10 EVALUATE RISKS

Risk evaluation is the *"process of comparing the results of risk analysis with risk criteria to determine whether the risk and/or its magnitude are acceptable or tolerable"* (AGD, 2015a, p. 12; Standards Australia, 2009, p. 6). Hence the evaluation of risks in accordance with these standards involves defining boundaries where risks are acceptable, tolerable or intolerable. The ALARP (As Low As Reasonably Practicable) principle, provided by the UK Health and Safety Executive (2001) and adopted by Standards Australia (2013), WorkSafe (2011) and NERAG (AGD, 2015b; NEMC, 2010), is applied to help define these boundaries and decide where risks need further analysis or treatment (Figure 67).

However, the new National Emergency Risk Assessment Guidelines, NERAG (AGD, 2015a) focus on assigning a priority to risks that reflects:

1. The need to improve the confidence in the level of risk through further study;
2. The need to treat the risk; and
3. The need for ongoing risk management (monitoring and review).

In focusing on managing the risk, NERAG (AGD, 2015a) does not provide guidance on whether risks are acceptable or tolerable, nor on the widely used ALARP approach. This is despite NERAG (AGD, 2015a) recognising the focus of risk evaluation on tolerability and their sample risk register using the ALARP approach (AGD, 2015b, Appendix H). As this study is a risk assessment and not a risk management plan, the guidance provided on tolerability in other standards (NEMC, 2010; Standards Australia, 2013; WorkSafe, 2011) has been used with the latest NERAG guidance (AGD, 2015a, 2015b).

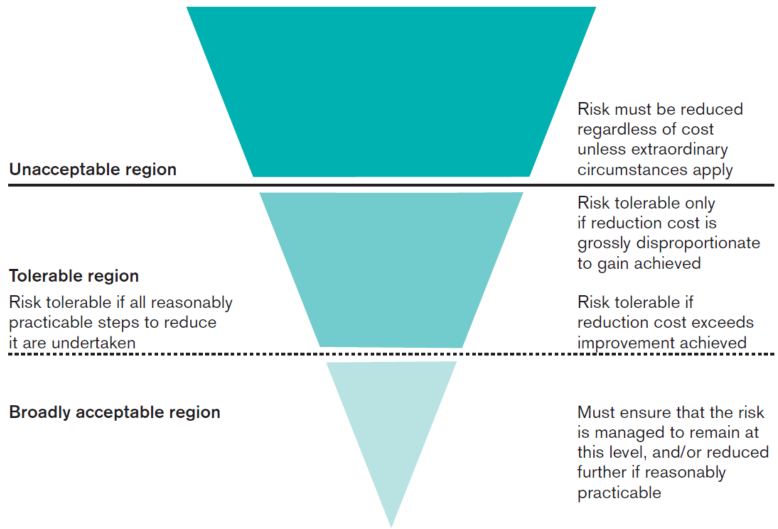

Figure 67 ALARP Principle (WorkSafe, 2011, Figure 9.1).

For a risk to be acceptable it needs to fall into the broadly acceptable region in Figure 67. Some risks may be tolerated, subject to being as low as reasonably practicable. Two factors to be considered in determining whether risks are broadly acceptable, tolerable subject to ALARP, or intolerable are the level of risk and the confidence level (AGD, 2015a; NEMC, 2010).

The confidence level refers to the degree of confidence that the assigned level of risk is correct. NERAG (AGD, 2015a; NEMC, 2010) discusses this tolerability of risk in terms of high to low confidence levels. As the level of confidence in the risk assessment drops from high to low the tolerance and acceptability of risk also drops as the assessor has less confidence that an outcome will be tolerable.

The author has adopted a moderate level of confidence in the levels of risk described in the risk register (Table 22) based on:

- The uncertainties around likelihood (Section 9.1.6.13);
- Quarrying has not complied with the geotechnical design and work plan in aspects that increase risk (Section 9.1.8.3);
- The complexity of the processes and the potential scenarios;
- The exclusion of societal risk (multiple fatalities) and the low tolerability for these risks;
- The exclusion of consequences such as the socio-political response;

Based on the likelihood (Table 10) and confidence ratings (Table 11), NERAG (NEMC, 2010, Table 7) and moderate levels of confidence, the tolerance or acceptability of risk can be described as shown in Table 16.

Table 16 Tolerance of risk – moderate confidence level

	Likelihood level				
Consequence level	Rare	Unlikely	Possible	Likely	Almost certain
Critical					
Major					
Moderate					
Minor					
Insignificant					

Intolerable	
Tolerable subject to ALARP	
Broadly Acceptable	

NERAG (AGD, 2015a) and Standards Australia (2009) highlight that the evaluation of risks involves comparing the level of risk with criterion set out in legislation, standards and guidelines to determine whether the risks are acceptable or tolerable. Such standards are a primary determinant of risk tolerability at Seymour Quarry. Risk criterion for bridges, the Goulburn River and public safety are discussed in Sections 10.1, 10.2 and 10.3 respectively. The Extractive Industries Guidelines for risk management (DEDJTR, 2015) are compared with these criterion in Section 10.4.

10.1 Risk criterion for the failure of bridges

The bridges on the Melbourne-Sydney rail corridor, and all other bridges in a fluvial environment, are designed and constructed to withstand scour processes such as pier scour, abutment scour and constriction scour. Large design flow events are used for scour processes as the consequences of these processes are high. Scour threatens undermining of the bridge foundations leading to catastrophic collapse and *"the knock-on effects from disruption to infrastructure services from emergency events can lead to significant secondary impacts." "In many scenarios, a prolonged infrastructure disruption may be the cause of the most significant consequence"* (AGD, 2015a, p. 44). The objective of designing for scour is to ensure that, despite the high consequences of catastrophic collapse, the likelihood is sufficiently low to give a tolerable risk.

The design life of bridges, including railway and road bridges and culvert structures supporting traffic, is 100 years (Standards Australia, 2004a, Sections 1 and 6.2). However *"historically, bridges have been one of the more permanent types of structure and a useful life far in excess of 100 years can be envisaged for most bridges unless they are replaced for other reasons, such as road realignment, width limitations or they are made of less durable material such as timber"* (Standards Australia, 2006, p. 5). The design life is *"the period assumed in design for which a structure or structural element is required to perform its intended purpose without replacement or major structural repairs"* (Standards Australia, 2004a, p. 6). These structures shall be designed to be stable, not reach an ultimate limit state, for an event that *"has a 5% probability of being exceeded during the design life. This represents an average return interval of 2000 years"* (Standards Australia, 2004a, p. 9).

"The ultimate limit states define the capability of a bridge to withstand, without collapse, any flood of a magnitude up to and including that with a 2000 year average return interval, whichever produces the most severe effect. It can be accepted that scour of the stream bed and considerable damage to approaches and embankments may take place, provided that the structural integrity of the bridge is maintained" (Standards Australia, 2004b, p. 49).

Hence, a tolerable likelihood for the failure for the railway bridges (Asset ID No.s 2 & 3) and the Emily Street bridge and culverts (Asset ID No.s 8 and 10) is the rare likelihood in Table 10. The tolerable level of risk for this infrastructure is *Low* (Table 14).

10.2 Risk criterion for the capture of the Goulburn River

The Goulburn River is an anabranching river that will change course naturally. The work of Erskine et al. (1993b) suggests that the time scale for the development of anabranches on the Murray River is probably several thousand years. This, and the work of a number of other authors (Brooks and Brierley, 2002; Makaske, 1998; Makaske et al., 2002; Morozova and Smith, 2000; Stouthamer and Berendsen, 2001), suggests that, in the absence of data for the Goulburn River, several thousand years is a reasonable estimate of the interval between avulsions in any given reach.

Some increase in the risk to the Goulburn River is required to facilitate the exploitation of resources such as sand and gravel. As the consequences of an avulsion into Seymour Quarry are greater than for a natural avulsion (Section 9.2.2.2), maintaining the natural likelihood will substantially increase the risk. A 500 year ARI (0.2% AEP) event is certain to occur over 3,000 years (99.8% probability, Equation 3) and is assumed to have a similar likelihood to a natural avulsion. Note, a 500 year ARI event has a likelihood of 18% over the adopted 100 year design life, the unlikely category in Table 10. This could be considered the tolerable likelihood of an avulsion of the Goulburn River. This likelihood and the critical consequences (avulsion of the Heritage River) give *Medium* as the tolerable level of risk (Table 14).

The MRSDA 1990 (S. 79(a)(v)) also states that *"A rehabilitation plan must take into account any potential long term degradation of the environment"*. This is a qualitative statement on risk that comments on both the likelihood *"potential long term"* and consequence *"any…degradation of the environment"*. Based on the quantification of likelihood (Table 10), the term *"potential long term"* may be equated to a possible event, a 30-70% chance of occurrence. Further, *"any…degradation of the environment"* may be related to the consequence of minor damage to the landscape/environment (Table 11). This combination of likelihood and consequence is a *Medium* risk in Table 14. The MRSDA 1990 (S. 79(a)(v)) states that a rehabilitation plan *"must take into account"* such a risk, implying that this risk is not broadly acceptable but tolerable and subject to ALARP.

10.3 Risk criterion for public safety (fatalities).

The risk to public safety is usually considered in terms of societal and individual risk. Societal risk is the potential for an incident to coincide in time and space with a human population, the potential for an incident to cause multiple fatalities.

