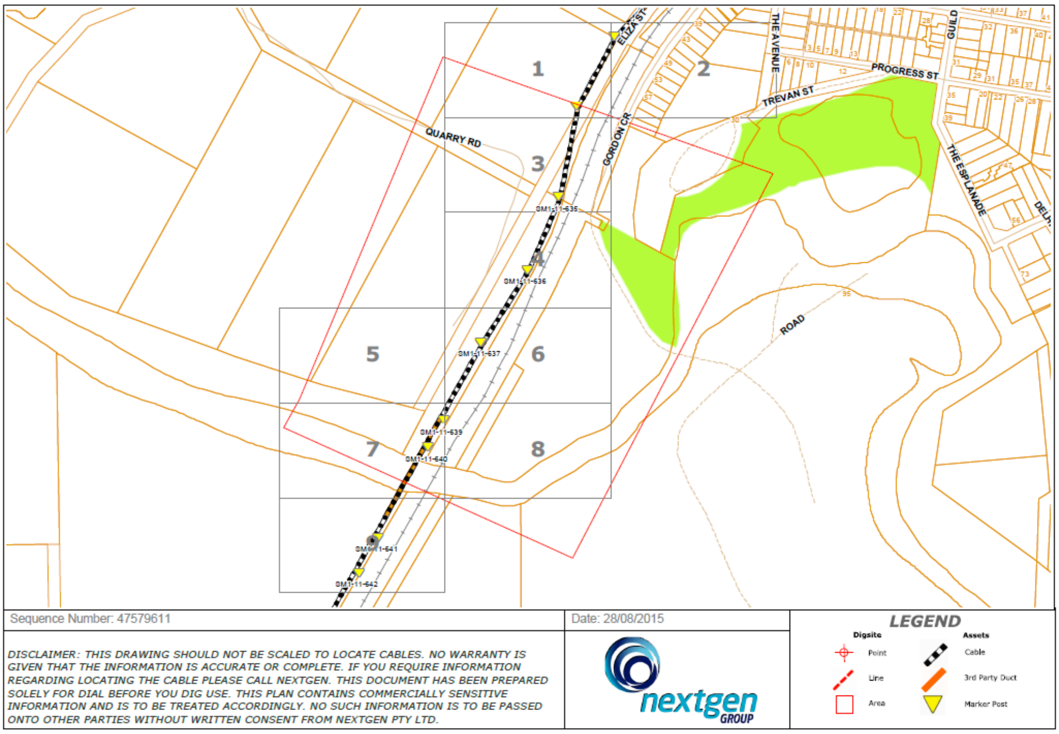

Figure 17 Nextgen assets along the rail corridor.

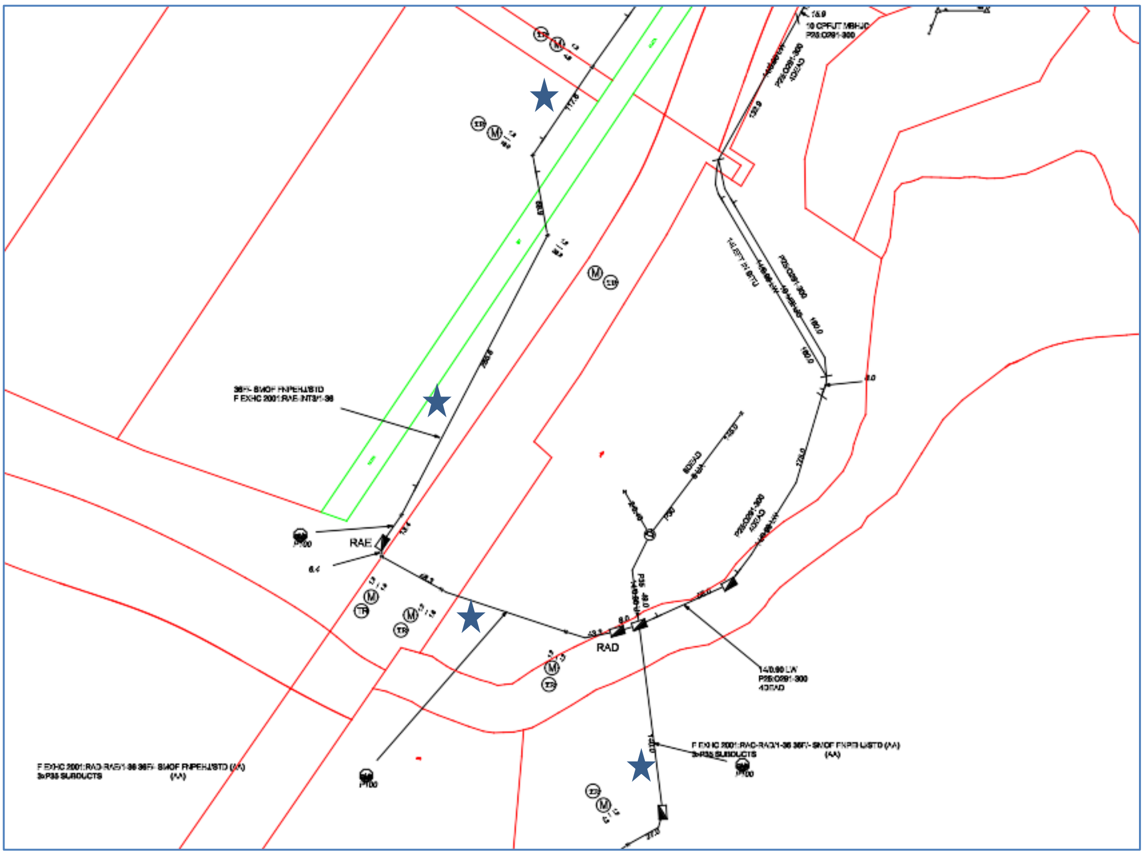

Figure 18 **Telstra assets adjacent the rail corridor. The author has annotated the fibre optic cables with a star.**