9.1.6.7.3 Shear stresses

The bed shear stresses generated as floodwater spills into and flows through the proposed and approved pits under Scenario 2 (rehabilitated quarry) are shown in the top image in Figure 48 through to Figure 52. Note, these figures are provided at shorter time intervals than Scenario 1 (operating quarry) as the duration of highly erosive conditions is shorter. Important aspects of the flow and erosion conditions around the proposed pits are described in Table 7. The average recurrence interval (ARI) of the flows was determined from the design event discharge rating curve adopted in the Seymour Floodplain Mapping Study (Walden et al., 2001, Figure 5.35).

Table 7 Scenario 2: rehabilitated quarry - flow distribution around the proposed pits and erosion conditions.

Time (hrs:min)	Flow at Seymour gauge (m^3/sec)	ARI of flow (years)	Key changes in erosion conditions
22:50	780	12 year	Floodwaters begin to spill from the Goulburn River down the south western corner of the southern pit (Figure 48, top).
23:30	844	14 year	Floodwaters begin to spill from palaeochannels down the western face of the southern pit (Figure 49, top). The width and number of spill points continues to increase over the next 6 hours. In the last hour (28:30-29:30 hours) the high shear stresses begin to moderate as the pit fills.
28:40	1,139	27 year	Floodwater begins to spill from the southern pit, down the southern face of the northern pit (Figure 51, top).
29:10	1,156	27 year	Floodwaters begin to spill from Deep Creek down the western face of the northern pit (Figure 52, top). The width and number of spill points continues to increase over the next 2 hours and 10 minutes until the northern pit is full.
31:20	1,232	35 year	Northern pit fills and the dominant flow path across the northern pit is north west, parallel to the Seymour levee (e.g. Figure 45).

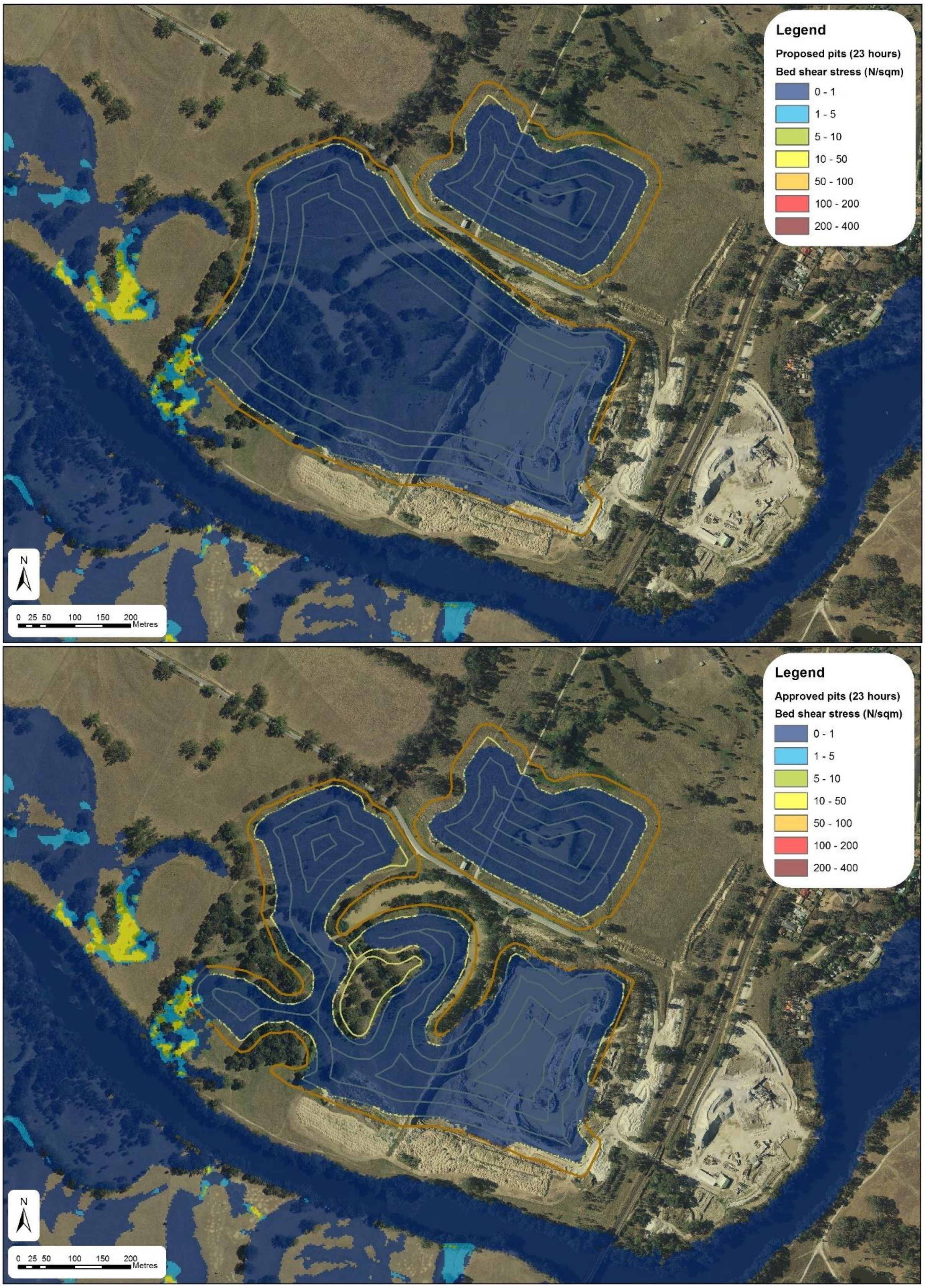
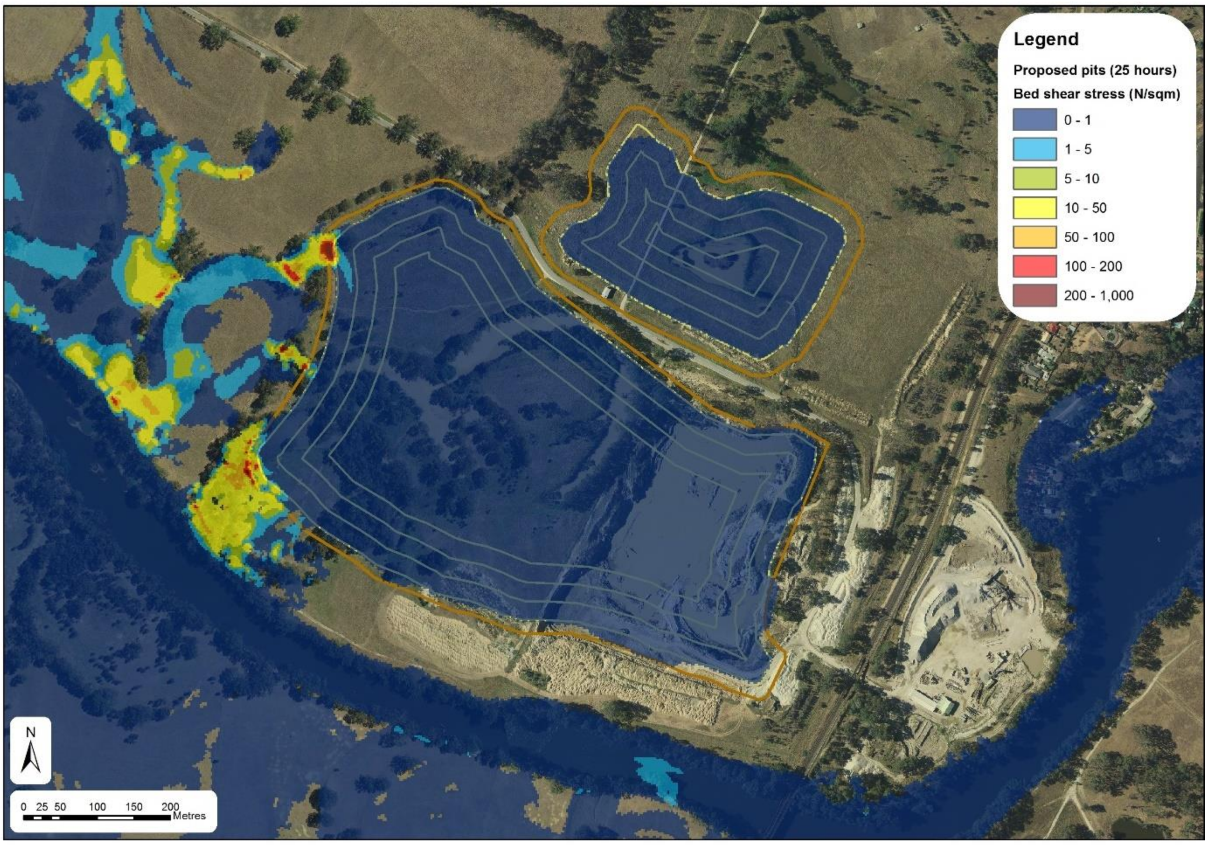


Figure 48 Bed shear stress at 23 hours for the proposed (top) and approved (bottom) pits.



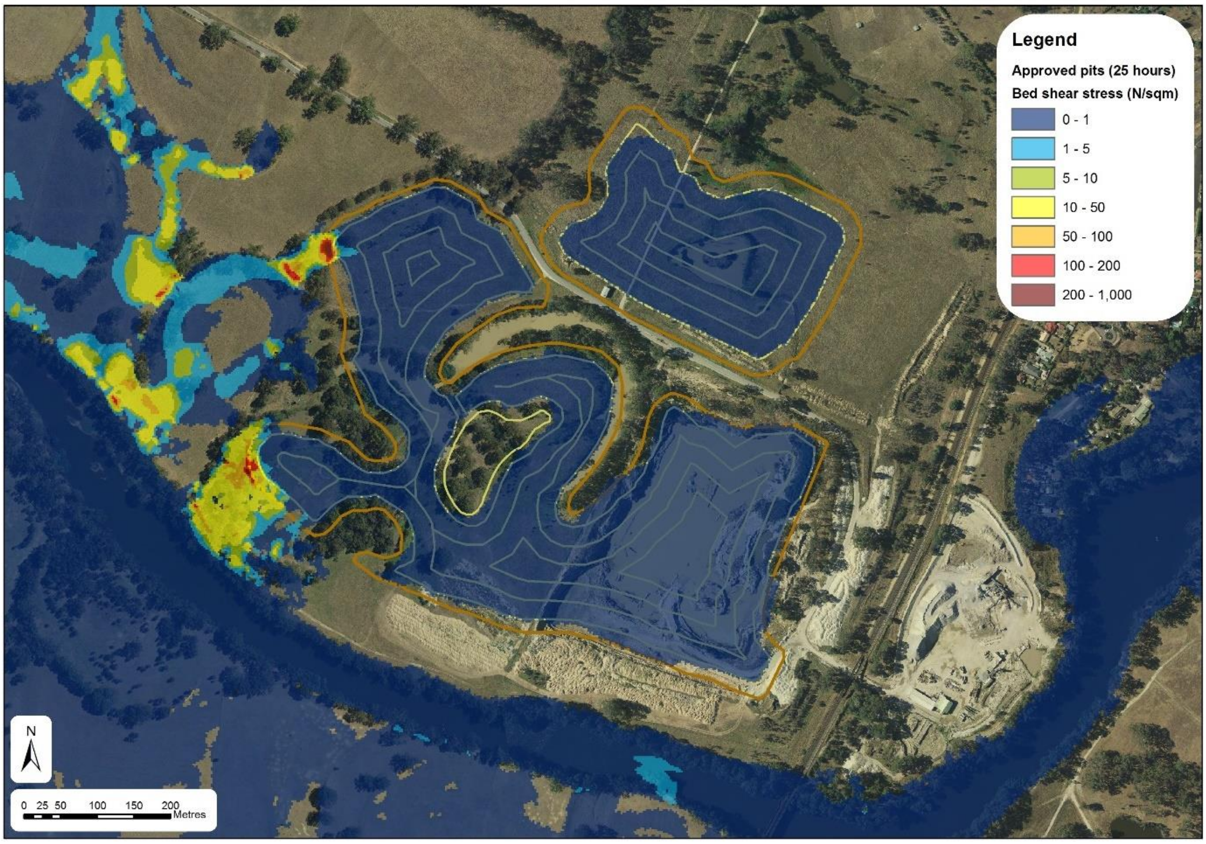


Figure 49 **Bed shear stress at 25 hours for the proposed (top) and approved (bottom) pits.**

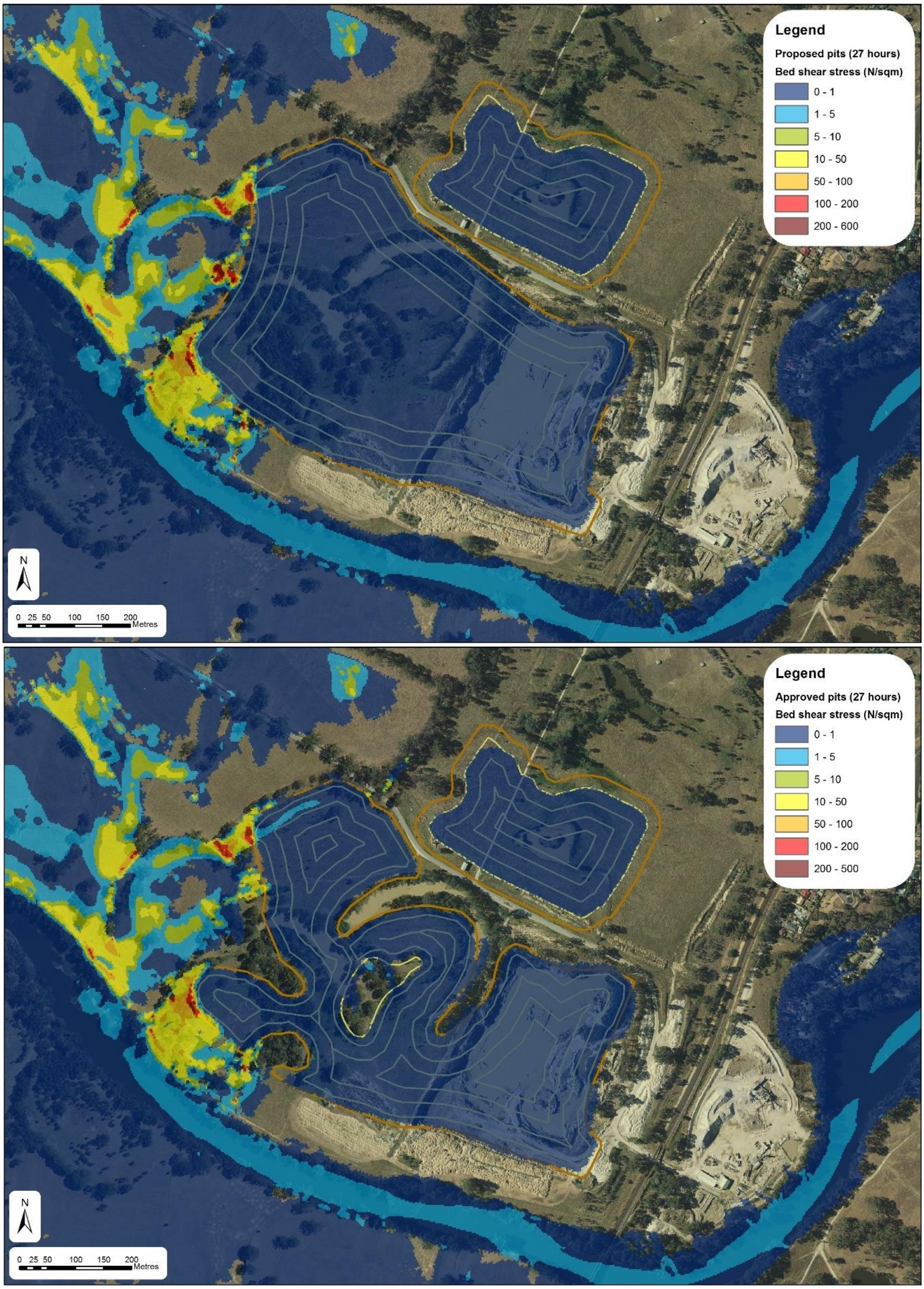


Figure 50 **Bed shear stress at 27 hours for the proposed (top) and approved (bottom) pits.**