Individual risk is the probability of a fatality at a particular point. It is assumed that the person will be at the point of interest 24 hours a day for the whole year. By convention, no mitigation is allowed, including any evasive action by the person.

The risk of a fatality to notional individuals around a site is considered as a probability (of fatality) per year. The thresholds for the tolerable and broadly acceptable risk of fatality proposed by WorkSafe Victoria (2011) and the Australian Geomechanics Society (2007a) are shown in Table 17. These criterion do not have legal status but provide guidance and are typical of other national and international criterion (AGS, 2007b).

The risk thresholds for existing development are generally an order of magnitude higher (more likely) than those for new development shown in Table 17 (e.g., AGS, 2007a). The Australian Geomechanics Society guidelines state *"Existing Development includes existing structures, and slopes that have been modified by cut and fill, that are not located on or part of a recognizable landslide and have demonstrated non-failure performance over at least several seasons or events of extended adverse weather, usually being a period of at least 10 to 20 years."* (AGS, 2007a, p. 78). The pits at Seymour Quarry fit the definition of new development as they are still being excavated. If there have not been any failures 10 to 20 years after completion of the pits, then Seymour Quarry will fit the definition of existing development.

Table 17 Criterion for individual risk from a new development.

Reference	Tolerable/ intolerable risk threshold	Tolerable/ broadly acceptable risk threshold
WorkSafe Victoria (2011)	1×10^{-5} AEP (0.001% AEP)	1×10^{-7} AEP (0.00001% AEP)
Australian Geomechanics Society (AGS, 2007a)	1×10^{-5} AEP (0.001% AEP)	1×10^{-6} AEP (0.0001% AEP)

In additional to the risk to individuals, societal risk (multiple fatalities) may need to be considered at Seymour Quarry based on the criterion for societal risk assessments applied to dams, for example, *"societal concerns which should be factored into the assessment of ALARP include:*

- *dams with very high consequences (e.g., an identified failure mode leading to a potential loss of life of more than 100);*
- *a highly vulnerable population at risk (such as a pre-school immediately downstream of a dam);*
- *known and strong interdependence of a dam with critical infrastructure and the provision of essential services; and*
- *situations where there is a lack of trust from the community that the risk is being adequately managed, perhaps resulting from an earlier dam safety incident."* (DSE, 2012, p. 16)

The author has not analysed societal risks. Note, hazards that give rise to intolerable risks to individuals also give rise to societal concerns which often play a far greater role in deciding if a risk is acceptable or not (HSE, 2001, p. 46).

10.4 Extractive Industries Guidelines

The draft Extractive Industries Guidelines (DEDJTR, 2015) state that a risk is only considered significant if it falls into the high or very high category and that a risk rating of low or medium only needs monitoring of the identified standard controls. That is, the proponent is not required to consider other controls to make the risk ALARP, the low and medium risks determined from the Extractive Industries Guidelines are considered broadly acceptable by DEDJTR.

In Table 18 the threshold for broadly acceptable risk proposed by DEDJTR, based on the risk matrix used by GHD (Table 13) (GHD, 2015, Appendix A), is shown for impact categories that are important at Seymour Quarry, public safety and major infrastructure. DEDJTR is proposing that the acceptable level of risk is multiple orders of magnitude higher than other standards, for example, more than five orders of magnitude higher for public safety (Section 10.3).

Table 18 Thresholds for Broadly Acceptable Risk based on the draft Extractive Industries Guidelines.

Impact category	Outcome	Consequence	Broadly acceptable likelihood	Threshold likelihood for Broadly Acceptable Risks (DEDJTR, 2015)	
				10 year project life	5 year history
Infrastructure	Loss of Melbourne-Sydney railway bridges	Major	Possible	1×10^{-1} AEP (11% AEP, 9 year ARI)	2×10^{-1} AEP (20% AEP, 5 year ARI)
Public safety	Loss of Melbourne-Sydney railway bridges leading to one fatality	Critical	Unlikely	4×10^{-2} AEP (4% AEP, 29 year ARI)	7×10^{-2} AEP (7% AEP, 15 year ARI)

The National Emergency Risk Assessment Guidelines were developed to respond to an upward trend in the cost of disasters in Australia and to concerns about the potential increase in the frequency of severe weather events. *"This approach involves a fundamental shift in focus beyond response, relief and recovery towards cost-effective, evidence-based disaster mitigation"* (NEMC, 2010, p. 4). The approach of DEDJTR (2015) runs counter to that of NERAG by facilitating the transfer of risk to the public and to an extent that is substantially greater than current standards allow. This socialisation of risk will increase future response, relief and recovery costs for the public whilst transferring a benefit to the quarrying industry through reduced requirements for development, including a reduction in the cost of risk prevention and preparedness controls. It is therefore concluded that the criterion for acceptable risk in the Extractive Industries Guidelines (DEDJTR, 2015) are not consistent with the principles of sustainable development, Section 2A of the Mineral Resources (Sustainable Development) Act 1990. Hence the author has not used the criterion for acceptable risk set by DEDJTR (2015). The author is effectively assuming that the presence of (or a proposal for) a quarry does not void the established risk standards for major assets and public safety around that quarry.

10.5 Risk controls and treatment

Risk controls can be either (AGD, 2015a):

1. Prevention and preparedness controls that can prevent or mitigate the asset being exposed to the event (likelihood) or the impact of the event on the asset (consequences); or

2. Response and recovery controls that can only mitigate the impact (consequences).

The risk controls that are currently in place are discussed in Section 10.5.1 and potential risk treatments in Section 10.5.2.

The level of control offered by risk treatments has been assessed in accordance with NERAG (AGD, 2015a, pp. 49–53). The assessment involves categorising the level of control based on the control strength, whether it is effective at preventing the risk or mitigating its impacts, and the control expediency, whether the control is available, difficult to use and acceptable to stakeholders (Table 19).

Table 19 Level of control based on qualitative descriptors of control strength and expediency (AGD, 2015a, Table 1).

Level	Control strength	Control expediency
High	Control is highly effective in reducing the level of risk	The control is frequently applied. A procedure to apply the control is well understood and resourced. The cost of applying the control is within current resources and budgets.
Medium	Control is effective in reducing the level of risk	The control is infrequently applied and is outside of the operators' everyday experience. The use of the control has been foreseen and plans for its application have been prepared and tested. Some extraordinary cost may be required to apply the control.
Low	Control has some effect in reducing the level of risk	The control is applied rarely and operators may not have experience using it. The use of the control may have been foreseen and plans for its application may have been considered, but it is not part of normal operational protocols and has not been tested. Extraordinary cost is required to apply the control, which may be difficult to obtain.
Very low	Control has almost no effect in reducing the level of risk	Application of the control is outside of the experience and planning of operators, with no effective procedures or plans for its operation. It has not been foreseen that the control will ever need to be used. The application of the control requires significant cost over and above existing resources, and the cost will most likely be objected to by a number of stakeholders.

10.5.1 Existing risk controls

The risk controls that are in place and their efficacy are summarised in Table 20. The level of control offered by these existing controls is considered low to very low. Overall, the existing controls will only facilitate warnings of flooding for low lying areas, reducing the likelihood of public safety impacts in some areas, and provide the response to a public safety emergency.

Table 20 Existing risk controls at Seymour Quarry.

Prevention and preparedness controls	Control strength	Level of control
Bureau of Meteorology flood warning	Flood warnings will notify of the hazard (flooding) in general but will not provide the specific warning required for Seymour Quarry and there is no emergency plan to the author's knowledge. A warning will also not mitigate the exposure of the asset to the event. Gauges may fail during floods.	Very low
Municipal Emergency Management Plan (MEMPC, 2015) and Flood Sub-Plan	Does not recognize the event and hence does not attempt to mitigate the exposure. However, at low lying assets (e.g. Seymour Caravan Park) where flooding causes a hazard in the absence of pit capture, the MEMP will facilitate warnings and advice and reduce the likelihood of public safety impacts.	Low
Recovery and response controls	**Control strength**	**Level of control**
Municipal Emergency Management Plan (MEMPC, 2015) and Flood Sub-Plan	Will help ensure medical services, emergency shelters, etc. are available.	Very low

10.5.2 Potential risk treatments

Potential risk treatment strategies are discussed below and summarised in Table 21. These treatments are then listed in the Risk Register (Table 22) to facilitate assessment of the residual risk. Note, all the treatments listed in Table 22 are prevention and preparedness controls as, in the case of Seymour Quarry, recovery and response will do little to address risk.

10.5.2.1 Flood warning system - prevention/preparedness control

Flood warning can assist in treating threats to public safety when the warning time is sufficient. Issuing flood warnings for Seymour Quarry are complicated by:

1. The Bureau of Meteorology (BOM) provides flood level forecasts for the gauge on the Goulburn River at Seymour with a target warning lead time of 3 hours (BOM, 2013).

2. The Bureau of Meteorology assigns a high priority to the gauges on the Goulburn River at Seymour and Sunday Creek at Tallarook 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). Thus risk management using flood warning

retains the residual risk of a loss of service during a flood. Note, an avulsion through Seymour Quarry also poses a threat to the accuracy of the gauge.

3. The critical erosive conditions for failure of the Seymour Quarry can be caused by a flood from Sunday and Sugarloaf Creeks, a flood from the Goulburn River or a combination of flows from the three waterways. Hence, substantial work is required to determine the scenarios for flooding and risks at Seymour Quarry and linking these to BOM's flood level forecasts.

4. Finally, the flood level forecast by BOM needs to be drawn into a flood warning system for Seymour Quarry such that flood levels are transformed into warnings and disseminating to the organisations that need them, the organisations can interpret the various levels of warning and know how to respond. An ongoing financial and institutional commitment to maintain and periodically upgrade the warning system is also required.

Warnings are only effective risk treatments if the response is effective. The erosion threat and hence threat to public safety will manifest under the water surface and not be amenable to monitoring. Therefore it is likely that relevant infrastructure/areas will need to be closed/evacuated when floods reach in the order of a 10 year ARI Goulburn River event. The design serviceability for infrastructure such as the Melbourne-Sydney rail corridor is the 20 year ARI event (Standards Australia, 2004a, Section 6.5, 2004b, Section 15.2.2). Hence, addressing the threat to public safety through infrastructure closure is likely to reduce the serviceability.

Alternately the rail corridor could be closed once a break in the rail signalling or railway track is detected. However, such a warning system has the following residual risks:

1. It is likely that, for an indeterminate period, undermined bridges shall support the rail signalling and track but not a train crossing the 165 metre length of bridge over the Goulburn River; and subsequently

2. Upon loss of the signalling/track there will be a delay between detecting the break and trains stopping.

In relation to the expansion of the quarry it should be noted that the draft Guidelines for Development in Flood-prone Areas state *"New development will not be supported based on the availability of flood warnings or due to the development of a flood emergency plan."* (Victorian Floodplain Management Forum, 2016, p. 26).

Unfortunately a flood warning system does not treat the risks to infrastructure, property, water quality and the environment. Treatments that address these risks and may be possible at Seymour Quarry include a levee, with or without a flow inlet structure, or partially refilling the pits with earth, as discussed below.

10.5.2.2 Levees or partially refilling quarry pits - prevention/preparedness control

A levee without flow inlet structures is considered the most viable at Seymour Quarry. To meet the design requirements, the flow inlet structures would need to be reinforced concrete or similar and hence it would be more economic to simply prevent inflows by fully encircling the pits with a levee. A levee with flow inlet structures constructed of quarried rock (rock chutes) would be more economic but will not meet the design requirements as:

- Rock chutes require substantial maintenance and are not sufficiently durable for the long duration floods on the Goulburn River. For example, evaluating 161 structures across 15 streams after 2-10 year ARI floods Frissell and Nawa (1992) found a median failure rate of 18.5% and median damage rate of 60%. Ladson et al. (2006) state *"there are also many situations where rock is lost in relatively small events where the extent of damage is often surprisingly large."*

- The use of rock chutes is restricted to low vertical heights, generally up to 1 metre. For example, the US National Engineering Handbook for Stream Restoration Design states a disadvantage of rock chutes is *"generally limited to less than about 3 ft drop heights"* (USDA, 2007, p. TS14G-4). If supplemented with a sheet pile or concrete cut-off wall a rock chute is suitable up to about a 6 ft height (USDA, 2007, p. TS14G-4). At Seymour Quarry an inlet structure would need to extend approximately 2 metres vertically below water level to accommodate the initiation of the hydraulic jump and the subsequent turbulence, giving structures that are potentially up to 9 metres in height, 500% of the maximum height of a rock chute if a cut off wall is used. Whilst dewatering is underway this vertical height is up to 27-28 metres.

- If the rock chutes do not terminate at the base of the pit (up to 27-28 metres high) then the structures are terminating on a batter face. The apron (downstream end) of rock chutes tends to unravel on the flat grade of a stream bed (e.g. Ladson et al., 2006) and would readily fail if terminated on a batter slope.

- High rock chutes, those 1 metre in height or more, are generally built at a grade of not more than 1V:10H. A 9 metre high structure may extend 60 metres into the 100 metre buffer zone between the southern pit and Goulburn River. A structure terminating at the base of the pit would extend into the Goulburn River.

The construction of levees without inlet structures around the proposed quarry pits will be complicated by a number of issues, including:

- The geotechnical design of the pit is based on a number of conditions that a levee around the pit may change. These include:
  - That embankments of fill are not placed within 20 metres of the top of the pit. The construction of a levee would constitute fill.
  - The 100 metre setback and hydraulic gradients inherent in the geotechnical design shall change substantially. A levee would increase the water level difference between the river and pit and the floodwater may be ponding only 40 metres from the pit.

- Due to the footprint of the levee, there are areas where pit design may need to change to accommodate the levee adjacent, for instance:
    - the railway infrastructure,
    - the optic fibre infrastructure of Telstra and Nextgen west of the rail corridor,
    - the Seymour town levee,
    - the need to provide an adequate setback to the heritage Goulburn River.
- If the risk of failure of the quarry is unacceptable without mitigation then the mitigation infrastructure may need to be designed to accommodate quarry operations.
- Tolerable probabilities of failure for major bridges are low (Section 10.1) and unlikely to be achieved with a levee.
- The design ARI event for a levee around Seymour Quarry is likely to be different to that of the adjoining Seymour town levee. The interaction of these levees and the potential for a levee around the quarry to lift flood levels along the town levee and at other assets on or adjacent the floodplain needs to be assessed.
- If the stability of critical infrastructure (e.g. railway bridges, and telecommunications infrastructure) relies on the performance of risk treatment infrastructure (e.g. a levee) then the risk treatment infrastructure needs an ongoing ownership and maintenance regime commensurate with that of the critical infrastructure. An *"essential principle"* of the Victorian Levee Management Guidelines is *"A levee is an expensive structure that needs to be appropriately managed. A levee cannot be relied on to provide flood protection if it has not been diligently maintained and if people are not trained and available to manage it during floods"* (DELWP, 2015a, p. 7).
- An *"essential principle"* of the Victorian Levee Management Guidelines is also *"A levee protects property, not lives (although lives may be at risk if a levee fails and contingency plans haven't been implemented)"* (DELWP, 2015a, p. 7). Hence many of the risks at Seymour Quarry are not addressed by a levee.
- *"Permanent or temporary flood walls, flood barriers or levees will not be supported to facilitate or permit new development on unsafe sites."* (Victorian Floodplain Management Forum, 2016, p. 27).
- After a levee has been constructed a residual level of risk remains, the risk of levee failure. The proposed expansion of Seymour Quarry increases this level of residual risk by increasing the consequences of levee failure. The appropriateness of creating such high risks at Seymour Quarry and then seeking to treat them with a levee is questionable as, for example, *"There were 11 stream captures into floodplain pits along varied rivers in Washington State, USA in spite of the presence of dikes or revetments, due to failure or overtopping during floods"* (Mossa and Marks, 2011, pp. 2–3). Highlighting the tendency for engineering works to fail Norman et al. (1998, p. 9) state *"In effect, dikes and levees*

are only short term solutions to long term natural processes such as channel migration and flooding".

- Developing deep quarries that require infrastructure such as levees raises strategic floodplain management issues associated with cumulative impacts, including:
  - The cumulative impact on flood storage and flood conveyance.
  - The progressive loss of aquatic and riparian habitat, particularly associated with billabongs, when sections of the floodplain are isolated by levees.
  - Levees also diminish the role of the floodplain in capturing and storing sediment in times of high flow and the subsequent water quality benefits.
  - As deep quarries are progressively developed the landscape becomes more fragile and the risk to the Goulburn River progressively increases.

Many of these issues are reflected in the planning practice note for the flood provisions *"Significant earthworks, including levees and raised roads, are inappropriate for floodway land. The construction of inappropriate earthworks can obstruct or divert flood flows, reduce natural flood storage areas, impact on environmental values and increase flood flows, flow velocities and flood damage"* (DELWP, 2015b, p. 4).

The treatment option of partially refilling the pits, to a level one metre above the thalweg of the river for instance, has the potential advantage that it does not change the design assumptions for the stability of the pit, does not encroach on infrastructure or the heritage river and it does not leave legacy infrastructure that requires ongoing management and maintenance. The disadvantage is that this option becomes progressively less feasible as the quarry expands. Note the literature indicates that if the base of the pits at Seymour Quarry were a metre above the thalweg of the Goulburn River (pit depth of 6-7 metres) they would still be inappropriate due to the proximity of infrastructure (Section 9.1.3).

10.5.2.3 Address impact of pit capture on assets– recovery response control

The efficacy of recovery/response controls depends on consequences, such as the deepening of the Goulburn River at the railway bridges, not being realised before the flood subsides. Given major flooding on the Goulburn River at Seymour persists for multiple days, the author considers it unlikely that deepening will not reach major infrastructure (Sections 9.1.4.2 and 9.1.6.10). Nonetheless, assuming infrastructure has not failed, attempts to undertake works on the river directly after a major flood are unlikely to be successful. Contractors would be working to stabilise active erosion features in a river channel running near full for a number of weeks as the 8,600 km^2 catchment drains. Further, the contractors would not be able to approach the erosion features on land as they will be bounded by steep, unstable banks.

Note, some of the difficulties of working on a destabilised pit and waterway were encountered during attempts to repair the breach between WA45 and Island Creek. This repair was unsuccessful even though the ephemeral Island Creek only flows briefly when the Yea River spills floodwater into it. The Goulburn River at Seymour does not stop flowing. Note, to the author's knowledge, Island Creek has not flowed since 2011. Nonetheless the breach into WA45 has not been fixed.