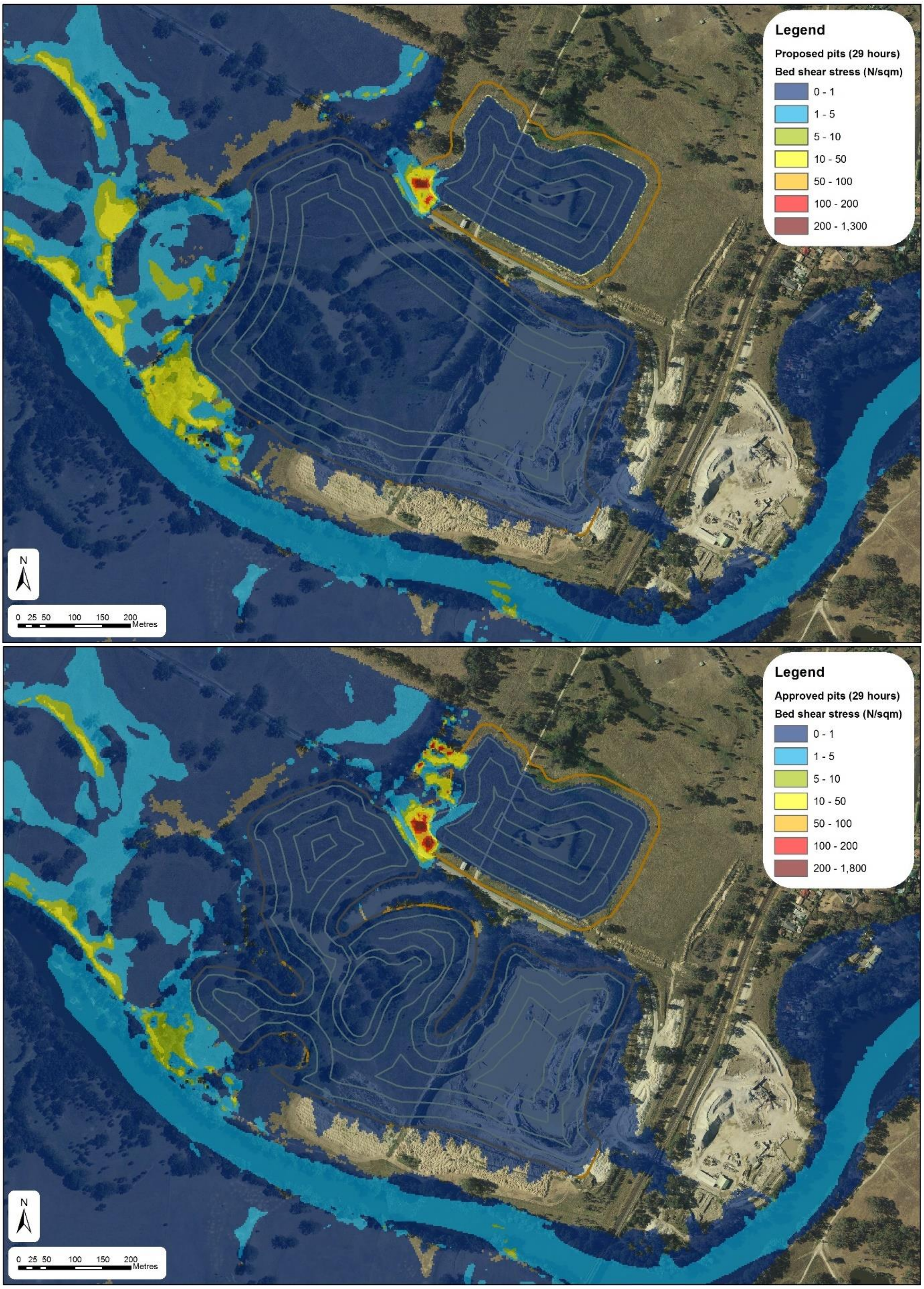


Figure 51 Bed shear stress at 29 hours for the proposed (top) and approved (bottom) pits.

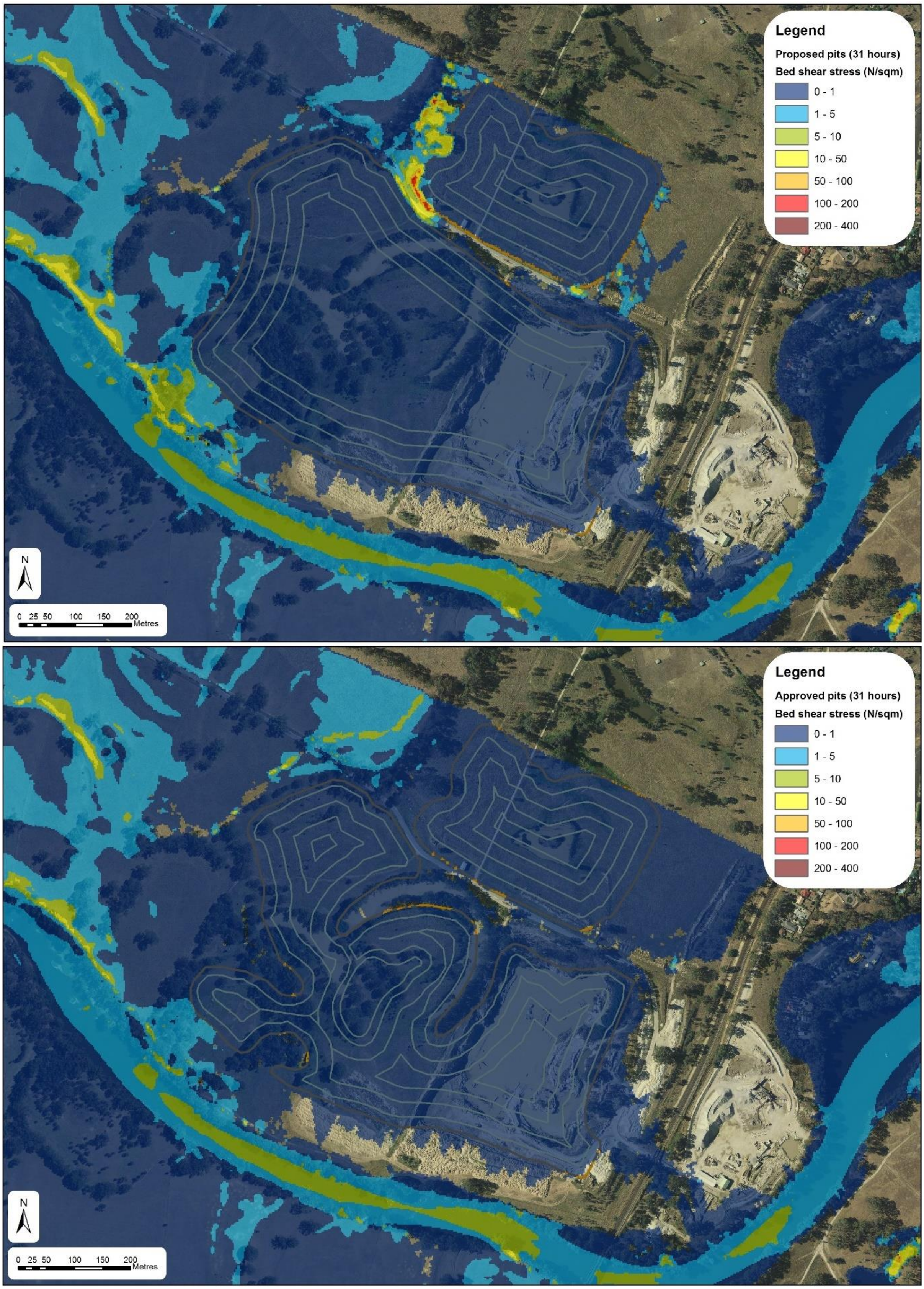


Figure 52 Bed shear stress at 31 hours for the proposed (top) and approved (bottom) pits.

Comparing Scenario 2: rehabilitated quarry (Table 7) to Scenario 1: operating quarry (Table 5):

- In Scenario 2 Seymour levee prevents floodwaters spilling from Deep Creek down the north face of the southern pit.
- In Scenario 2 floodwater spills from the Goulburn River to the southern pit 2 hours and 30 minutes earlier in the flood due to the removal of fill.
- In Scenario 2 floodwater spills from the palaeochannels down the western face of the pit 20 minutes later, potentially due to the above upstream diversion of flow from the Goulburn River into the pit.
- In Scenario 2 floodwater spills into the northern pit 7 hours and 10 minutes earlier and fills 9 hours earlier, primarily due to the lack of pit dewatering.

The impact of the expansion of the southern pit on the duration and magnitude of high shear stresses in Scenario 2 is shown in Table 8 and Figure 53 through to Figure 55.

Table 8 Scenario 2: rehabilitated quarry - change in flow and erosive conditions due to the expansion of the southern pit

Aspect	Key changes in flow and erosion conditions due to expansion of the southern pit	Summary of changes
High shear stresses on the southern side of the southern pit	At the key flow paths from the Goulburn River to the southern side of the southern pit the proposed expansion doubles the depth of the pit (e.g. Figure 50) increasing the risks at these points. High shear stresses from floodwater spilling from the Goulburn River persist for 6 hours and 30 minutes for the proposed pit and 5 hours and 40 minutes for the approved pit.	Proposed expansion increases the duration of high shear stresses by 15% and doubles the depth of the pit at the key flow paths.
High shear stresses on the western side of the southern pit	High shear stresses from floodwater spilling from the palaeochannels along the western side persist for 5 hours and 20 minutes for the proposed pit and 4 hours and 40 minutes for the approved pit.	Proposed expansion increases the duration of high shear stresses by 14%.
High shear stresses on the southern side of the northern pit	High shear stresses from floodwater spilling from the southern pit persist for 2 hours and 30 minutes for both the proposed and approved pits.	No change

Aspect	Key changes in flow and erosion conditions due to expansion of the southern pit	Summary of changes
High shear stresses on the western side of the northern pit	High shear stresses from floodwater spilling from the Deep Creek along the western side persist for 2 hours and 10 minutes for the proposed pit and 2 hours for the approved pit.	Essentially no change

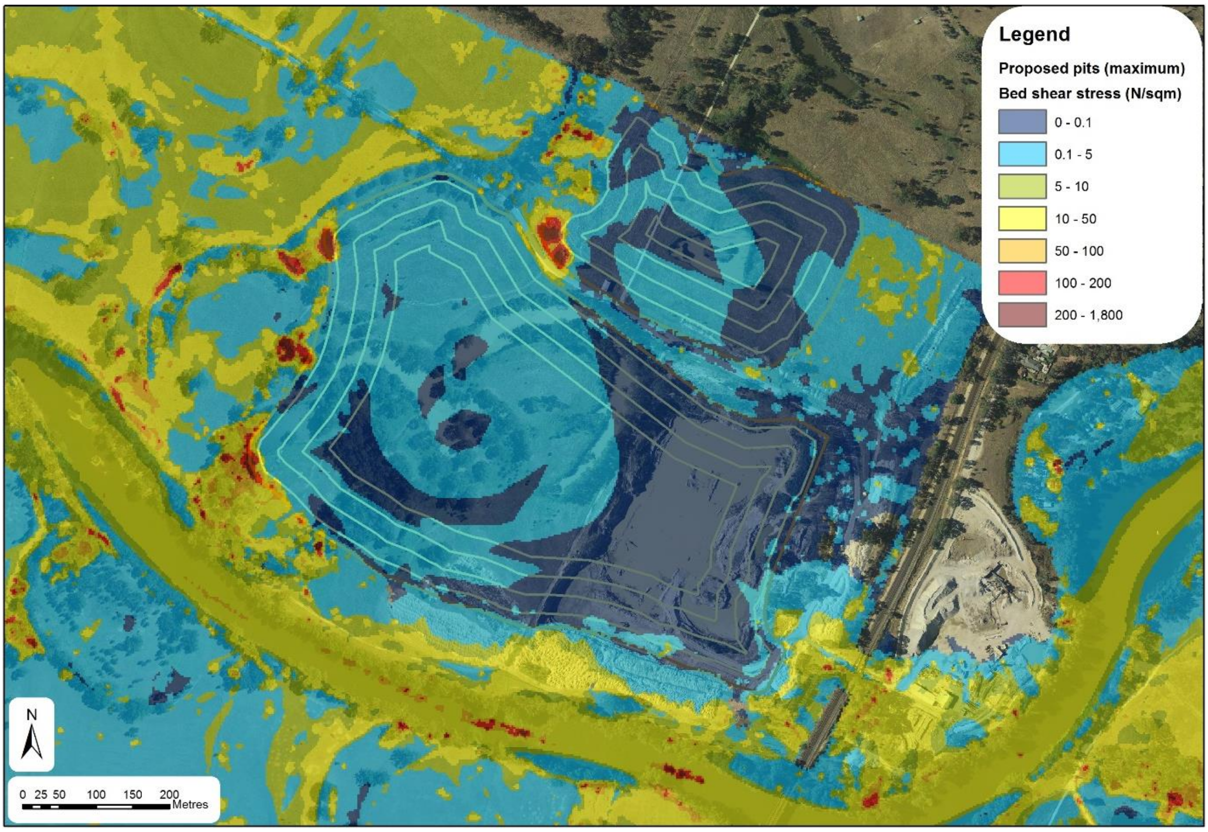


Figure 53 Maximum bed shear stress with the proposed pits (N/m²).