Table 21 Potential risk treatment strategies at Seymour Quarry.

Prevention and preparedness controls	Control strength	Control expediency	Level of control
Design flood warning system and update the Municipal Emergency Management Plan (MEMPC, 2015) and Flood Sub-Plan	Recognition of the pit capture event in the MEMP and any changes required to manage it will reduce the likelihood of impacts on public safety. It will not change the consequences of any risks or the likelihood of risks to property, the environment or infrastructure. A flood warning system relies on river flow gauges which may fail during floods. There may also be a failure to implement prevention/preparedness controls in response to a warning.	Substantial work would be required to set up a flood warning system for Seymour Quarry. A permanent commitment of resources is required to maintain, operate and periodically upgrade a warning system and emergency plan.	Low
Mitigate exposure of the asset to the event - urban planning	Seymour Quarry is located near existing assets, planning may only reduce the likelihood that future assets will be exposed to pit capture.	Difficult to implement due to regulatory and cost burden that is shifted onto public and private developers of assets.	Very low
Building regulations/asset design	Assets are existing and have not been designed for the pit capture event.	Difficult to implement due to regulatory and cost burden that is shifted onto public and private developers of assets.	Very low
Design and construct levee banks	A low likelihood of failure is required to reduce the risks to a tolerable level. The required standard of levee design, construction and maintenance is unlikely to be achieved/practical. Does not address risks to public safety.	Substantial work is required for investigations, consultation, approvals, design and construction. The process normally takes a number of years, particularly in a developed area like Seymour. A suitable ongoing ownership or maintenance regime is unlikely. May not be acceptable to stakeholders.	Very low
Recovery and response controls	**Control strength**	**Control expediency**	**Level of control**
MEMP (MEMPC, 2015) and Flood Sub-Plan	Modification of the MEMP to address consequences for assets is unlikely to be effective (Section 10.5.2.3).		Very low

11 RISK REGISTER

The risk register (Table 22) records the results of risk identification (Section 8), risk analysis (Section 9) and risk evaluation (Section 10). Two key elements of the risk identification that are not specified in the risk register are that the hazard is riverine flooding and the cause is flood flow through the pit and the subsequent erosion of the strip of land between the pit and the river. Other aspects of the risk identification in Table 22 are the *Ref. No.*, a unique identifier for each risk considered, and the *Scenario*, one of the two flood flow scenarios analysed in detail, Scenario 1 for the operating quarry (Section 9.1.6.6) and Scenario 2 for the rehabilitated quarry (Section 9.1.6.7).

In the risk identification and treatment sections of the risk register, only risk controls that were found to have a level of control above very low (Section 10.5) were included.

The tolerability of the risks in Table 22 is based on the criteria in Section 10.1 for the major railway and road bridges and culverts (Asset ID No.s 2, 3, 8 and 10), Section 10.2 for the Goulburn River (Asset ID No. 1), Section 10.3 for critical public safety risks (fatalities) and Table 16 for all other assets and public safety risks.

Of the 17 risks that are intolerable (Table 22), the tolerability of 15 risks was determined from Sections 10.1, 10.2 and 10.3. For the remaining 2 intolerable risks, the loss of the Telstra and Nextgen optic fibre connections (risk Ref. No. 6) and the impact on potable and irrigation water quality (risk Ref. No. 20), the tolerability was determined from Table 16.

Although it can be quantitatively demonstrated that expanding Seymour Quarry increases the risks (Section 9.3), and hence the risks are less acceptable than is described in Table 22, the author has not attempted to translate this increase into the partially qualitative assessment of risk tolerability for the reasons outlined in Section 9.3.

Table 22 Risk register for the approved Seymour Quarry.

Risk Identification							Risk Analysis			Risk Evaluation					
Ref No	Scenario	Asset	Outcome	Prevention/ preparedness controls	Recovery/ response controls	Impact category	Consequence	Likelihood	Risk	Tolerance	Treatment strategies	Residual consequence	Residual Likelihood	Residual Risk	Tolerance after Treatment
1	1&2	1. Goulburn River	Erosion of the strip of land between the pit and the river, diverting the river into the pit	-	-	Landscape/ environment	Critical	Almost certain	Extreme	Intolerable	-	Critical	Almost certain	Extreme	Intolerable
2	1&2	2. Northern railway bridges	Headward erosion from the pit undermines the bridges	-	-	Infrastructure	Major	Possible	High	Intolerable	-	Major	Possible	High	Intolerable
3	1&2	2. Northern railway bridges	Undermining of the bridges causes train derailment	Currently not considered in MEMP	MEMP	Public safety	Critical	Unlikely	Medium	Intolerable	Improve MEMP - close rail corridor in ≥10 year ARI event	Critical	Rare	Medium	Intolerable
4	1&2	3. Goulburn railway bridges	Headward erosion from the pit undermines the bridges	-	-	Infrastructure	Major	Likely	High	Intolerable	-	Major	Likely	High	Intolerable
5	1&2	3. Goulburn railway bridges	Undermining of the bridges causes train derailment	Currently not considered in MEMP	MEMP	Public safety	Critical	Possible	High	Intolerable	Improve MEMP - close rail corridor in ≥10 year ARI event	Critical	Unlikely	Medium	Intolerable
6	1&2	4&5. Telstra & Nextgen optic fibre	Headward erosion from the pit leads to loss of infrastructure	-	-	Infrastructure	Major	Likely	High	Intolerable	-	Major	Likely	High	Intolerable
7	1&2	6. Seymour caravan park	Headward erosion from the pit and consequent widening and lateral migration undermine buildings	-	-	Infrastructure	Minor	Likely	Medium	Tolerable[#]	-	Minor	Likely	Medium	Tolerable[#]

Risk Identification							Risk Analysis			Risk Evaluation					
Ref No	Scenario	Asset	Outcome	Prevention/ preparedness controls	Recovery/ response controls	Impact category	Consequence	Likelihood	Risk	Tolerance	Treatment strategies	Residual consequence	Residual Likelihood	Residual Risk	Tolerance after Treatment
8	1&2	6. Seymour caravan park	Undermining of buildings/ loss of assets	MEMP - expect warning of flooding prior to pit capture	MEMP	Public safety	Critical	Unlikely	Medium	Intolerable	-	Critical	Unlikely	Medium	Intolerable
9	1&2	7. Seymour water supply	Headward erosion from the pit and consequent widening damage offtake infrastructure	-	-	Infrastructure	Moderate	Possible	Medium	Tolerable#	-	Moderate	Possible	Medium	Tolerable#
10	1&2	8. Goulburn (Emily St) bridge	Downstream progressing degradation along Goulburn River undermines major bridge	-	-	Infrastructure	Major	Unlikely	Medium	Intolerable	-	Major	Unlikely	Medium	Intolerable
11	1&2	8. Goulburn (Emily St) bridge	Undermining of major bridge	MEMP - expected to be closed for >25yr ARI flows	MEMP	Public safety	Critical	Unlikely	Medium	Intolerable	-	Critical	Unlikely	Medium	Intolerable
12	1	9. DoD pumping station	Downstream degradation of Goulburn River damages offtake infrastructure or avulsion of the Goulburn River denies water supply	-	-	Infrastructure	Moderate	Likely	High	Tolerable#	-	Moderate	Likely	High	Tolerable#
13	1	10. Emily Street	Downstream degradation along Deep Creek undermines major culvert structure	-	-	Infrastructure	Moderate	Possible	Medium	Intolerable	-	Moderate	Possible	Medium	Intolerable

Risk Identification							Risk Analysis			Risk Evaluation					
Ref No	Scenario	Asset	Outcome	Prevention/ preparedness controls	Recovery/ response controls	Impact category	Consequence	Likelihood	Risk	Tolerance	Treatment strategies	Residual consequence	Residual Likelihood	Residual Risk	Tolerance after Treatment
14	1	10. Emily Street	Undermining of major culvert structures	MEMP - expected to be closed for >25yr ARI flows	MEMP	Public safety	Critical	Unlikely	Medium	Intolerable	-	Critical	Unlikely	Medium	Intolerable
15	1	11. Local roads	Downstream degradation undermines minor culvert structure	-	-	Infrastructure	Minor	Possible	Medium	Tolerable#	-	Minor	Possible	Medium	Tolerable#
16	1	11. Local roads	Collapse of minor culvert structure causes injuries to road users	MEMP - expected to be closed for >25yr ARI flows	MEMP	Public safety	Moderate	Unlikely	Medium	Tolerable#	-	Moderate	Unlikely	Medium	Tolerable#
17	1	12. Homes and businesses	Downstream degradation along Deep Creek undermines buildings	-	-	Infrastructure	Minor	Possible	Medium	Tolerable#	-	Minor	Possible	Medium	Tolerable#
18	1	12. Homes and businesses	Undermining of buildings	MEMP - expected to be closed for >25yr ARI flows	MEMP	Public safety	Critical	Unlikely	Medium	Intolerable	-	Critical	Unlikely	Medium	Intolerable
19	1	14. Seymour gauge	Gauge needs to be relocated due to the diversion or avulsion of the Goulburn River	-	-	Infrastructure	Moderate	Likely	High	Tolerable#	-	Moderate	Likely	High	Tolerable#
20	1&2	15. Water quality (incl. potable & irrigation water supplies)	Ongoing erosion/ channel change results in turbid water increasing treatment costs or requiring alternate supplies	-	-	Infrastructure	Moderate	Almost certain	High	Intolerable	-	Moderate	Almost certain	High	Intolerable

Risk Identification							Risk Analysis			Risk Evaluation					
Ref No	Scenario	Asset	Outcome	Prevention/ preparedness controls	Recovery/ response controls	Impact category	Consequence	Likelihood	Risk	Tolerance	Treatment strategies	Residual consequence	Residual Likelihood	Residual Risk	Tolerance after Treatment
21	2	9. DoD pumping station	Downstream degradation of Goulburn River damages offtake infrastructure or avulsion of the Goulburn River denies water supply	-	-	Infrastructure	Moderate	Possible	Medium	Tolerable#	-	Moderate	Possible	Medium	Tolerable#
22	2	10. Emily Street	Downstream progressing degradation along Deep Creek undermines major culvert structure	-	-	Infrastructure	Moderate	Unlikely	Medium	Intolerable	-	Moderate	Unlikely	Medium	Intolerable
23	2	10. Emily Street	Undermining of major culvert structures	-	MEMP	Public safety	Critical	Unlikely	Medium	Intolerable	Improve MEMP - warn areas protected by Seymour levee in >30yr ARI event	Critical	Rare	Medium	Intolerable
24	2	11. Local roads	Downstream progressing degradation undermines minor culvert structure	-	-	Infrastructure	Minor	Unlikely	Low	Broadly acceptable	-	Minor	Unlikely	Low	Broadly acceptable
25	2	11. Local roads	Collapse of minor culvert structure causes injuries to road users	-	MEMP	Public safety	Moderate	Rare	Low	Tolerable#	Improve MEMP - warn areas protected by Seymour levee in >30yr ARI event	Moderate	Rare	Low	Tolerable#
26	2	12. Homes and businesses	Downstream degradation along Deep Creek undermines buildings	-	-	Infrastructure	Minor	Unlikely	Low	Broadly acceptable	-	Minor	Unlikely	Low	Broadly acceptable

Risk Identification							Risk Analysis			Risk Evaluation					
Ref No	Scenario	Asset	Outcome	Prevention/ preparedness controls	Recovery/ response controls	Impact category	Consequence	Likelihood	Risk	Tolerance	Treatment strategies	Residual consequence	Residual Likelihood	Residual Risk	Tolerance after Treatment
27	2	12. Homes and businesses	Undermining of buildings	-	MEMP	Public safety	Critical	Unlikely	Medium	Intolerable	Improve MEMP - warn areas protected by Seymour levee in >30yr ARI event	Critical	Rare	Medium	Intolerable
28	2	13. Seymour levee	After pit capture, downstream degradation undermines the levee, substantial damage in town as flood water flows through and ponds inside levee	-	-	Infrastructure	Major	Possible	High	Tolerable#	-	Major	Possible	High	Tolerable#
29	2	13. Seymour levee	Levee undermined and flood water flows through and ponds inside levee	-	MEMP	Public safety	Critical	Possible	High	Intolerable	Improve MEMP - warn areas protected by Seymour levee in >30yr ARI event	Critical	Unlikely	Medium	Intolerable
30	2	14. Seymour gauge	Gauge needs to be relocated due to the diversion or avulsion of the Goulburn River	-	-	Infrastructure	Moderate	Possible	Medium	Tolerable#	-	Moderate	Possible	Medium	Tolerable#

\# Risks should be driven to the broadly acceptable region (Figure 67) but some of these risks may be tolerated subject to being as low as reasonably practicable.

ANCOLD (2003) defines the ALARP (As Low As Reasonably Practicable) principle as *"that principle which states that risks, lower than the limit of tolerability, are tolerable only if risk reduction is impracticable or if its cost is grossly disproportionate (depending on level of risk) to the improvement gained."* WorkSafe (2011) provides a similar definition (e.g. Figure 67). In Table 22 none of the risks labelled as tolerable subject to ALARP have been shown to be as low as reasonably practicable; hence they cannot be confirmed as tolerable.

The finding that the approved Seymour Quarry presents intolerable risks (Table 22) is consistent with the following features of the site. These are also features of the proposed Seymour Quarry.

- The high likelihood that floodwater spilling into Seymour Quarry will initiate rapid erosion of the floodplain (Sections 9.1.6.8 and 9.1.6.9) and that it is probable that this erosion will propagate a substantial distance up the Goulburn River in a single flood (Section 9.1.6.10);
- The natural behaviour of anabranching rivers such as the Goulburn and the factors increasing the likelihood of an avulsion at Seymour (Sections 9.1.1 and 9.1.4);
- Overseas guidance on the management of pit capture suggesting quarrying should not be close to infrastructure and, if it were an appropriate distance away, then the basement of the pit should be above the bed of the Goulburn River, only one quarter of the pit depth proposed at Seymour Quarry (Section 9.1.3);
- Despite the recent history of large quarry pits on the mid-Goulburn River, and that they are largely untested by significant floods, pit capture has occurred at two quarries (Section 9.1.5) and significant erosion at Seymour Quarry (Section 9.1.6.8.3);
- The potential for a full avulsion of the Goulburn River into the township of Seymour (Section 9.1.6.11); and
- The likelihood and consequences of pit capture described in case studies and the high values associated with the infrastructure and the Goulburn River around Seymour Quarry (Sections 9.1.2, 9.2.2 and 9.2.3).

Overall this risk assessment has only been able to use the consequence table and an adaption of the likelihood table from the draft Extractive Industries Guidelines (DEDJTR, 2015). The Guidelines have the following shortcomings, in order of priority. The three highest priority shortcomings had to be addressed for the veracity of the risk assessment. However, the three lower priority shortcomings were accepted by the author as the effect on the veracity of the risk assessment was considered acceptable relative to the benefit of retaining some consistency with the DEDJTR (2015) guidelines.

1. The thresholds for broadly acceptable risks in the Extractive Industries Guidelines permit much higher risks than the risk tolerance standards for public safety, infrastructure and the environment. For many high consequence risks (infrastructure and fatalities) the acceptability of risk is based on the AEP and ARI (Sections 10.1 and 10.3) not the total probability over a period of time used in the DEDJTR Guidelines.

2. DEDJTR (2015) proposes the risk assessor to consider likelihood as a percentage probability over a short time frame, 5 years or the project life (Table 9). This allows the assessor to categorise likely events, with high annual exceedance probabilities (AEP), as unlikely. However, this may be unacceptable as risks can be ongoing and hence the likelihood of such events needs to be calculated over longer time spans.

3. The qualitative risk table generated by RRAM (DEDJTR, 2015) contains misleading descriptions for risks, as discussed in Section 9.3. Note this shortcoming compounds any errors in calculating likelihood. An understated likelihood may still be a high risk but may be further understated by the risk description.

4. The likelihood ratings (Table 9) do not include categories sufficiently rare (unlikely) for identifying tolerable and broadly acceptable risks to public safety (Section 10.3). For example, NERAG includes very rare and extremely rare categories (AGD, 2015a, Table 10). This shortcoming did not need to be addressed for this report as public safety risks at Seymour Quarry are reasonably described by the likelihood categories in Table 10.

5. The DEDJTR (2015) consequence categories do not address societal concerns that are in national guidelines for risk assessment (AGD, 2015a; Standards Australia, 2013), including consequences for public administration and social setting (or, for a private company, management and reputational consequences). Societal concerns are relevant at Seymour Quarry, particularly as the Goulburn River is a Heritage River in part due to the high social values (Section 9.2.2.1).

6. The likelihood range of possible (Table 9) includes events that are more than twice as likely to happen (70% chance) than not happen (30% chance). Describing such events as possible is misleading. Descriptors such as probable or likely are more apt.

12 FACTS, MATTERS AND ASSUMPTIONS UPON WHICH THE REPORT PROCEEDS

The facts, matters and all assumptions upon which this report proceeds have been referenced within the text and are listed in Section 13.

13 DOCUMENTS, LITERATURE AND OTHER MATERIALS USED

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14 PERSONS CARRY OUT ANY TESTS OR EXPERIMENTS RELIED UPON

The author utilised the results of geotechnical investigations undertaken by Smith (2011) as an input to the determination of the threshold of motion for sediment on batter slopes (Section 9.1.6.8.2).

15 STATEMENTS

15.1 Summary of the author's opinion

Based on the review of the literature and the recent history of quarrying on the mid-Goulburn River, the author's opinion is summarised as:

- Local and international case studies indicate that, for quarries that are of generally lower risk than Seymour, the capture of floodplain pits is essentially inevitable in the long term;
- The natural behaviour of an anabranching river such as the Goulburn indicates that the excavation of deep pits at Seymour Quarry will cause the river channel to re-occupy this part of the floodplain;
- The literature recommends intervention to manage the impacts of floodplain mining including locating pits above the 100-year ARI floodplain, restricting the maximum depth of extraction to remain above the channel thalweg (or levees) and substantial setbacks from major infrastructure. As such aspects are not included in the design of Seymour Quarry or the plans for expansion the development is high risk;
- The long duration of flooding at Seymour, the connection of the southern pit to an existing downstream channel and that this channel is on a substantially shorter course than the Goulburn River all increase risks of a full avulsion at the site; and
- Although large quarry pits have only recently developed on the floodplain of the mid-Goulburn River, and have not been tested by large floods, pit capture has occurred at the other two large quarries and significant erosion at Seymour Quarry. This empirical evidence suggests that large pits such as those proposed at Seymour Quarry will not be stable.