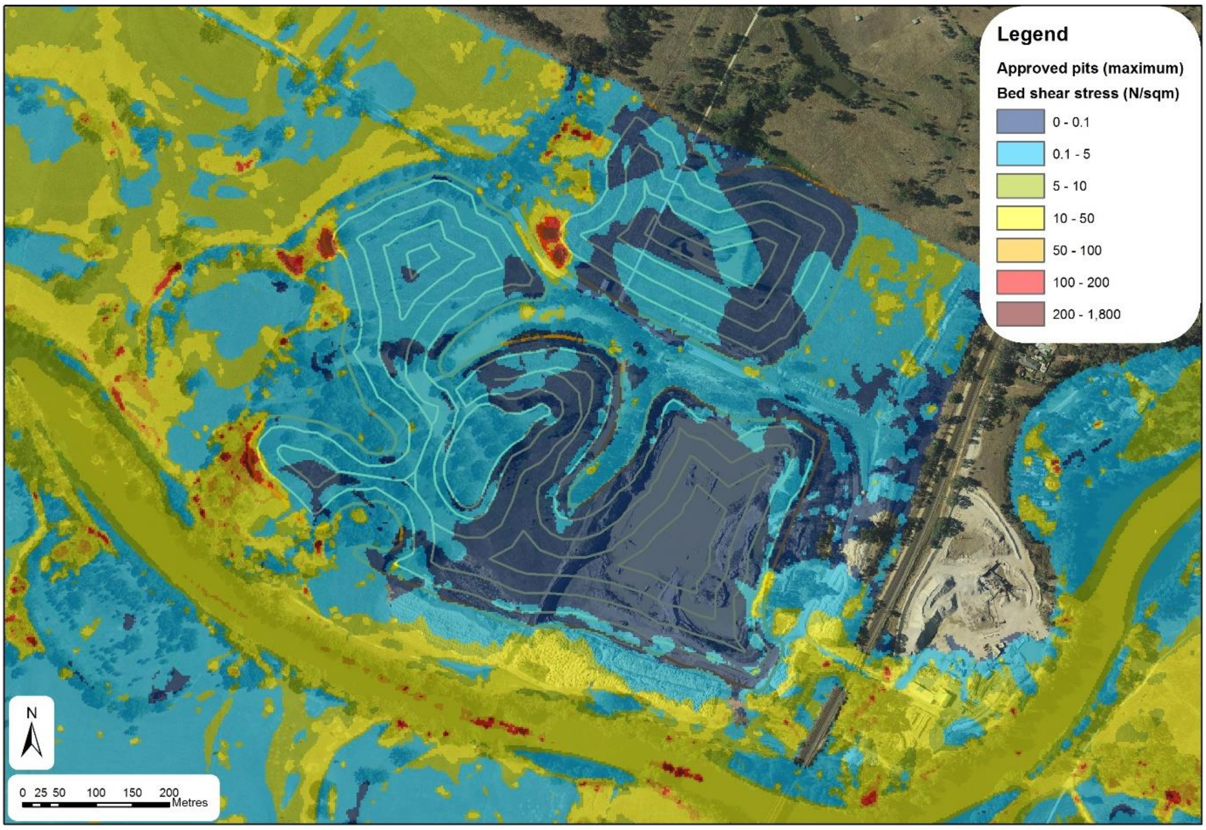


Figure 54 **Maximum bed shear stress with the approved pits (N/m^2).**

Overall, without dewatering the proposed southern pit only takes 15% longer to fill than the approved pit (Table 8). These similar durations ensure shear stresses and the area subject to erosion are similar. An exception is one location on the western side where the proposed expansion intersects a depression, concentrating the spill of flood water and hence high shear stresses locally (Figure 55).

Unlike Scenario 1, in Scenario 2 the northern pit is filling under similar flow rates for the proposed and approved pits and there is negligible difference in the erosive conditions.

In Scenario 1 and Scenario 2 the hydraulic results indicate that a connecting channel is likely to be scoured between the southern and northern pits. Once the pits are connected, the erosive conditions closer to the Goulburn River (on the southern and western sides of the southern pit) will persist for longer in subsequent floods as the cascade of floodwater will continue until both pits are full.

The magnitude of the shear stresses caused by flooding into the proposed and approved pits at Seymour Quarry provides an indication of both the likelihood of initiating erosion (Section 9.1.6.8.2) and the subsequent rate of erosion (Section 9.1.6.9).

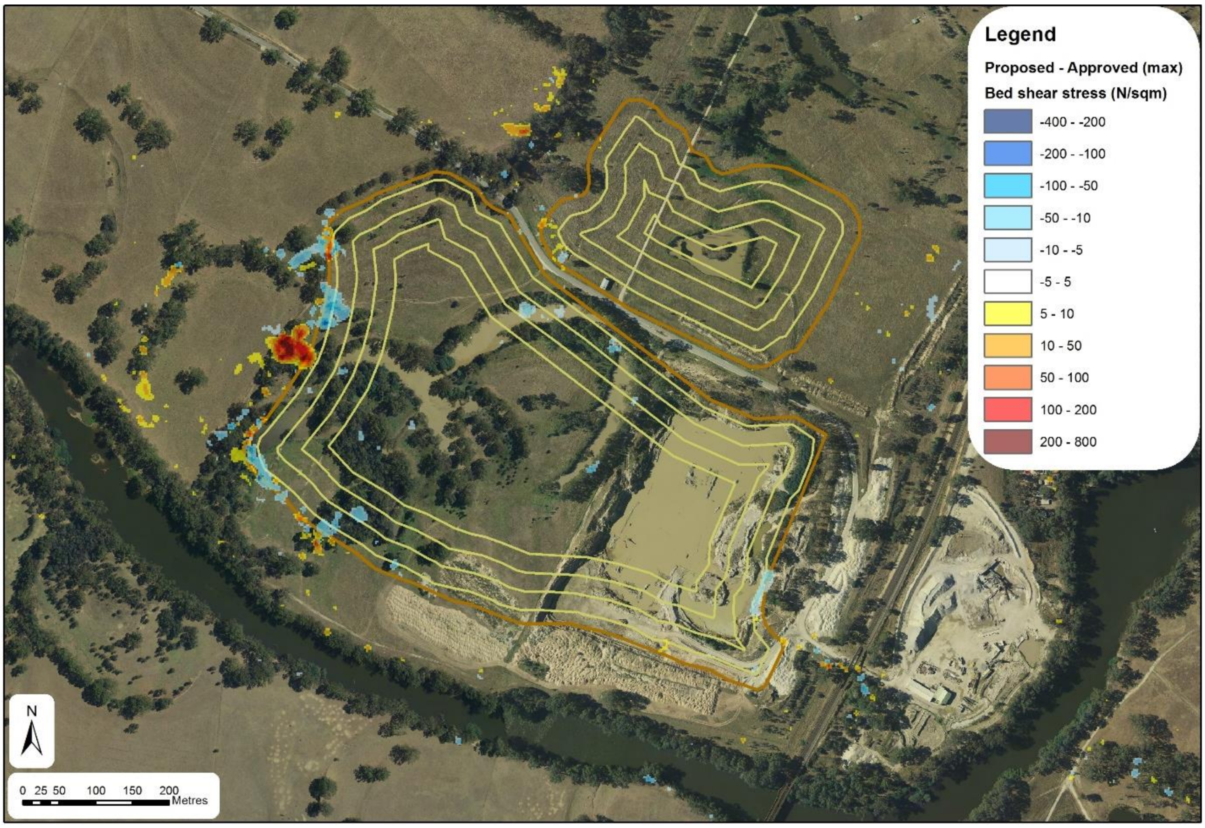


Figure 55 **Maximum bed shear stress with the proposed pits minus the maximum with the approved pits (N/m²).**

9.1.6.8 Initiation of erosion

The likelihood that floodplain flow into the pits will cause erosion can be better understood by comparing the shear stresses that develop (the hydraulic model results) to the threshold of motion, the shear stress at which erosion will commence on the pit batters. This is done here by considering the threshold of motion for vegetation (Section 9.1.6.8.1) and for the floodplain sediment (Section 9.1.6.8.2) and the erosion that occurred in September 2010 (Section 9.1.6.8.3).

9.1.6.8.1 Threshold of motion of vegetation

Vegetation such as a well maintained grass cover can increase the threshold of motion of sediment substantially. For grassed swales Ree (1949) documented permissible velocities of 1.2 to 3 m/s, equivalent to shear stresses of 80 to 200 N/m^2 (Reid cited in Prosser et al., 1995). Prosser and Slade (1994) found that shear stresses of 160 to 300 N/m^2 did not cause visible erosion under dense covers of grass and sedge, although after heavy disturbance, including the tearing of roots, they estimated a threshold of motion of 70 N/m^2. Similarly, Prosser et al. (1995) found that with almost complete grass cover only small amounts of sediment were transported at boundary shear stresses of 100 to 180 N/m^2. On fully clipped grass, much relatively loose sediment was not scoured by stresses of between 25 and 43 N/m^2. Prosser (1996) suggested that lightly degraded and undisturbed tussock and sedge had thresholds of motion exceeding 180 and 240 N/m^2 respectively.

The above thresholds are for flat surfaces, on the batter slopes at Seymour Quarry these would be reduced by approximately one-third (e.g., Buffington and Montgomery, 1997). Hence, the threshold of motion for grassed batters could potentially be as low as 20 N/m^2 in heavily disturbed areas and up to around 120 N/m^2 in lightly disturbed areas, all well below the maximum shear stresses imposed when floodwater spills into the quarry pits (Figure 36 to Figure 41 and Figure 49 to Figure 51).

Further, large areas of the batter face were not grassed and once rehabilitated the regeneration of overstorey is likely but the extent of grass cover is uncertain (Figure 56), as is the degree of disturbance from livestock. The regeneration of trees on batters also introduce local turbulent flow around obstructions that can also initiate knickpoints and subsequent avulsion development (Gibling et al., 1998; Tooth and Nanson, 1999).

When floodwater is spilling into the quarry pits the high shear stresses on the batters extend all the way to and for a distance below the ponded water level. At a depth below the ponded water level a hydraulic jump is initiated, the sudden transition in flow regime from supercritical to sub-critical flow that is associated with substantial turbulence, energy expenditure and the likely rapid erosion of floodplain sediments. Hence, when floodwater spills into the quarry there will be no grass cover below the ponded water level and the sediment of the pit batter will be directly subjected to the high shear stresses and the hydraulic jump. Thus the threshold of motion of sediment is critical to understanding the likelihood that the floodplain will erode.

9.1.6.8.2 Threshold of motion of floodplain sediment

The composition of the pit batter is described in the geotechnical investigation (Smith, 2011) as silty sand to depths of between 5.0 to 8.0 metres overlying sandy gravel to depths of between 10 and 25 metres.

The threshold of motion or shear resistance of non-cohesive materials such as gravels and sands can be estimated using the Shields Entrainment Function (Shields, 1936). Substantial further work has found the Shields Entrainment Function to be valid, with the spread of data shown by (Raudkivi, 1998, p. 33). The particle size analysis at the site (Smith, 2011, Appendix C) indicates that the floodplain is primarily non-cohesive sediments.

From the Shields entrainment function the critical shear stress (τ_c) can be expressed as a function of the Shields parameter or dimensionless critical shear stress (Θ_c, Equation 1).

$$\tau_c = \theta_c(s_s - 1)\rho g d$$

Equation 1

where: d is the diameter of the particle (m)

s_s is the specific gravity of the grains of sediment (2.65 for most sediments)

g is the acceleration due to gravity (m/s^2)

ρ is the density of water (kg/m^3)

Although the Shields Entrainment Function was developed based on uniform sediment, it can reasonably be applied to sediment with a range of grain sizes using the median (D50) size

(Lamb et al., 2008), approximately 0.25mm for the overburden material (Smith, 2011, Appendix C), a fine to medium sand (Chang, 1988, Table 4.1).

Figure 56 Rehabilitated pit batters at WA 781. Note the regeneration of trees and lack of grass cover.

The Shields parameter (θ_c, Equation 1) was developed based on the assumption that the surface subject to erosion is flat. However, the high shear stresses are on the batters shown on the work plan (1 V to 3.6 H). Note, batter slopes in the November 2013 aerial laser survey are in many areas steeper, up to 1 V to 1.2 H (exceeding the slope of 1 V to 1.7 H for operational faces in the work plan).

Although few studies address the influence of slope on the Shields parameter, studies examining a similar particle size (0.9mm) on bed slopes of 12 degrees and 18 degrees gave a Shields parameter of 0.031 and 0.027 respectively (Buffington and Montgomery, 1997, Table 1b). The pit batter slopes in the hydraulic model (1 V to 3.6 H) represent a slope angle of 15.5 degrees. A Shields parameter of 0.031 was adopted as the overburden is slightly finer than the sediment used for the results in Buffington and Montgomery, implying a slightly higher Shields parameter (Raudkivi, 1998). Hence for the silty sand to depths of between 5.0 to 8.0 metres, the shear stress at which there is general movement of the bed is (Equation 1):

$$\tau_c = 0.031(2.65 - 1)\ (1000)(9.81)(0.00025)$$

$$\tau_c = 0.1\ N/m^2$$

For the particle size distributions measured by Smith in the deeper and coarser sandy gravels, the largest median sediment size found in the floodplain was 10mm (Smith, 2011, Appendix C), a medium gravel (Chang, 1988, Table 4.1). As the threshold of motion is approximately proportional to the sediment size, these coarser sediment will have a higher critical shear stress, as shown below.

$$\tau_c = 0.031(2.65 - 1)\ (1000)(9.81)(0.01)$$

$$\tau_c = 5.0\ N/m^2$$

Note this calculation of the threshold shear stress to initiate erosion does not include a factor of safety to address the uncertainties in the hydraulic conditions imposed and the shear resistance of the floodplain.

The hydraulic conditions during floods at Seymour Quarry (e.g. Figure 36 through to Figure 41) indicate that flood flows into the pits will cause erosion as the imposed shear stresses (τ_0) are two to three orders of magnitude higher than the shear resistance of floodplain sediments (0.1-5 N/m^2).

9.1.6.8.3 Erosion of the floodplain in September 2010

In early September 2010 there was minor flooding around Seymour with the flow at Seymour gauge peaking at 680 m^3/s (9 year ARI) on 5th September 2010 (Figure 57). Aerial photography was flown across the floodplain of the Goulburn River, including Seymour Quarry, on the following day (Figure 58). This photography shows an erosion feature where the floodwater from the billabong set in the northern side of the southern pit spilled down the face of the pit.

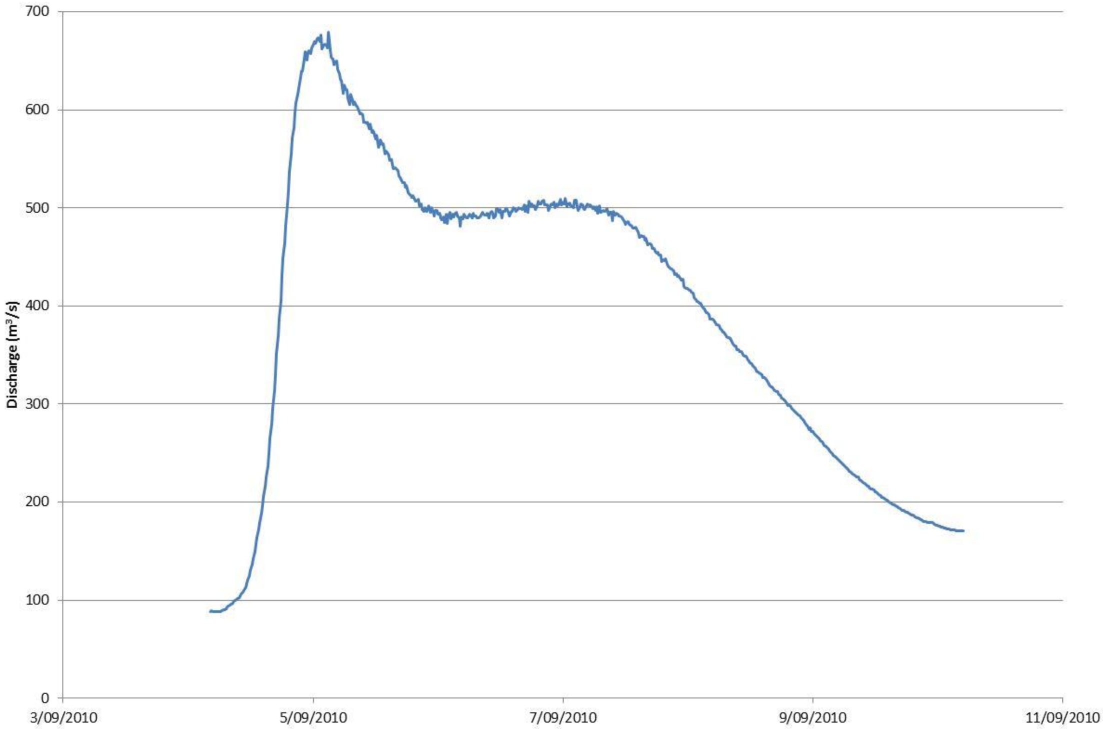


Figure 57 Flows at the Seymour gauge from the 4th to the 10th of September 2010.

Figure 58 **Aerial flood photography taken on the 6th September 2010.**

The erosion feature has been of sufficient concern for the quarry to construct a bank across the spill point from the palaeochannel. Fortunately, in this case, the flood has peaked at the approximate threshold for spilling floodwater into the pit (Table 5). Hence, not much flood water has spilled into the pit, evidenced by the sediment fan and other features still being visible in the base of the pit. Nonetheless the erosion feature is 147 metres long from the sediment fan to the constructed bank and has eroded 112 metres upstream of the top of batter of the pit.

9.1.6.9 Rate of erosion

Whilst it is not possible to accurately quantify the rate of erosion caused by flood flow through Seymour Quarry, bed load transport formulas give a quantitative indication of the extent of the issue. Equation 2, developed by DuBoys, relates bed load transport per unit width (q_b) to applied (τ_0) and excess shear stress (τ_0-τ_c) and is a form of bed load transport equation that has influenced the development of many other expressions (Chang, 1988).

$$q_b = C_d \tau_0 (\tau_0 - \tau_c)$$

Equation 2

where: C_d is the characteristic sediment coefficient (m³/kg/sec), a constant for a given sediment diameter.

It can be seen from DuBoys equation (Equation 2) that when the applied shear stresses greatly exceed the threshold of motion (τ_c), the rate of erosion is varying with the square of the applied shear stress and rapid erosion will result. Hence, reflecting the fine to medium sand and lack of cohesion (silt and clay) in the overburden (Smith, 2011), and hydraulic conditions where floodwater spills into Seymour Quarry, applied shear stresses are orders of magnitude higher than the threshold of motion and rapid erosion is predicted (e.g. Figure 36 to Figure 41 and Section 9.1.6.8.2). Such rapid erosion occurred as the Suncook River avulsed into a quarry at Epsom, New Hampshire. The new river channel was cut at the rate of 25-50 metres/hour (Perignon, 2008).

9.1.6.10 Propagation of the erosion

The high shear stresses generated by flood water spilling into the quarry pits will cause erosion (Section 9.1.6.8). The distribution of shear stresses on a slope in theory causes the erosion to reduce the gradient of the slope (self-battering) until the sediment transport discontinuity is too small to cause further erosion. However, self-battering assumes the eroding material has a consistent threshold of motion (Judd, 2005).

If the top or surface of the eroding feature has a higher threshold of motion than underlying material, then the underlying material will erode more rapidly, undermining and collapsing the resistant surface layer as it migrates, thereby maintaining a vertical erosion feature. This vertical feature maintains the sudden change in hydraulic conditions and hence the turbulence and sediment transport discontinuity required to continue the propagation of erosion upstream (Brush and Wolman, 1960; Gardner, 1983; Judd, 2005; Rich, 1938). This is commonly referred to as head cutting, knickpoint or headward erosion.

This self-perpetuating feedback between the erosive forces and the morphology caused by erosion is why Galay (1983, p. 1089) concluded that *"degradation can occur very rapidly, within one flood event, and can proceed for many kilometres up or down a river."* Similarly, a number of authors have noted rapid erosion migrating many kilometres in floods (e.g. Brizga, 1990; Mohrig et al., 2000; Qian, 1990). In particular, Erskine et al. (1993a) noted that on the Goulburn River at Acheron, on the mid-Goulburn like Seymour Quarry, over 5 kilometres of new river channel was cut in one flood.

The erosion initiated on the batters of Seymour Quarry will migrate upstream to intersect either the general floodplain with ground cover (e.g. grasses) or palaeochannels lined with cohesive sediments. Both ground cover and cohesive sediments have a higher threshold of motion than the underlying sediments (Prosser and Slade, 1994; Prosser et al., 1995; Raudkivi, 1998). Thus, erosion initiated on the batters of Seymour Quarry is likely to emanate from the pits as vertical knickpoints. These knickpoints will migrate through the floodplain or palaeochannel along the primary flow path, in many cases these flow paths reach the Goulburn River within 100-400 metres.

Once a connecting channel is cut between the Goulburn River and Seymour Quarry, bed load sediment transport will tend to cut this channel towards a bed gradient that represents dynamic equilibrium in this fluvial setting. A representative bed grade is that of the Goulburn River at Seymour, variable (e.g. 0.002-0.0005 m/m) and typically in the order of 0.001 m/m. Given the fluvial base level for a connecting channel is 110 metres AHD (base of the quarry pit) and the adjacent bed of the Goulburn River ranges between 130.22 and 124.6 metres AHD, the river bed is between 14.6 and 20.2 metres above the basement level of the quarry. The bed of connecting channels between the pit and Goulburn River would be approximately 200-500 metre long, accommodating 0.2 to 0.5 metres of height difference at a grade of 0.001 m/m. Hence there is the potential for up to 14-20 metres of deepening of the Goulburn River at Seymour Quarry.

The primary locations where long durations of high shear stresses indicate that connecting channels might form are along the palaeochannels on the western side of the southern pit or a direct channel across the 100 metre buffer to the Goulburn River (Figure 36 through to Figure 39).

The Goulburn River has an armoured bed (Erskine et al., 1993a) that has a higher threshold of motion than underlying sediments. Hence deepening of the Goulburn River at Seymour Quarry is likely to result in the migration of vertical knickpoint(s) up the Goulburn River. As conditions are favourable for the perpetuation of such knickpoints there is the potential for them to migrate kilometres upstream. More generally, Kondolf (Kondolf, 1997, p. 541) notes *"Mining-induced incision may propagate upstream for kilometers on the main river and up tributaries"*.

The degradation of the connecting channel between the quarry and river and the degradation of the Goulburn River will differ in one important respect. Once a channel is cut into the quarry, this diversion will initially carry less flow than the Goulburn River. At the diversion, flows along the river will in part continue downstream along the existing channel. Hence, although the connecting channel will erode rapidly whilst flood water is cascading into the pit, as bed load is transported at a rate dependent on stream discharge (Einstein, 1950), the quantum of flows in the Goulburn River (Figure 46) is also likely to propagate erosion rapidly up the river towards key infrastructure.

9.1.6.11 Avulsion

The above discussion of the propagation of erosion (Section 9.1.6.10) primarily focuses on the diversion of the Goulburn River into Seymour Quarry and not the full avulsion of the river away from its current course (Figure 14). The hydraulic modelling informs the likelihood of avulsion.

The flood behaviour at Seymour Quarry is somewhat unusual in that flows first enter the pit via water flowing "upstream" along Deep Creek, under Quarry Road, to cascade down the northern face of the pit (Figure 36). This behaviour is likely to be important as:

1. In the absence of the proposed Seymour levee, this is the spill point for flood flow at which highly erosive conditions persist for the longest time (Table 6).

2. Whereas the buffer distance between the Goulburn River and the southern pit is 100 metres, the fill that separates Deep Creek from the southern pit (Quarry Road) is only 30 metres wide. Hence, relative to the Goulburn River, less erosion is required along Deep Creek to connect a channel to the southern pit.

3. Whilst Deep Creek is considerably smaller than the Goulburn River it is nonetheless a substantial channel (Figure 59), approximately30 metres wide and 5.5 metres deep.

Compared to the other inflow points into the southern pit, a point of difference at the inflow point under Quarry Road is the presence of the 1.5 metre diameter pipe. However, this pipe is unlikely to stop headward erosion. For example, when the 20 metre deep pit at Yea Sand and Gravel (WA45) captured Island Creek in 2010, the road crossing approximately 180 metres upstream of the breach into the pit and constructed on a reinforced concrete base slab that was further protected by rock beaching (Figure 60), did not withstand the upstream migration of deepening (Figure 61). By comparison, the pipe at Quarry Road is not founded on a reinforced concrete slab and is much closer to what will be a deeper quarry pit than the pit at WA45.

Figure 59 Deep Creek in the reach immediately downstream (north) of the southern pit at Seymour Quarry.

Whilst upstream degradation and the cutting of a diversion into a pit is a rapid process, the formation of the channel downstream of the pit and hence a full avulsion, can be a process that takes a number of floods or does not happen at all (Section 8.2). However, the potential for a full avulsion of the Goulburn River through the quarry and into the township of Seymour (B+C, Figure 14) is real given:

1. There is already an avulsion channel downstream of the pit (Deep Creek);
2. Unusually, the channel downstream of the pit is subject to the rapidly migrating upstream degradation for a considerable time at the start of the flood (Table 6);
3. The avulsion course along Deep Creek is just half the length of the current course of the Goulburn River (Section 9.1.4.1); and
4. The current course of the Goulburn River may be perched or hung up on bedrock (Section 9.1.4.1).

Figure 60 The road crossing over Island Creek before 2010 flood and pit breach.

Figure 61 The road crossing in Figure 60 after pit capture.

9.1.6.12 Definition of likelihood

The qualitative terms and quantitative definitions of likelihood adopted for this study (Table 10) were developed from the likelihood ratings in the draft Extractive Industry Guidelines (DEDJTR, 2015), as shown in Table 9.

In Table 10 the likelihood *"rating"* and *"probability"* descriptions proposed by DEDJTR (Table 9) were adopted. As explained in the following discussion, the *"description of rating"* was also used in Table 10 but the project life was changed to design life to reflect the nature of the risks and assets at Seymour Quarry. Further, the *"historical"* descriptions (Table 9) were not used for the risks assessed herein.

Table 9 Likelihood Rating (DEDJTR, 2015, Appendix VII).

Rating	Description of rating	Probability	Historical
Almost certain	Very high probability of the consequences occurring during the project life	Has a > 90% chance of occurring after the implementation of standard control and /or additional control	Has occurred several times in the past year and in each of the previous 5 years in Victoria
Likely	High probability of the consequences occurring during the project life	Has a 70-90% chance of occurring after the implementation of standard control and /or additional control	Has occurred once or twice in the past year and in each of the previous 5 years in Victoria
Possible	Even probability of consequences occurring during the project life	Has a 30-70% chance of occurring after the implementation of standard control and /or additional control	Has occurred in the past 5 years in the industry, but not in Victoria
Unlikely	Low probability of occurrence during the project life but not negligible	Has a 5-30% chance of occurring after the implementation of standard control and /or additional control	Has occurred once or twice in the industry
Rare	Very low probability of the consequences occurring during the project life but not impossible	May occur in exceptional circumstances, i.e. less than 5% chance of occurring after the implementation of standard control and /or additional control	Unheard of in the industry and has not occurred in the past 5 years

Many of the risks associated with quarries are transient and cease or are easily mitigated at mine closure, for example noise, dust, traffic and contaminant spills (Kondolf, 1998). For these risks the probability can be calculated based on the 5 year period suggested in the *"historical"* descriptions or the project life suggested in the *"description of rating"* (Table 9). However, the risks to floodplain and river stability from Seymour Quarry are ongoing. If a risk is ongoing then it is certain to occur eventually.

To differentiate the likelihoods of ongoing risks, the probability can be calculated based on the intended design life of the asset at risk. A 100 year design life has been used for the probability calculations in Table 10 as this is standard for major civil infrastructure such as bridges (Section 10.1).

An example of adopting an appropriate time period for assessing the likelihood of ongoing risks is Piccolo and Mostyn (2011) using a 100 year time period to calculate the probability of a quarry posing risks to the assets of Sydney Water Corporation (reservoirs, major pipes and land). A 100 year time period is also considered a reasonable planning horizon for an avulsion of the Goulburn River, particularly into a feature of the scale of Seymour Quarry. The Mineral Resources (Sustainable Development) Act 1990 (MRSDA 1990), Section 79(b), requires the consideration of risks to the environment over the long term, stating *"A rehabilitation plan must take into account any potential long term degradation of the environment"*. These issues and the tolerable likelihood of failure for assets around Seymour Quarry are discussed in more detail in Sections 10.1 and 10.2.

Table 10 Definition of likelihood.

Likelihood Rating	Description of rating	Probability	Equivalent annual exceedance probability (AEP)	Equivalent average recurrence interval (ARI)
Almost certain	Very high probability of the consequences occurring during the design life	Has a > 90% chance of occurring after the implementation of standard control and /or additional control	>2.28%	<44 years
Likely	High probability of the consequences occurring during the design life	Has a 70-90% chance of occurring after the implementation of standard control and /or additional control	1.2% to 2.28%	84 to 44 years
Possible	Even probability of consequences occurring during the design life	Has a 30-70% chance of occurring after the implementation of standard control and /or additional control	0.36% to 1.2%	281 to 84 years
Unlikely	Low probability of occurrence during the design life but not negligible	Has a 5-30% chance of occurring after the implementation of standard control and /or additional control	0.05% to 0.36%	1950 to 281 years
Rare	Very low probability of the consequences occurring during the design life but not impossible	May occur in exceptional circumstances, i.e. less than 5% chance of occurring after the implementation of standard control and /or additional control	<0.05%	>1950 years

In relation to the *"historical"* descriptions in Table 9, for an episodic event such as a flood, historic pit stability over 5 years may just indicate a drought, not the likelihood of risks. Using historic data to establish the likelihood of instabilities at quarries under flood conditions would require the quarry to have been completed 50-100 years ago, depending on the average recurrence interval of the flood of interest. Empirical evidence for the likelihood of flood related risks at an operation on the scale of Seymour Quarry is not really available in the international literature (Section 9.1.2) let alone the local industry.