The detailed investigation of the risks related to floodplain flow found intolerable risks associated with Seymour Quarry as:

- Floodwater spilling into Seymour Quarry will initiate rapid erosion of the floodplain, as occurred when some floodwater spilt into the pit in September 2010;
- Considering the duration of flooding and rates of upstream degradation, once the Goulburn River has been captured by Seymour Quarry it is probable that erosion will propagate a substantial distance upstream in a single flood;

- There is the potential for a full avulsion of the Goulburn River into the township of Seymour;
- 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;
- The Goulburn River is a Heritage River and has high environmental, social and economic values. Failure of a pit of the size and depth of Seymour Quarry is likely to cause large scale and essentially permanent damage to the Goulburn River; and
- The scale of the landscape changes Seymour Quarry may instigate, and their potentially rapid progression, combines with the proximity of critical infrastructure and the public to create intolerable risks.

The proposed expansion of Seymour Quarry significantly increases risks in two fundamental ways:

1. The expansion increases the likelihood of Seymour Quarry capturing the Goulburn River as high shear stresses will persist for longer and the expansion may also increase the magnitude and area of these shear stresses. Increased shear stresses cause higher erosion rates and longer durations of high shear stresses cause a greater quantum of erosion.
2. The expansion increases the consequences from Seymour Quarry capturing the Goulburn River as the expanded pit is likely to cause more erosion and it will take longer for the landscape to stabilise.

15.2 Provisional opinions that are not fully researched for any reason (including the reasons why such opinions have not been or cannot be fully researched);

The author did not express any provisional opinions that are not fully researched.

15.3 Questions falling outside the author's expertise.

The author has not addressed any questions falling outside the author's expertise.

15.4 Indication of whether the report is incomplete or inaccurate in any respect.

Understanding the likelihood that floodplain flow will destabilise Seymour Quarry is complicated by the number of variables and the temporal concurrence of these. The author has limited the scenarios to allow for more analysis and interpretation of the results.

15.5 Declaration.

"I have made all the inquiries that I believe are desirable and appropriate in relation to the reliance of the Applicant on my research to provide a design basis for the quarry pits. No matters of significance which I regard as relevant have to my knowledge been withheld from the Tribunal."

8/4/16

Appendix A Hydraulic modelling

TERRAIN OR DIGITAL ELEVATION MODEL

The geometry of the hydraulic model was based on a digital elevation model (DEM) created from the ESRI Ascii files supplied by DELWP (formerly DEPI) via the November 2013 aerial laser survey. The November 2013 DEM was modified in TUFLOW to both more accurately reflect current ground surface and to reflect the proposed terrain at Seymour Quarry.

Where there is water in the landscape the aerial laser survey details the water surface level not, for instance, the bed level of the Goulburn River. To take account of this the bathymetry of the Goulburn River was cut out of the aerial laser survey. This issue was addressed in the 2001 Seymour Floodplain Mapping Study (Walden et al., 2001) where they used the SR&WSC cross sections of the Goulburn River but also repeated five of these cross sections for verification. The locations of the existing SR&WSC cross sections and those that were verified are shown in Figure 4.

CALIBRATION OF THE HYDRAULIC MODEL

The hydraulic model was calibrated to refine the performance of the model and ensure it can accurately replicate the hydraulic characteristics of the river and floodplain. This then provides some confidence in the accuracy with which the model will predict flow properties during a design flood such as the 100 year ARI event.

Approach

The 1974 flood is the only historic event for which a number of high quality flood levels have been collected at Seymour. The flows for the 1974 flood were based on the water levels recorded at Seymour gauge (gauge 405202, Figure 68) and the rating (the height verses discharge relationship) of the gauge. It is noted that the rating of the gauge at higher flows was checked by WBM (Walden et al., 2001) using their hydraulic model, thereby providing some confidence in the flows at Seymour gauge during the 1974 flood.

An issue with calibrating a hydraulic model at Seymour is that the gauges describing the inflows from Sunday Creek, Sugarloaf Creek at Ash's Bridge (gauge 405240) and Sunday Creek at Tallarook (gauge 405212), did not record continuous flows for the 1974 flood. This is important as the 1974 flood was the result of flooding from Sunday Creek coinciding with elevated flows in the Goulburn River (Walden et al., 2001).

With accurate flow data only available at the Seymour gauge, the upstream boundary of the hydraulic model was established immediately upstream of the gauge for the calibration runs. Model runs of the larger area including the Seymour Quarry were used to establish an upstream inflow boundary alignment at the gauge that followed a line of equal water level.

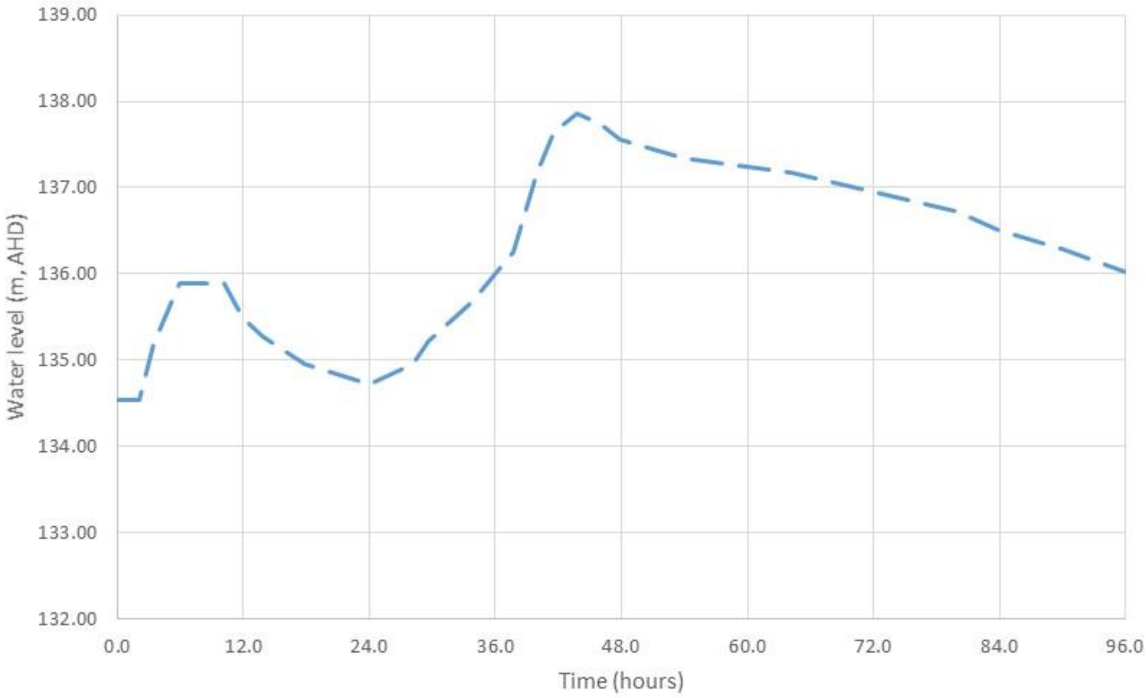

Figure 68 **Water levels measured at the Seymour gauge from the 14th to the 18th May 1974.**

For calibration, the roughness values for the floodplain and river channel were incrementally adjusted in the hydraulic model to achieve an acceptable fit between the high water marks surveyed after the 1974 flood and those produced by the hydraulic model. Counting the height recorded at the gauge, there are 19 high water marks for the 1974 flood downstream from the Seymour gauge (SR&WSC, 1983). However, high water mark number 214 was not used as the recorded water level is 2.1 metres below ground level.

Results of the calibration

The difference between the water levels generated by the calibrated hydraulic model and those observed (surveyed) at the 18 high water marks is shown in Figure 69. These water level differences are shown spatially in Figure 70 and Figure 71.

The calibrated hydraulic model generated a water level (No. 205 at the Canadian Hotel in Emily Street (SR&WSC, 1983)) 0.634 metres below the recorded flood level, a difference that could not be explained if the local modelled velocity head was converted to water depth (water "standing" against an object/structure). Given the otherwise good calibration results in this region of the model, the roughness was not changed to address this one water level.

Upon calibration, the hydraulic model was validated by comparing the water level measured at the maximum gauged flow at Seymour gauge (approximately a 12 year ARI event, 771 m^3/s) to the water level generated by the calibrated hydraulic model at the same discharge. The hydraulic model generated a water level just 0.02 metres higher for the gauged flow rate at the Seymour gauge.