For the equivalent average recurrence intervals (ARIs) in Table 10, the probability (P) of at least one event in a given period of time is defined as (x100 for percentage):

$$P = 1 - (1 - \frac{1}{T})^n$$

Equation 3

where:

> n (years) is the design life of the asset at risk, the period of time for which the asset should be stable.
>
> T (years) is the average recurrence interval (ARI) of the event or the design return period.

Based on the definitions in Table 10, the likelihood that Seymour Quarry will impact on assets is discussed in Sections 9.1.6.13 and 9.1.6.14 and recorded in the risk register (Section 11, Table 22).

9.1.6.13 Likelihood of Seymour Quarry capturing the Goulburn River

The likelihood of the Goulburn River being captured by Seymour Quarry is informed by the hydraulic model and the 9 year ARI flow that initiates the spill of floodwater into the pit (Table 5). The 9 year ARI flood in September 2010 verifies that this flood approximates the onset and hence likelihood of substantial erosion of the pit wall (Section 9.1.6.8.3). What probably saved the pit from capture in September 2010 was that the flood only just reached the threshold for pit inflows and only attained this peak flow briefly (Figure 57).

A 20 year ARI flow is sufficient to cause widespread overtopping into the pit, the associated erosive conditions (Table 5 and Table 7) and hence approximates the threshold flow and probability at which pit capture will occur. Associating pit capture with floods as frequent as the 20 year ARI is consistent with Judd's (2005) finding that smaller floods are important to the initiation and propagation of avulsions. Likewise Erskine et al. (1993a) proposed that over 5 kilometres of new Goulburn River channel, the Acheron Breakaway, scoured in 1931, a less than 10 year ARI flow at Eildon (Jordan et al., 2015). Similarly on the King River a 12 year ARI flow (DELWP, 2012) scoured 340-2,100 metre long reaches of new channel (1,020 metres of channel on average) at six different sites in September 2010 (Loffler and Martin, 2011). Consistent with Section 9.1.4.2, the shorter lengths of avulsion channel scoured on the King River probably relate to the smaller catchment (453 km^2 or 5% of the Goulburn River at Seymour).

As 20 year ARI flows are well within the "almost certain" range in Table 10, this is considered the likelihood that there will be pit capture at Seymour Quarry. The probability of at least one 20 ARI flood in the next 20 years is 64% (approximately two chances in three) and 99% over 100 years, essentially certain (Equation 3).

9.1.6.14 Likelihood that capture of the Goulburn River will impact on other assets

Based on the analysis throughout Section 9.1.6, the likelihood that assets in addition to the Goulburn River (Section 8.3) will fail due to flood flow through the approved Seymour Quarry is identified in Table 22 for the two scenarios. Note, although the coincident failure of the northern and southern pits will increase the consequences of failure (Section 9.2), capture of the southern pit is considered sufficient for the likelihoods in Table 22.

Whilst the author has adopted the likelihoods in Table 22, for assets close to and upstream of the quarry (the Goulburn River railway bridges and the optic fibre interconnectors, Asset IDs 3, 4 and 5) the likelihood of failure may be higher (almost certain). This is dealt with in Section 10 by adopting a moderate confidence level.

Under Scenario 1 (operating quarry) (Section 9.1.6.6), the assets that are primarily only threatened by downstream progressing degradation (Asset ID No.s 8, 10, 11 and 12) have been given lower likelihoods of failure as the progression of this process is slower. Increased flooding associated with an avulsion of the Goulburn River may increase the likelihood of damage to these assets but this has not been assessed and may change in the future with the construction of the Seymour levee.

Under Scenario 2 (rehabilitated quarry) (Section 9.1.6.7), Seymour levee blocks Deep Creek and, for up to the 100 year ARI flood, would force floodwater around the assets in town. Hence, floodwaters do in some areas concentrate against the levee and it is therefore possible for downstream progressing degradation to undermine the levee. The assets in town are even less likely than the levee to be damaged by erosion as, if the levee fails, downstream degradation may not progress inside the levee. In lowering the likelihood of an avulsion, the Seymour levee also reduces the likelihood that the Department of Defence pumping station will lose water supply.

The scenarios investigated here are not comprehensive as, for example, the likelihood of failure of the Seymour levee (part of Scenario 2) will be higher whilst the northern pit is dewatered (part of Scenario 1).

9.1.6.15 The effect of the proposed expansion on the likelihood of pit capture

Under Scenario 1 the proposed expansion of the southern pit increases the duration of erosive conditions on the external batters by approximately 50% and increases shear stresses (Table 6 and Figure 42 to Figure 44). Table 6 also highlights that the area of high shear stresses increases due to the proposed expansion of the pit. Note:

- Increased shear stresses cause higher erosion rates (Equation 2);
- Longer durations of high shear stress cause a greater quantum of erosion; and
- The larger area of high shear stresses potentially causes a larger erosion feature and hence failure path to develop.

Under Scenario 2 the proposed expansion of the southern pit increases the duration of erosive conditions on the external batters by approximately 15% (Table 8).

Hence, even if the increase in the area and magnitude of erosive conditions is ignored, the proposed expansion of the southern pit results in an approximate 50% increase in the likelihood that erosion will be initiated and propagated from the batters of the southern pit under Scenario 1. Under Scenario 2, the increase in likelihood is approximately 15%.

In Scenario 1 the expansion of the southern pit reduces the duration of high shear stresses at the northern pit but increases shear stresses and the area eroded. In Scenario 2 conditions at the northern pit are largely unchanged by the expansion. Overall, the volume of water spilling into the northern pit, unchanged by the proposed expansion, can be taken as a proxy for the likelihood of erosion and capture.

There are hydrologic scenarios where a flood may not deliver enough volume to fill the approved pits. In these scenarios the approved and proposed pits probably have a similar likelihood of capturing the Goulburn River. The erosion episode in September 2010 (Figure 58), the hydraulic modelling and the potential long duration of floods on the Goulburn River suggest that such similar likelihoods may be restricted to Goulburn River floods with ARIs up to the 9 year event.

Other issues that influence the likelihood of pit capture include:

- The banks constructed around Seymour Quarry (Figure 11) will serve to concentrate the spill of floodwater into the pits and are thereby likely to increase the risk to infrastructure and the Goulburn River.
- At the two key flow paths directly from the Goulburn River to the southern side of the southern pit the proposed expansion doubles the depth of the pit (e.g. Figure 38), increasing the area of erosion and risks at these points.
- Lower (more likely) flood peaks that do not spill floodwater at all the locations as in the 100 year ARI flood, may be more detrimental to the stability of the approved or proposed pits as the same volume of water will enter the pits at fewer locations, concentrating the quantum of erosion.

9.1.6.16 Other issues influencing the likelihood of pit capture due to floodplain flow

Of critical importance to the primary issue dealt with here, erosion caused by hydraulic conditions, is the capacity of hydraulic models to describe these conditions. TUFLOW is only a two dimensional hydraulic model. That is it gives a depth-averaged velocity that in turn uses the log profile method to estimate bed shear stress (BMTWBM, 2010). The true basal shear stress is a good indicator of the erosive potential of flow but there are limitations in the method TUFLOW uses to estimate this (e.g., Rashid, 2010).

Another important issue is that most of the key erosive conditions identified in this study are associated with supercritical flow that then transitions to the subcritical pool of water in the quarry pit via a hydraulic jump. Hydraulic software such as TUFLOW does not deal with the impact of such behaviour on erosion processes, as highlighted in the following limitation specified by the software developers, *"In areas of super-critical flow through the 2D and 1D domains, the results should be treated with caution, particularly if they are in key areas of interest.*

Hydraulic jumps and surcharging against obstructions may occur in reality – these highly 3D localised effects are not modelled by software such as TUFLOW" (BMTWBM, 2010, p. 2-15).

Thus, whilst the hydraulic model can identify where erosion may develop it cannot assure that erosion will not occur in other areas. Hence the likelihood of failure also needs to be considered in the context of the literature and what has happened at other quarries (Sections 9.1.1, 9.1.2, 9.1.3, 9.1.4 and 9.1.5). The literature indicates there is a high likelihood of pit capture due to flood flow through Seymour Quarry.

It is noted that both of the geotechnical investigations conclude *"At times of river flooding and if overflow should occur on the southern bank and over any banks in the southern half of the quarry, rapid erosion of the banks will occur, representing a high risk of breaching."* (Slade, 2014, p. 10; Smith, 2011, p. 25). The author considers this a reasonable conclusion in relation to risk. However, floodwater entering the pit from any direction represents a risk as that floodwater is spilling from the Goulburn River and can therefore precipitate a river diversion.

Smith (2011, p. 25) and Slade (2014, pp. 9–10) also noted, without reference to a flood study, *"It is understood that previous studies have indicated that any flood waters will only enter the quarry on the northern (away from the river) part of the quarry"*. The WBM Oceanics study (Walden et al., 2001), that is cited extensively in the Seymour Quarry Work Plan (Prowse and Castle, 2012) and was available to Smith and Slade, shows flood water entering the pit from the eastern, western and southern sides. The hydraulic modelling detailed herein indicates that flood water enters the southern pit on the eastern, western, southern and northern sides. Although aware that flood flow posed a *"high risk"* to the stability of the pits, Smith (2011) and Slade (2014) did not adequately research their opinion on the flood behaviour around Seymour Quarry.

9.1.7 Assessment of the likelihood of pit capture due to lateral migration

To gauge the likelihood that bank erosion (lateral migration) of the Goulburn River will capture the Seymour Quarry, the historic rate of bank erosion was estimated. The contemporary location of the banks of the Goulburn River was determined from the November 2013 aerial laser survey (ALS) and is shown in Figure 62. The historic location of the banks was determined by georeferencing the survey by T.W. Pinniger (Victoria Surveyor General's Office, 1855) into ArcGIS (Figure 62). The georeferencing was checked by comparing the contemporary lot boundaries that had been surveyed in 1855 and checking that relatively straight sections of river were aligned.

Where the comparison of the 1855 and 2013 surveys indicates the banks have eroded by more than 20 metres the area is shaded in Figure 62 and labelled with the maximum migration distance. Consistent with the laterally migrating nature of the Goulburn River, banks are migrating at all the river bends around Seymour Quarry. Note, downstream of the quarry, on the left or western side of Figure 62, the Goulburn River has straightened via a meander cut-off.

Overall the comparison of the surveys indicates that at the short radius (tighter) bends the banks have eroded 60-110 metres whereas the longer radius bends have eroded 25-50 metres. Hence over the 158 years that separate the two surveys this equates to average bank migration rates in the order of 0.4-0.7 metres/year at short radius bends and 0.2-0.3 metres/year at longer radius bends. These migration rates accord with those reported by Wilson et al. (2005)

for the 40 kilometre reach of the middle Goulburn River between Eildon and Molesworth but are less than half the median erosion rate of 1.6% of channel width per year (1.5 metres/year on the Goulburn River at Seymour) reported from data on 100 rivers (Abernethy and Rutherfurd, 1999).

In areas where the surveys indicate that the floodplain has accreted rather than eroded, in particular to the south of the meander cut-off and to the north and east of the meander bend upstream of the quarry, the aerial laser survey shows the remnants of the features surveyed by Pinniger and provides verification of these changes in river planform.

Unlike floodplain accretion, bank erosion is a destructive process and hence harder to verify. However, the locations of the bank erosion in Figure 62 correspond with the expected translation (migration downstream) and extension (migration transverse to the meander belt) of meanders. At the first bend upstream (east) of the quarry the convex (inside) bank is eroding. This response occurs where the adjacent concave bank is relatively resistant to erosion and on this bend the surveys show a relatively stable concave bank. Some confidence can also be drawn from the association of higher rates of bank erosion with a lower bend radius of curvature around Seymour Quarry, a relationship that is consistent with the literature (Nanson and Hickin, 1986).

Figure 62 Extract of the survey by T. W. Pinniger (Victoria Surveyor General's Office, 1855) overlayed with the top of bank from the November 2013 aerial laser survey (ALS). Areas where the surveys indicate more than 20 metres of bank erosion are shaded and labelled with the maximum distance the bank has migrated.

Based on the average historic rates of erosion, the Goulburn River will migrate through the 100 metre setback to Seymour Quarry in around 300 years. Prior to the erosion of the whole of the setback, the reduced width of the riparian zone will impact the health and stability of the Goulburn River.

Based on the definitions in Table 10, failure of the southern pit due to lateral migration of the river is considered to have a rare likelihood. As this risk assessment is not hazard/event centric but is focused on the risks to assets (Section 7.1.2), and the likelihood of pit capture due to floodplain flow is higher than rare (Section 9.1.6.13), the hazard of lateral migration does not need further consideration in the risk assessment process. However, lateral migration may increase the likelihood that other hazards will cause pit capture (Section 9.1.8.1).

9.1.8 Assessment of the likelihood of pit capture due to geotechnical instability.

The author is not an expert in geotechnical engineering or hydrogeology and so this evidence is limited to providing context on how the requirements for geotechnical stability (Slade, 2014; Smith, 2011) may be impacted by lateral migration and flood flows and examining the extent of non-compliance to the work plan. The author is unable to advise of the likelihood of capture of the Goulburn River due to geotechnical instabilities.

9.1.8.1 Lateral migration of the Goulburn River

The geotechnical investigation specifically excludes consideration of the stability of the Goulburn River banks (Smith, 2011, Section 3). As stable banks is generally not a valid assumption on a laterally migrating river (e.g. Section 9.1.7) the setback recommended for geotechnical stability needs to be added to the setback required for the lateral migration of river banks.

The setback between the southern pit and the river for lateral migration can in part be based on historic erosion rates. However, the historic average rate of bank erosion (Section 9.1.7) should not be used as a basis as it would effectively amount to designing the pit to fail. Further:

- Bank erosion can be highly episodic. A large proportion of the lateral migration recorded over a period of time can occur in a single flood or sequence of floods.
- The composition of the floodplain is variable. Hence, erosion on what has been a relatively stable bank may accelerate as more erodible sediments are intersected.
- The geometry of a meander bend changes as it erodes and this will change the hydraulic conditions. Factors such as the decreasing radius of bend curvature may progressively increase rates of bank erosion (Nanson and Hickin, 1986).

Given the potential consequences associated with the northern bank of the Goulburn River collapsing into a pit of the depth proposed at Seymour Quarry (Section 9.2) a conservative assumption should be made regarding rates of bank migration and the erosion that can be associated with a single or sequences of floods. The risks warrant further analysis of the temporal and spatial variability of channel migration on this reach and influences on bend migration rate such as radius of curvature, bank height, channel width and stream power (Nanson and Hickin, 1986).

9.1.8.2 Flood and river flows

Flood flows around the southern pit first begin to pond in the series of palaeochannels along western boundary of WA1189 (Figure 27), variable features 40 to 75 metres wide and up to 4-4.5 metres deep. In floods with an ARI of 9 years or more these depressions will hold floodwater from the Goulburn River, potentially for days at a time. The Working Plan submitted for the variation to the Seymour Quarry (C. K. Prowse & Associates Pty Ltd, Drawing Number R118-B1-5) shows that the quarry shall extend to the tree line along these waterways. The author's spatial analysis indicates that the north-western edge of the southern pit will extend to the invert of one of these palaeochannels (Figure 8).

It is worth noting that at the next floodplain quarry upstream, Yea Sand and Gravel (WA45), the extraction pit was also extended to the tree line along an anabranch and similar palaeochannels of the Goulburn River. After extraction along these depressions there were geotechnical failures along the pit wall the first year the depressions flowed. Overall, the requirement for pits to have a setback from the Goulburn River for geotechnical stability (Slade, 2014; Smith, 2011) appears inconsistent with no requirement for a setback along the western depressions.

The seepage and geotechnical stability analysis, undertaken on the cross-section of boreholes 1 to 7, appears to have used the groundwater levels measured in the boreholes (Smith, 2011). The groundwater levels measured in borehole 7 are 5.7-5.8 metres below the elevation of the top of bank of the Goulburn River (138.1 metres AHD). Borehole 7 is 16 metres north of the top of bank of the Goulburn River. The author questions whether the design case for slope stability should just adopt observed groundwater levels or should consider the potential influence of sustained river flows or minor flooding on groundwater levels and slope stability.

As an example, Figure 63 shows the flows at Seymour in September and October 1993 and the river flow of 280 m^3/s required to reach bankfull at borehole 7. Figure 63 shows a period of 18 days where water levels in the Goulburn River are essentially at or above top of bank and a period of six weeks where flows exceed top of bank 71% of the time. Given the high sand and gravel content in the floodplain (Smith, 2011), it does not seem credible that groundwater levels at borehole 7, only 16 metres from the Goulburn River, could remain 5.7-5.8 metres below top of bank level in such flow events.

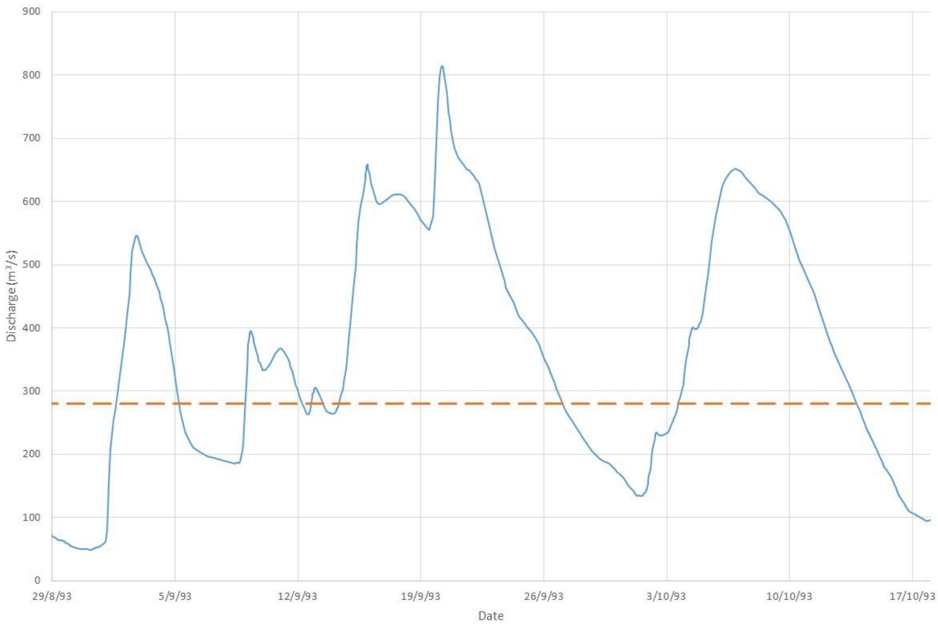


Figure 63 Flow rates at the Seymour Gauge through early spring 1993.

Overall it appears the exclusion of *"extreme flood events"* from the geotechnical analysis (Smith, 2011, Section 3) needs to be generalised to exclude all flood events and any in-channel flows above low flow conditions. The further geotechnical assessment (Slade, 2014) appears to use lower groundwater levels than Smith (2011) but the author was unable to confirm the exact location of this analysis.

9.1.8.3 Compliance to the geotechnical design and work plan

An issue of concern is that the geotechnical investigation highlights that the southern face of the pit is heavily surcharged by stockpiles and that banks of fill need to be setback a minimum of 20 metres from the pit wall for the reasons of slope stability (Smith, 2011). However, the November 2013 aerial laser survey still shows substantial areas of fill with a batter slope contiguous with the wall of the pit (Figure 11). The further geotechnical assessment again highlights that fill is surcharging the wall of the pit (Slade, 2014). Additionally, the extent of these stockpiles does not comply with the requirements for flood flow specified in the work plan (Prowse and Castle, 2012, Section 7.1).

The geotechnical design of the southern wall of the southern pit also appears to have been based on a pit batter slope of 1V:3.6H (Smith, 2011). The further geotechnical assessment notes a very steep slope (1V:1.4H) on the lower part of the southern batter and that the pit wall is marginally unstable (Slade, 2014). This slope found by Slade greatly exceeds the design slope for the southern wall and exceeds the slope specified in the work plan (1V:1.7H) for any working face batter in the pit (Prowse and Castle, 2012, Section 7.4).

To examine working batter slopes in the southern pit more generally, the November 2013 aerial laser survey was processed into slopes using the 3D Analyst extension to ArcGIS 10.2 (Figure 64). Figure 64 shows large areas of batter slope exceed the 1V:1.7H working batter slope specified in the work plan (areas shaded red and maroon in Figure 64). The exceedance of the working batter slope is not marginal with faces commonly up to 1V:1.2H.

Thus, whilst Slade is clearly raising the concern regarding the slope of the southern face substantially exceeding the design parameters, slopes of 1V:1.2H match or exceed the adopted effective shear angle of material (Smith, 2011, Table 12-1) and are a probable explanation for why local sections of the batter, such as parts of the east and west batters along the deep eastern section of the pit, have retreated beyond the approved pit extent (Section 7.2.3 and Figure 9).

Overall, it appears that Seymour Quarry has not been operated in accordance with key aspects of the geotechnical design and work plan, thereby increasing the likelihood of pit failure.

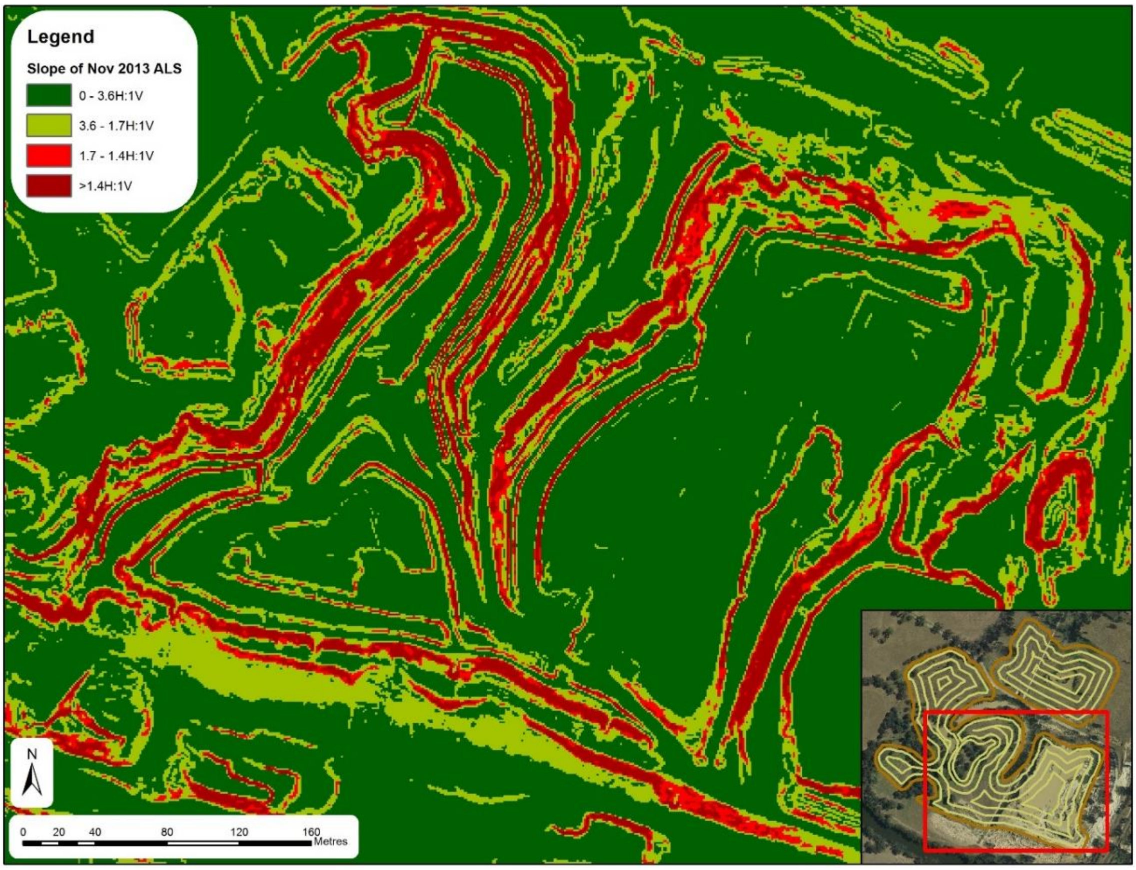


Figure 64 The November 2013 aerial laser survey classified by slope.

9.2 Consequences

9.2.1 Description of the levels of consequence

The levels of consequence for public safety, infrastructure and the landscape/environment are described in Table 11. These consequence levels have been adopted from the guidance provided for the industry (DEDJTR, 2015, Appendix VI). DEDJTR states that the examples of consequences provided in Table 11 that are not exhaustive.

Based on Table 11 and the discussion in Sections 9.2.2 and 9.2.3, consequence ratings were adopted for each of the assets listed in Section 8.3 and recorded in the risk register (Section 11, Table 22). For most assets the consequences are similar whether the Goulburn River is diverted into the quarry, avulses through it or forms a cut-off (Figure 14). Where the consequences vary substantially with the nature of pit capture this has been highlighted.

Table 11 Description of the consequence ratings (DEDJTR, 2015, Appendix VI).

Consequence Rating	Public safety	Community Facilities – include property and infrastructure	Land and environment
Critical	• One or more fatalities or life threatening injuries or illness • Public exposed to a severe, adverse long-term health impact or life-threatening hazard	• Services suspended for an extended (years) period of time • >100,000 people being unable to access the service or experiencing disrupted access to the service	• Irreversible widespread damage to: – Listed species (Biodiversity) – Groundwater Dependent Ecosystems – Groundwater and surface water quality • Significant contribution to multiple environmental pollution events
Major	• One or more injuries or illness requiring surgery or resulting in permanent disablement • Public exposed to a hazard that results in surgery or permanent disablement • Hospitalisation for extensive treatment from injury or illness –> 4 weeks	• Services suspended for a major (months) period of time • 50,000 – 100,000 people being unable to access the service or experiencing disrupted access to the service	• Extensive, reversible and long term (remediation lasts longer than 3 years) or irreversible and localised damage: – Listed species (Biodiversity) – Groundwater Dependent Ecosystems – Groundwater and surface water quality
Moderate	• One or more injuries or illness requiring treatment by a physician or hospitalisation • Public exposed to a hazard that could cause injuries or health effects requiring treatment by a physician or hospitalisation • Hospitalisation (e.g. for observation) for injury or illness < 4 weeks	• Services suspended for a moderate (weeks) period of time • 1,000 – 50,000 people being unable to access the service or experiencing disrupted access to the service	• Localised, extended (remediation lasts < 3 years) and reversible damage: – Listed species (Biodiversity) – Groundwater Dependent Ecosystems – Groundwater and surface water quality
Minor	• One or more injuries or illness requiring treatment by a qualified first aid person • Public exposed to a hazard that could cause injuries or adverse health effects requiring treatment by a qualified first aid person • Medical treatment required for injury or illness (but not resulting in hospitalisation) – not a Lost Time Injury	• Services suspended for a minor (days) period of time • 100 – 1,000 people being unable to access the service or experiencing disrupted access to the service	• Localised, temporary (remediation lasts < 1 year) and reversible damage: – Listed species (Biodiversity) – Groundwater Dependent Ecosystems – Groundwater and surface water quality
Insignificant	• An injury or ailment that does not require medical treatment by a physician or a qualified first aid person (e.g. minor bruises, cuts, abrasions, etc. involving only local first aid)	• Services suspended for a negligible (hours) period of time • <100 people being unable to access the service or experiencing disrupted access to the service	• Superficial, short term damage with cosmetic remediation required for impacts on: – Listed species (Biodiversity) – Groundwater Dependent Ecosystems – Groundwater and surface water quality

9.2.2 Consequences for the Goulburn River

The consequences of damaging the landscape and environment of the Goulburn River are informed by an understanding of the values of the Goulburn River.

9.2.2.1 Values of the Goulburn River

The Goulburn River is the largest river in Victoria with the largest annual flow, contributing 13.7% of stream flows from the state (Goulburn Broken CMA, 2013). It is also one of the largest tributaries of the Murray River, providing 11% of the stream flow for the Murray Darling Basin.

The Goulburn River supports irrigated agriculture and horticulture that generates 20% of the total value of Victoria's agricultural production. Food processing in the catchment accounts for 25% of rural economic output (MDBA, 2013). The water of the Goulburn River is also an important supply for human consumption, including many towns across central and northern Victoria and the regional cities of Shepparton-Mooroopna, Bendigo and Ballarat. There is also a supply offtake from the Goulburn River to Melbourne but this is located at Killingworth, substantially upstream of Seymour.

The Goulburn River is a Heritage River (Heritage Rivers Act, 1992), including the reach through Seymour. This status recognises a range of high environmental, social and economic values along the Goulburn River, including:

- Intact understorey in River Red gum open forest/woodland, and yellow and grey box woodland/open forest communities.
- Wetlands of state significance.
- Significant habitat for vulnerable or threatened wildlife including Macquarie perch, Squirrel gliders, Large footed myotis, Barking march frogs, Barking owls and Brush-tailed phascogales.
- A wide range of recreational activities, including fishing, canoeing and camping.
- Scenic landscapes – with particular mention of the reach from Seymour to Molesworth.
- Cultural heritage sites.