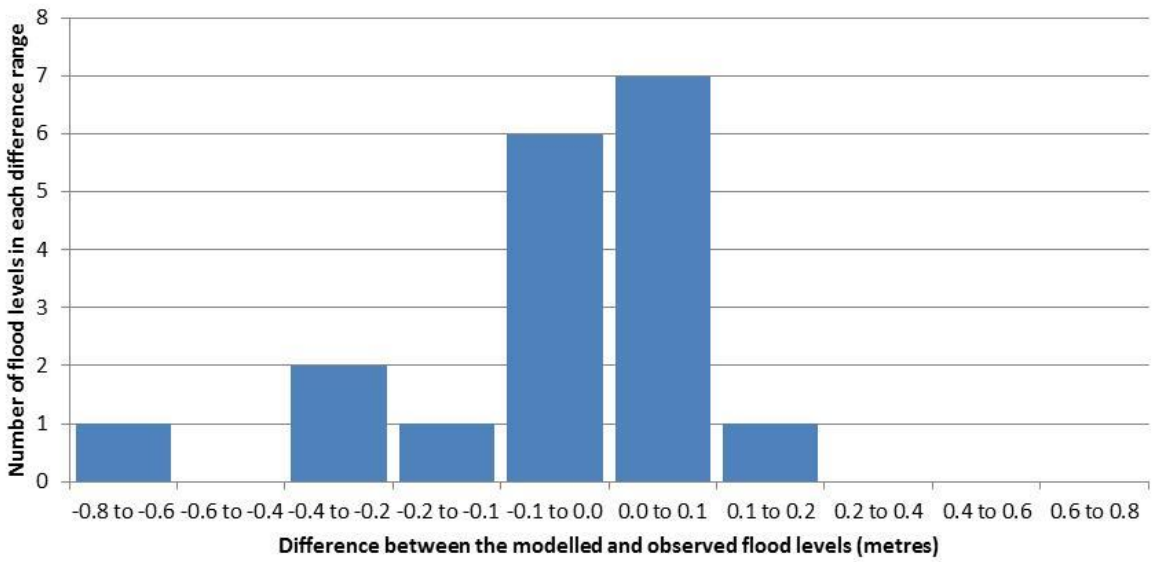

Figure 69 The number of flood levels in each range of difference. The difference is the modelled flood level minus the surveyed (observed) flood level.

Figure 70 Difference between the 1974 flood levels modelled in TUFLOW and the surveyed high water marks in the township of Seymour.

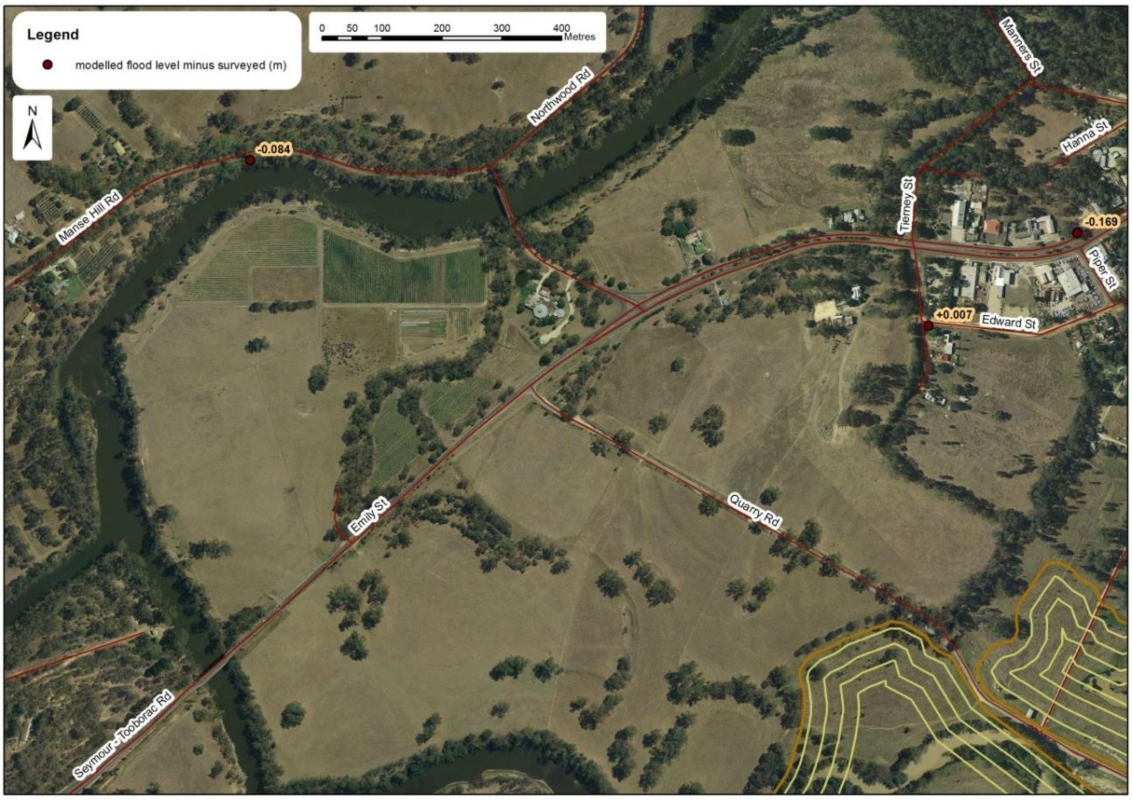

Figure 71 **Difference between the 1974 flood levels modelled in TUFLOW and the surveyed high water marks on the upstream side of Seymour.**

Adopted roughness parameters

Table 23 summarises the Manning's roughness values applied within the TUFLOW and ESTRY hydraulic model domains. The values were primarily determined through calibration to the existing flood levels. However, a number of values were adopted from the literature that are either predictable and/or not possible to determine via calibration.

For the concrete box and pipe culverts a Manning's n value of 0.012 was adopted based on the culverts being straight structures with some debris present (Chow, 1959).

The Manning's roughness values for the quarry pits were determined based on commonly adopted ranges of Manning's n. The unusual aspects of the proposed southern quarry pit and the northern pit that reduce the hydraulic roughness relative to the adjacent natural channel are listed below. The influence of factors such of these on roughness was first discussed by Cowan (1956).

- The uniformity of the cross-section;
- The straight planform;
- The depth (roughness reduces as depth increases);
- The width (roughness of banks and associated vegetation has less influence);

- The pits do not have the in-stream roughness elements such as large woody debris and bars and benches that are found in natural channels.

It is noted that the above characteristics do not equally apply to all of the approved southern pit as parts of it does not have a straight planform, it is not uniform in cross section and in many locations it is half the depth and a fraction of the width of the proposed southern pit.

With reference to the general literature on Manning's roughness for stream channels that might have some application to quarry pits, Henderson (1966) provides a range of Manning's n of 0.025-0.030 for natural river channels that are clean and straight. For excavated or dredged channels in gravel that are clean with a uniform section Jarrett and Petsch (1985) provide a range of Manning's n of 0.022-0.030. Hence a Manning's n value of 0.025 was adopted for the northern pit, the proposed southern pit and for the deepest sections of the approved southern pit. A value of 0.030 was adopted for the areas of the approved southern pit that are sinuous, half the depth and of substantially less width than the proposed pit.

For other Manning's n values adjusted via the calibration the adopted values were checked against guides provided in the literature to ensure they were in acceptable ranges:

- Natural river channel, winding with pools and shoals 0.033-0.04 (Henderson, 1966)
- Roads 0.015-0.025 (AR&R, 2012)
- Treed areas with heavy stands of timber, a few down trees, little undergrowth, flood stage below branches 0.08-0.12 (Chow, 1959)
- Floodplain with scattered brush and heavy weeds 0.035-0.07 (Chow, 1959).
- Built-up areas with buildings, gardens and fences combined 0.08-0.3 (AR&R, 2012)

Table 23 Adopted Manning's roughness values.

Land use	Adopted Manning's n roughness
Waterways	0.035
Quarry pits	0.025-0.03
Floodplain with grass and shrubs	0.065
Treed areas	0.09
Residential areas	0.3
Commercial areas	0.35
Pipe and box culverts	0.012
Roads	0.022

Figure 72 is the direct check file output from TUFLOW showing where the land use areas and hence roughness values in Table 23 were applied to the hydraulic model.