Due to the significance of flows from the Goulburn to the Murray-Darling Basin, the river and its operation downstream of Lake Eildon is considered important to the implementation of the Murray-Darling Basin Plan.

9.2.2.2 Quantum of channel change

If Seymour Quarry captures the Goulburn River there is likely to be bed incision upstream and downstream of the pit giving rise to bank erosion and collapse. Some of the consequences of quarry pit capture are highlighted in the following passage. *"After avulsion has occurred, the temporary fluvial base is the pit bottom. Therefore, for a considerable distance upstream, the river channel tends to incise and straighten as it works to establish a new equilibrium and grade. Because of this, existing channels…may be abandoned and replaced by a deep channel as wide as the pit. Sediment eventually fills the pit, and a new stream channel is formed. While the breached* *pit is filling with gravel from up-stream sources, little gravel will be transported past the pit to downstream areas. The downstream channel and bars consequently will erode if they are not replenished with course bed material"* Norman et al. (1998, pp. 9–10). Further, *"Unless sediment removed from the upstream channel during headcut migration is replaced, and the pre-flood channel conditions are restored, the headcut will continue to deepen and extend upstream during subsequent floods. In effect, the bottom of the excavation will become the stream's new base level to which the upstream reaches will adjust."* (JE Fuller/Hydrology and Geomorphology Inc., 2004, pp. 6-10 to 6-11). "Hence, Norman et al. and JE Fuller/Hydrology and Geomorphology Inc. imply that an avulsion into Seymour Quarry may:

- Cause the Goulburn River to deepen by 14 to 20 metres at Seymour Quarry, giving a total river depth of 25-30 metres, in accordance with the streams new base level being the bottom of the excavation (JE Fuller/Hydrology and Geomorphology Inc., 2004; Norman et al., 1998), and the extrapolation of a stable grade from this base level (Section 9.1.6.10); and
- Cause the Goulburn River to widen by 260 metres to the 360 metre width of the proposed southern pit at the upstream (eastern) end.

Under natural conditions, where an avulsion scours through billabongs (palaeochannels), the new river channel also tends to be deeper and wider than the parent river channel (i.e. the Goulburn River). The difference between the parent and avulsion channels generally varies from site to site, illustrated in the following two examples in North East Victoria:

- At Acheron on the mid-Goulburn River the avulsion channel is approximately 170% of the width and 150% of the depth of the abandoned (parent) channel (estimated from the 2010 aerial laser survey, Water Technology and URS (2008) and SR&WSC (1935)).
- At Everton on the Ovens River there is an avulsion currently developing along Deep Creek. The lower half of Deep Creek is 235% of the width of the adjoining Ovens River and 135% of the depth (Judd, 2005).

These changes to channel width and depth caused by avulsions can be applied to the dimensions of the Goulburn River at Seymour to give some indication of the potential size of an avulsion channel under natural conditions. The Goulburn River adjacent the Seymour Quarry has an average width at top of bank of 95 metres and depth of 10.5 metres (November 2013 aerial laser survey and Section 7.2.1). Thus, subject to substantial uncertainty, an avulsion channel through the natural floodplain depressions at Seymour may scour a channel some 15 metres deep and 200 metres wide, around 5 metres deeper and 100 metres wider than the current Goulburn River.

Clearly the pits at Seymour Quarry are nothing like natural depressions (Figure 19) and hence the scale of deepening and widening caused by a diversion and/or avulsion into such pits is likely to be considerably larger. Overall, it is not possible to accurately predict the response of the Goulburn River once captured by Seymour Quarry. However, it is likely the degree of channel change will be greater in the vicinity of the pit and reduce with distance upstream and downstream.

For the sake of adopting a predicted channel size for the Goulburn River after capture by Seymour Quarry, 10 metres of deepening and 150 metres of widening is considered a potential outcome in the vicinity of Seymour Quarry. These changes exceed those that might be caused by a natural avulsion but are substantially less than the 14 to 20 metres of deepening and 260 metres of widening that may occur based on the literature (JE Fuller/Hydrology and Geomorphology Inc., 2004; Norman et al., 1998). The author predicts a predominance of widening over deepening as banks destabilised by deepening will be susceptible to erosion by other fluvial processes, increasing the width-to-depth ratio of the Goulburn River. The above examples of natural avulsions also illustrate the predominance of widening over deepening.

Note that five cross sections of the Goulburn River through Seymour (SR&WSC, 1980a) were re-surveyed by WBM Oceanics (Figure 4) and showed one cross-section largely unchanged, two shallower (by 1.5 and 2.7 metres) and two deeper (by 3.0 and 3.3 metres), the 3.3 metres of deepening was measured at the cross-section just downstream of the railway bridges. The largest flood between these surveys, the 13 year ARI event in September 1993, was likely sufficient to mobilise and redistribute the bed material of the Goulburn River (e.g. Haschenburger and Wilcock, 2003). This degree of bed change demonstrates that the fluvial setting of the Seymour Quarry is dynamic with seemingly minor variations in hydraulic conditions along the river channel causing significant change.

Overall, the literature indicates that the larger and deeper the captured pit, the greater the potential river change (Mossa and Marks, 2011; Norman et al., 1998). Hence the expansion of the southern pit proposed in the work plan variation will increase the consequences for the Goulburn River and adjoining property and infrastructure.

9.2.2.3 Quantum of erosion

An understanding of the consequences of pit capture for the Goulburn River requires consideration of both the local processes in the Goulburn River and the literature. Examining the sediment transport regime of the Goulburn River, Erskine et al. (1993a, p. 66) found *"all of the incoming sand and gravel are trapped in large dams like Eildon Reservoir"*. They quantified the sediment trap efficiency of Eildon as 98.5-99.5%. Examining sediment transport further downstream, including at Seymour, Erskine et al. (1996, 1993a) found that very little if any bed load is being transported. Erskine et al. (1996) concluded that the sediment replenishment rate for the mid-Goulburn River is too small to allow commercial extraction.

Hence, if the Goulburn River avulses into the Seymour Quarry there is little incoming bed load sediment supply to refill the pit and stabilise the river. Collins (1995) found that once a river avulses into a mining pit, the river will continue to be destabilised until the pit refills with bed sediment. This suggests that the Goulburn River will continue to deepen and widen upstream of the pit until locally sourced bed load sediments (sands and gravels) have largely refilled the pit.

The scale of erosion of the local landscape required to refill the proposed pits can be appreciated by comparing the proposed volumes of the southern and northern pits (6,896,000 m^3, Table 1) to the cross sectional area of the Goulburn River, approximately 700 m^2. That is, as an example, the cross-sectional area of the Goulburn River would need to double over a length of approximately 10 kilometres to refill the pits.

Further, although Seymour Quarry will not initiate anymore erosion once it has been refilled with sediment, the knickpoints that are initiated will not stop eroding because the pit has refilled. Hence, Seymour Quarry is capable of generating substantially more erosion than the quantum of sediment extracted.

9.2.2.4 Other changes to the Goulburn River

The time frame of recovery for the river increases with the size of the extraction pit(s) captured (Collins, 1995; Netsch et al., 1981; Norman et al., 1998). *"Wherever a channel shifts into a gravel pit or multiple pits that are large relative to the scale of the floodplain and the rivers sediment transport regime, natural recovery of original floodplain environment and similar channel morphology could take millennia"* (Collins 1997 cited in Norman et al., 1998).

The avulsion, diversion or cut-off of a river into a quarry sets off a range of associated impacts summarised by Norman et al. (1998, p. 5) as:

- *"lowering the river bed upstream and downstream of mining operations, causing river bed erosion and (or) channel incision and bank erosion and collapse,*
- *eroding of footings for bridges or utility rights-of-way,*
- *changing aquatic habitat,*
- *unnaturally simplifying the complex natural stream system,*
- *increasing suspended sediment, and*
- *abandoning reaches of spawning gravels or damaging these gravels by channel erosion or deposition of silts in spawning and rearing reaches."*

Similarly, in describing the impacts of pit capture Collins (1995) finds that river deepening and the bank collapse it causes will result in a deep, wide channel, considerable loss of riparian vegetation, substantial degradation of in-stream and riparian habitat and poor water quality. The continuum of bank collapse and the associated loss of remnant trees along Island Creek (Figure 61) provides a small scale example of the impact of capturing the Goulburn River at Seymour Quarry.

The author notes that floodplain mining pits can be designed and rehabilitated to leave a features that compliment floodplain and river habitat (Norman et al., 1998). However, this applies to operations similar in scale to the natural features/channels, a description that does not fit Seymour Quarry. For example, thermal, oxygen, salt and density stratification tends to occur at deep dredge holes (deeper than 5-6 metres), greatly reducing the aquatic habitat available (Turner and Erskine, 2005).

9.2.3 Consequences for infrastructure

The scale of potential channel changes along the Goulburn River (Sections 9.2.2.2 and 9.2.2.3) are unlikely to be compatible with rigid infrastructure such as bridges. Norman et al. (1998, p. 9) highlights the consequences for infrastructure of an avulsion into a quarry, stating *"Hazardous consequences of this kind of erosion can be undercutting of levees, bridge supports, pipelines, and utility towers and other structures"*.

As Seymour Quarry is located near infrastructure and the town of Seymour there are potential consequences for infrastructure.

9.2.3.1 Rail corridor

A diversion or avulsion due to floodplain flow through the Seymour Quarry would be initiated in the form of headward erosion migrating upstream towards the source of flow, the Goulburn River and the bridges on the Melbourne-Sydney rail corridor. The consequences of this avulsion will, in part, be explained by the size of the avulsion channel that is scoured upstream. In Section 9.2.2.2 a total of 10 metres of deepening and 150 metres of widening was discussed as a possible outcome in the vicinity of Seymour Quarry.

There are two parallel railway bridges across the Goulburn River at Seymour (Figure 16). The construction drawing for the upstream (eastern) railway bridge over the Goulburn River (Figure 65) has four concrete bridge piers in the channel of the Goulburn River. The tops of the timber piles supporting these concrete piers are between 4 and 8 feet (1.2-2.4 metres) below the bed of the Goulburn River (recessed 1 foot into the base of the pier). The 20 timber piles supporting each of these four concrete piers are 30 feet (9.1 metres) long. Thus, if 10 metres of deepening were to occur at the railway bridges, shown as the orange dashed line in Figure 65, the deepest timber piles on five of the bridge piers would only be embedded to a depth of 0.5-1.5 metres and likely collapse, the other 13 concrete bridge piers would have no foundations and collapse.

If the deepening and widening of the river at the rail corridor was only what a natural avulsion might cause (Section 9.2.2.2), the orange dot-dash line in Figure 65, then around six piers would have no foundations resulting in the collapse of at least eight spans of the bridge.

Although the author obtained the drawing of the superstructure for the downstream (western) railway bridge for the purposes of hydraulic modelling, this did not include the depths of the foundations. However, the total length of both the main railway bridges over the Goulburn River is only 165 metres and hence, on this basis alone, neither is likely to withstand the significant river deepening and particularly the widening that Seymour Quarry has the potential to cause (Section 9.2.2.2).

The bridges on the northern floodplain are just 65 metres long and hence the consequences of channel development are greater relative to the bridges over the Goulburn River. Further, based on the pile driving record for the upstream (eastern) bridge (Vic Rail, 1941a), the piers are founded at a high elevation, just below floodplain level and similar to the floodplain piers at either end of the Goulburn River bridge (Figure 65).

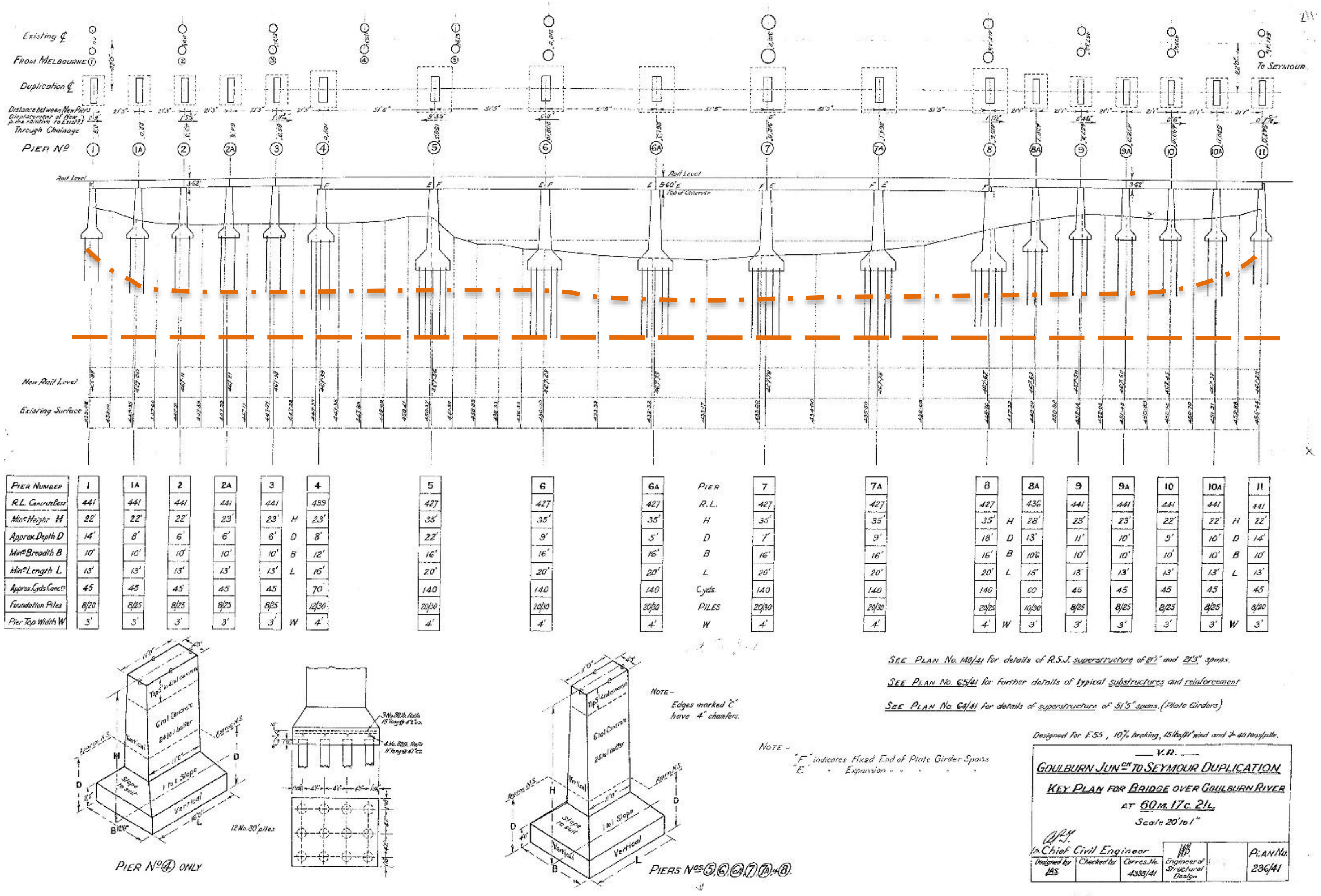


Figure 65 **Victorian Railways drawing of the upstream (eastern) bridge over the Goulburn River (Vic Rail, 1941b).**

The extreme consequences described here are consistent with literature such as Mossa and Marks (2011) describing 10-15 metre deep floodplain pits causing degradation that exceeded 6 metres on the Tangipahoa River and the subsequent collapse of the bridge on State Highway 10 near Arcola. Harvey and Smith (1998) found that instream and floodplain sand and gravel mining led to the capture of floodplain pits in subsequent floods and an average of 3 metres (a maximum of 4.6 metres) of deepening over a 7.5 kilometre reach of the San Benito River, California. *"Channel degradation and degradation-induced channel widening have resulted in the loss of one bridge and severe damage to two others in the reach. The City of Hollister's water and sewer lines have had to be replaced and the Hollister Conduit is threatened by further degradation"* (Harvey and Smith, 1998, pp. 308–309). The causal link between gravel mining and bridge failures even drew the attention of the US federal government when *"In 1995, the US Department of Transportation issued a notice to state transportation agencies indicating that federal funds will no longer be available to repair bridges damaged by gravel mining"* (Kondolf, 1997, p. 545).

The potential for sudden bridge failures and the threat to life associated with the processes discussed herein is illustrated by the March 2001 collapse of the steel and concrete Hintze Ribeiro Bridge on the Douro River, Portugal. The collapse killed 59 people, including those in a bus and three cars driving across the bridge. The collapse was caused by streambed scouring due to in-stream sand extraction which compromised the stability of the bridge's pillars (Figueiredo et al., 2013).

The ongoing destabilisation of the Goulburn River that would result from capturing the Seymour Quarry (Section 9.2.2.4) would have serious implications for the reinstatement of infrastructure. Even the ongoing disturbance at the essentially natural avulsion of the Goulburn River at Acheron caused the original 4 span bridge over the breakaway to be lengthened to 9 spans with The Age reporting that further allocations of funding were also required for ongoing erosion works several years after the avulsion (The Age, 1934). Based on the loss of one bridge and severe damage to two others due to instream and floodplain sand and gravel mining, Harvey and Smith found that *"Channel degradation has significantly increased the cost of bridge replacement by increasing piling depths, construction time and complexity and by requiring temporary dewatering during construction. Degradation-induced channel widening has necessitated a wider bridge span"* (Harvey and Smith, 1998, p. 307).

9.2.3.2 Dwellings, other buildings and roads in Seymour

In the event of an avulsion of the Goulburn River through Seymour Quarry, the development of a new river course downstream of the pit will tend to focus on the depressions that carry the most flow and offer the shortest (highest energy gradient) course for the river. The hydraulic analysis suggests that this course is likely to be Deep Creek (Section 9.1.6.11). Once the Seymour levee is completed the shortest course is along the base of the levee.

The avulsion of the Goulburn River into Deep Creek is likely to initiate enlargement of the waterway (Section 9.2.2.2), threatening the homes and businesses in Seymour in close proximity to the waterway. This developing avulsion channel will cross Emily Street and other streets in Seymour. The change in watercourse morphology associated with the avulsion is likely to require new structures across these streets.

Seymour Caravan Park is located on the floodplain at the downstream end of a concave bank of the Goulburn River, a location relative to the planform of the Goulburn River that is most likely to be threatened by lateral migration. The caravan park is also 900 metres upstream of the quarry along the current course of the Goulburn River. Assets at the caravan park are as close as 20-30 metres from the top of bank of the Goulburn River. The disturbance caused by an avulsion may set off deepening, widening and lateral migration that threatens assets in the caravan park.

9.2.3.3 The proposed Seymour levee

After pit capture, downstream progressing degradation (channel development) along the base of the levee has the potential to cause unexpected levee failure. If the proposed Seymour levee failed unexpectedly there would likely be substantial damage to buildings and infrastructure. Further, the depth of flooding in many areas of the town would not be safe for people or vehicular traffic and hence represent a threat to life. Levee failure may also impact both vulnerable communities and emergency services (e.g. Seymour Hospital, Ambulance Station and Police Station).

9.2.3.4 Water pumping stations and water quality impacts

There is a Department of Defence pumping station on the current course of the Goulburn River downstream of Emily Street, assumed to be the potable water supply for Puckapunyal military base (Figure 66). The avulsion of the Goulburn River into the quarry and on a new course downstream of the quarry would likely deprive this pumping station of a water supply. Alternately, the diversion of the Goulburn River into Seymour Quarry and the subsequent erosion would result in a substantial suspended sediment load (silts and clay), increasing the cost or even threatening the feasibility of water treatment.

Deepening of the Goulburn River may also extend upstream to Seymour's water supply pumping station. The water supply to Seymour would thereby be impacted by reduced water quality and potential damage to offtake infrastructure.

The consequences of ongoing erosion of the Goulburn River, and the associated turbidity, for potable and irrigation water supplies are somewhat uncertain. Further to Section 9.2.2.1, the waters passing through this reach of the Goulburn River are a major supply source for Goulburn Valley Water and Goulburn Murray Water, and used by Central Highlands Water and Coliban Water to provide adequate security of supply for Bendigo and Ballarat. It is not clear what proportion of these values are at risk and hence the consequences of pit capture for water quality have been assumed to be moderate.

9.2.3.5 Seymour gauge

The avulsion of the Goulburn River onto a new course through the quarry would require the relocation of Seymour gauge. Relocation of the gauge would also need to be considered in response to the diversion of the Goulburn River into the southern pit as the pit is directly connected to Deep Creek, diverting flows around the gauge. Relocation of the gauge has a number of consequences, including:

- The cost of constructing a new gauge;

- The cost of gauging a range of flows at the new site to develop a new rating curve (stage-discharge relationship);
- The cost of the Bureau of Meteorology (BoM) changing the flood warning service, changes to the Municipal Emergency Management Plan and flood study; and
- Seymour gauge has a high priority as a service outage during a flood emergency will have a *"direct and significant high level impact"* on the provision of flood forecast and warning services (BOM, 2013, p. 6). As an avulsion of the Goulburn River would tend to occur during a flood, flood warnings may be compromised during this flood and for the subsequent period whilst the gauge is re-established.

9.2.4 Consequences for property

Widening in response to the capture of Seymour Quarry (Section 9.2.2.2) has the potential to occur over a substantial reach (Sections 9.1.6.10 and 9.2.2.3) and cause the loss of considerable public and private property.

Figure 66 Department of Defence pumping station on the Goulburn River 90 metres downstream of the Emily Street bridge.

9.2.5 Summary of consequences

The following is a summary of the consequences of Seymour Quarry capturing the Goulburn River:

- Substantial deepening and widening of the Goulburn River would ensue (Section 9.2.2.2) and associated loss of in-stream habitat and riparian vegetation (Section 9.2.2.4).

- Erosion knickpoints initiated by a feature such as Seymour Quarry can progress long distances (Section 9.1.6.10).
- The increased extraction proposed in the work plan variation (Figure 10):
    - increases the amount of channel change (erosion) caused by pit capture;
    - increases the length of time for which the river is unstable; and
    - these increases in the amount of erosion and the duration of instabilities are both likely to increase the impacts on infrastructure, water quality and ecological values.
- In accordance with Table 11, the consequences for people, infrastructure and the landscape/environment can in a number of cases be described as major or critical.

9.3 Level of risk

The qualitative level of risk can be described by combining the likelihood (Table 10) and consequences (Table 11) of events using a matrix of risk ratings. The Extractive Industry Guidelines provided by DEDJTR do not contain the risk matrix for combining likelihood and consequence, this is generated by the on-line RRAM tool (DEDJTR, 2015, p. 24). The author and the Goulburn Broken CMA were unable to access this data as it is only provided to applicants preparing a work plan. Following repeated requests from the Goulburn Broken CMA, Earth Resources Regulation (DEDJTR) provided the risk matrix shown in Table 12.

Table 12 Risk matrix provided by DEDJTR on 31 March 2016.

Consequence	Rare (1)	Unlikely (2)	Possible (3)	Likely (4)	Almost Certain (5)
Critical (5)	Medium	Significant	High	High	High
Major (4)	Medium	Medium	Significant	High	High
Moderate (3)	Low	Medium	Medium	Significant	High
Minor (2)	Low	Low	Medium	Medium	Significant
Insignificant (1)	Low	Low	Low	Medium	Medium

Likelihood

The author did not use Table 12 as it is clearly superseded. The Extractive Industry Guidelines state the risk levels are low, medium, high and very high (DEDJTR, 2015, p. 24), not the levels shown in Table 12. The risk matrix used by GHD for Seymour quarry (GHD, 2015, Appendix A) (Table 13) is from a superseded version of the Guidelines but it has the same risk levels as

DEDJTR (2015, p. 24). However, comparing Table 12 and Table 13, there is a substantial shift in the distribution of risk levels within the matrices.

Table 13 Risk matrix used by GHD (2015, Appendix A).

	Likelihood				
Consequences	Rare	Unlikely	Possible	Likely	Almost Certain
Critical	Medium	Medium	High	High	Very high
Major	Low	Medium	Medium	High	High
Moderate	Low	Low	Medium	Medium	High
Minor	Low	Low	Medium	Medium	Medium
Negligible	Low	Low	Low	Medium	Medium

Overall, DEDJTR is making major changes to the risk matrix as the Guidelines are revised and the author is unable to source the matrix for the November 2015 draft of the Extractive Industry Guidelines. Hence, with consideration for the risk matrices developed by DEDJTR (e.g. GHD, 2015, Appendix A) and those in the standards (AGD, 2015a, Table 11; Standards Australia, 2013, Table C6 and C7), the risk matrix shown in Table 14 was developed for this assessment. Note the author was unable to directly adopt risk matrices from the standards as the DEDJTR likelihood and consequence intervals are different (Table 10 and Table 11, (DEDJTR, 2015)).

The adoption of Table 14 has the benefit of addressing inappropriate risk ratings proposed by DEDJTR. For instance, Table 13 proposes that a quarry operation is only a medium risk if there is up to a 70% chance (possible likelihood) that it will cause a major railway bridge or highway bridge to collapse. That is, a quarry that has only a 30% chance of not causing the collapse of a major bridge is a medium risk. In Table 14 such a risk is described as high rather than medium.

Table 14 Qualitative level of risk

	Likelihood level				
Consequence level	Rare	Unlikely	Possible	Likely	Almost certain
Critical	Medium	Medium	High	Extreme	Extreme
Major	Low	Medium	High	High	Extreme
Moderate	Low	Medium	Medium	High	High
Minor	Low	Low	Medium	Medium	Medium
Insignificant	Low	Low	Low	Low	Medium

Note the levels of risk (Table 14) are just qualitative descriptions and are not important relative to the question of whether a risk is acceptable or tolerable (Section 10). However, if the descriptions are misleading they may cause the risk assessor to make errors in determining the acceptability of risk.

As it was assessed that there is a rare likelihood of failure due to lateral migration (Section 9.1.7), and the author is not an expert in the geotechnical analysis, the likelihoods and consequences of failure due to flood flow through the pit were used to determine the level of risk to each of the assets from Table 14. This level of risk was recorded in the risk register (Table 22) for the approved Seymour Quarry.

The analysis of the influence of the proposed expansion of Seymour Quarry on the likelihood of capture of the Goulburn River found that, by taking the duration of erosive conditions as a proxy for likelihood, the expansion increases the likelihood of river capture by at least 50% under Scenario 1 (operating quarry) and 15% under Scenario 2 (rehabilitated quarry) (Section 9.1.6.15).

The evaluation of the consequences found that the proposed expansion would approximately double the consequences for the Goulburn River if only the southern pit is captured (Section 9.2.2). If both the southern and the northern pit are captured then the expansion increases the consequences of capture by 70% (size of proposed pits is 170% of the approved quarry, Section 7.2.3.2).

In accordance with risk being defined as *"probability x consequence"* (Cox, 2008) the changes in likelihood and consequences due to the proposed expansion are combined to estimate the change in risk (Table 15). Table 15 indicates that the proposed expansion of Seymour Quarry increases risks to the Goulburn River (Asset ID No. 1) in the order of 2-3 fold relative to the approved quarry. This increase in risk would also apply to other assets where the consequences increase proportionally to the amount of erosion. The quality of potable and irrigation water (Asset ID No. 15) probably fits this category.

Table 15 The increase in likelihood, consequence and risk due to the proposed expansion of the approved Seymour Quarry.

Scenario modelled	Pits captured	$\frac{\text{Likelihood (proposed)}}{\text{Likelihood (approved)}}$	$\frac{\text{Consequences (proposed)}}{\text{Consequences (approved)}}$	$\frac{\text{Risk (proposed)}}{\text{Risk (approved)}}$
Scenario 1 (operating quarry)	Southern pit captured	1.5	2	3
	Southern & northern pits captured	1.5	1.7	2.5
Scenario 2 (rehabilitated quarry)	Southern pit captured	1.15	2	2.3
	Southern & northern pits captured	1.15	1.7	2

Where the approved quarry will cause sufficient erosion to undermine infrastructure, potentially Asset ID No.s 2 through to 14 (Table 2), the proposed expansion has less impact on consequences and hence risk. In these cases the increase in risk will primarily relate to the change in likelihood, in the order of 1.15-1.5 times the risk associated with the approved quarry. Nonetheless it should be noted that the proposed quarry expansion increases both the quantum of channel change and the duration of river destabilisation at infrastructure such as the railway bridges (Sections 9.2.2.2, 9.2.2.3 and 9.2.2.4). These impacts will increase the consequences and risks due to quarry expansion beyond the change in likelihood.

Overall, the processes that will realise risks at Seymour Quarry are complex and influenced by a number of variables. Hence Table 15 is only representative of a subset of the possible scenarios at Seymour Quarry. However, Scenario 2 was designed to describe how the cessation of dewatering, appropriate landscaping of the site and the construction of Seymour levee may collectively reduce the risks due to the proposed expansion. The analysis finds that the proposed expansion of Seymour Quarry still substantially increases risks under this scenario.

The increase in likelihood and consequence and hence risk due to the proposed expansion of Seymour Quarry (Table 15) was not incorporated into the risk register (Table 22). *"Qualitative risk analysis techniques rely on descriptive and or comparative characterization of consequence, likelihood and the level of risk comparative (rather than using numerical measures)"* (Standards Australia, 2013, p. 110). *"Experience has shown that qualitative assessments and mathematical data are seldom in harmony"* (NEMC, 2010, p. 28). For example, the consequence ratings (Table 11) are nominal or ordinal and not quantitative, so a quantitative change in consequence (e.g. Table 15) cannot be readily expressed as a change in a qualitative rating (Standards Australia, 2013).