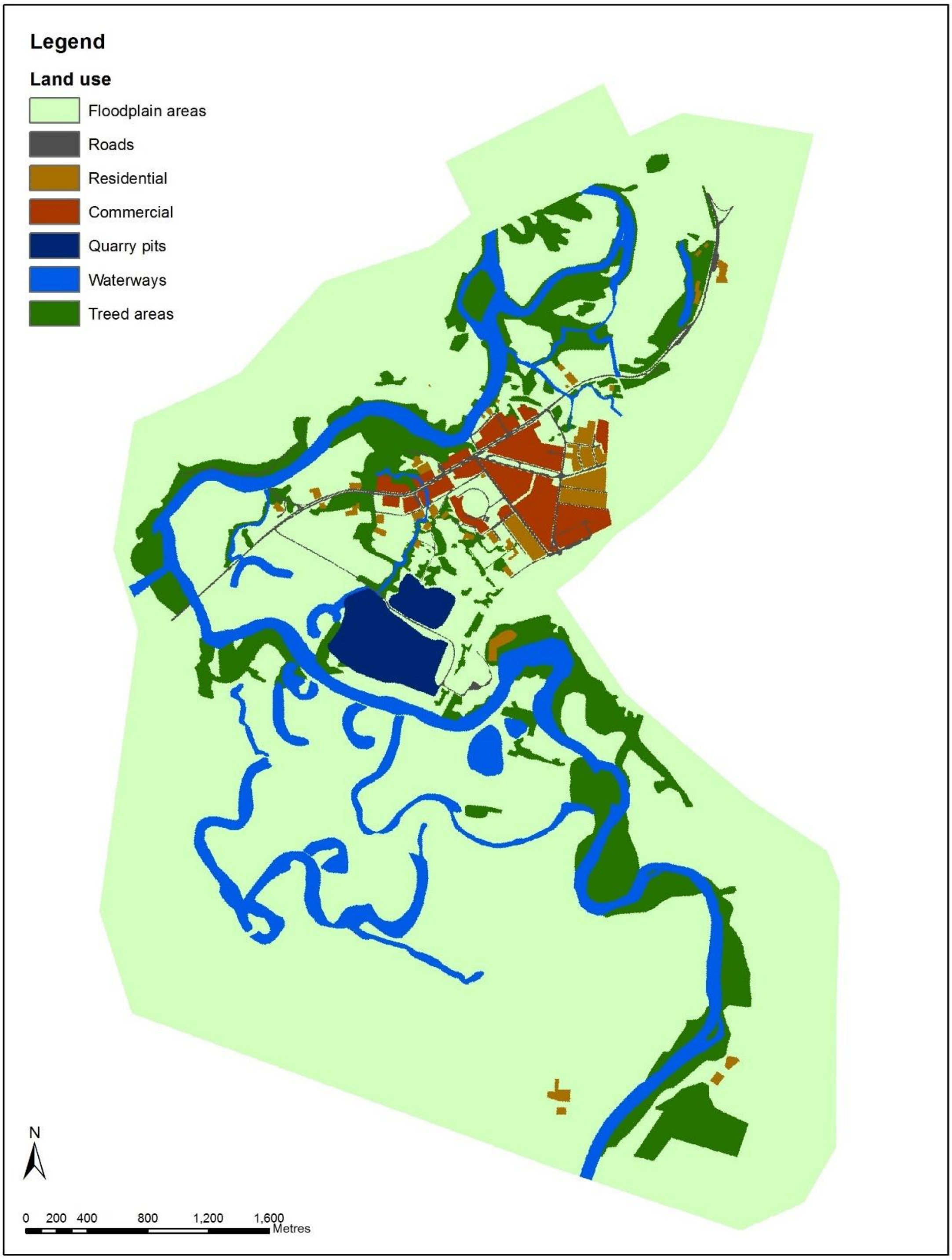

Figure 72 **The areas assigned the land use and Manning's roughness values in Table 23.**

Appendix B Professional experience

PROFESSIONAL HISTORY

2011 – 2016	Floodplain and River Health Project Co-ordinator, Goulburn Broken CMA.
2010 – 2011	Senior Fluvial Geomorphologist, SKM Pty Ltd.
2007 – 2010	Group Manager (River Management and Ecology), Water Technology P/L.
2006 – 2007	Senior River Management Engineer and Fluvial Geomorphologist, Earth Tech Pty Ltd.
2005 – 2006	Research Fellow, School of Anthropology, Geography and Environmental Studies, University of Melbourne.
2002 – 2005	Postgraduate Research Scholar, Cooperative Research Centre for Catchment Hydrology and Monash University.
2002 – 2004	Senior River Management Engineer, Earth Tech Pty Ltd (part-time whilst undertaking a doctorate).
1999 – 2002	Regional Manager, Senior River Management Engineer, ID&A Pty Ltd.
1997 – 1998	Senior Civil Engineer, Infrastructure Division, Sinclair Knight Merz Pty Ltd.
1996 – 1997	Senior Environmental Engineer, Environmental Division, CMPS&F Pty Ltd.
1994 – 1996	Civil Engineer, Infrastructure Division, CMPS&F Pty Ltd.
1993 – 1994	Postgraduate Research Student/Research Assistant, University of Essen, Germany.
1991 – 1993	Civil Engineer, Heavy Industry Division, CMPS Pty Ltd.
1990 – 1991	Civil and Structural Engineer, John Mullen & Partners Pty Ltd.

PROFESSIONAL EXPERIENCE

Fluvial Geomorphic and Process Investigations

Goulburn Broken CMA

- Luing Breeders –v- Goulburn Broken CMA. – Preparation of an expert report on the Rubicon River as evidence for the Victorian Civil and Administrative Tribunal. Discussed technical issues at mediation. Negotiation of resolution with Luing Breeders on-site.
- Field assessments and design. – Undertaken numerous assessments to provide geomorphic advice to resolve the appropriate strategy for managing stream health and stability issues. Undertaken the detailed design of waterway management works.

SKM Pty Ltd

- Geomorphic Investigation of upper King Parrot Creek (Goulburn Broken CMA, 2011). – A study of the fluvial geomorphology of upper King Parrot Creek and the development of recommendations to manage the physical form of the stream.

Water Technology Pty Ltd

- Lake Eildon Foreshore Erosion (Lewenberg & Lewenberg, 2010). – Preparation of an expert witness report for the Supreme Court of Victoria on the causes and progression of foreshore erosion at Lake Eildon.
- Geomorphic assessment of Mullaroo Creek and the Lindsay River (Mallee CMA, 2010) – Project manager and fluvial geomorphologist for this Living Murray project quantifying the impact of environmental watering on geomorphic processes to prioritise management intervention.
- Strategic Geomorphic Overviews of Port Phillip and Westernport Catchments (Melbourne Water, 2006 - 2008) - Project manager and fluvial geomorphologist for three major strategic investigations of the catchments included in the jurisdiction of Melbourne Water in 2005. These projects investigated the morphology of the steams of the Mornington Peninsula, the Bass River and the Werribee and Lerderderg River catchments to identify and prioritise using risk weightings the intervention for the River Health Strategy. Werribee and Lerderderg River catchments studied whilst at Earth Tech.
- Geomorphic Classification of the tributaries of Port Phillip and Westernport Bays (Melbourne Water, 2007) - Conducted an introduction for geomorphologists and waterway engineers to the geology and geomorphology of Port Phillip and Western Port Bays. Reviewed the classification for the rivers and streams of all tributaries of Port Phillip and Westernport Bays.
- Maroochy River and Mountain Creek geomorphic studies (Sunshine Coast Regional Council, 2008) – Project manager and fluvial geomorphologist identifying the key processes causing the deepening and enlargement of Mountain Creek and the erosion of banks on the estuary of the Maroochy River.
- Aura Vale Lake Geomorphic Study (Melbourne Water, 2009) – Project manager and fluvial geomorphologist studying the impact of Cardinia Reservoir and Aura Vale Lake on the destabilisation of Muddy Creek. Changes to catchment hydrology and sediment transport were found to be factors along with the diversion of the creek for infrastructure.
- Harrap Creek Geomorphic Study (Melbourne Water, 2009) - Project manager and fluvial geomorphologist studying the impacts of residential development in the Harrap Creek catchment and the threat the associated sediment supply poses to the Balcombe Creek estuary.

Earth Tech Pty Ltd

- Geomorphic Overview of Parwan Creek and Tributaries (Melbourne Water, 2007) - Project manager and fluvial geomorphologist. Detailed investigation of erosion control structures and the morphology and processes of change along the streams of the Parwan Valley. Risk based prioritisation of management intervention.

- Flood Damage Assessments for the Flinders Ranges (Department for Transport, Energy and Infrastructure, South Australia, 2007) - Assessment of the fluvial geomorphic and hydraulic causes of flood damage during the January 2007 floods of an estimated 1 in 1000 years average recurrence interval in the Flinders Ranges Region.

- Dandenong and Dobsons Creek and the Blind Creek Project Concept Plans (Melbourne Water, 2006 - 2007) - Project manager and fluvial geomorphologist interpreting the morphology of these systems and developing a concept plan for creek restoration in associated with ecologists and landscape architects and in consultation with stakeholders, including the community.

- Strategic Restoration Plan (Wimmera CMA, 2006) - Strategic and risk based assessment of the stability and management issues on Mt Williams Creek, Fyans Creek, Yarriambiack Creek, Dunmunkle Creek and the middle Wimmera River.

- Fluvial geomorphology of the Murray River (NSW Department of Water and Energy, 2004 - 2009) - Seven separately commissioned river management plans for reaches of the Murray River requiring fluvial geomorphic investigation and the development of management recommendations to address the effects of regulated flow on ongoing channel evolution.

- Avulsion management plans (North East CMA, 2003 - 2004) - Project manager and fluvial geomorphologist for three separate studies identifying the key processes driving major channel development and specifying actions to effectively manage this process.

- Geomorphic classification (various CMAs & CWMs, 2002 - 2004) - Undertaking various strategic projects to assess the geomorphic classification of rivers for Catchment Water Management Boards and the Catchment Management Authority in:

    - The catchments of the Glenelg and Hopkins Rivers;

    - The Adelaide Hills; and

    - The Barossa Valley

- Technical Guidelines for Waterway Management, Victoria (DSE, 2005) - Fluvial Geomorphologist and Senior Waterway Engineer co-authoring the Technical Guidelines for Waterway Management for Victoria.

University of Melbourne

- Lower Goulburn Floodplain Geomorphology Study (Sinclair Knight Merz, 2005) - Investigation of the likelihood of an avulsion occurring as a result of increasing flows to the floodplain channels. Further erosion risk work was also undertaken separately for GBCMA whilst at Earth Tech.
- Fluvial geomorphology of the lower and middle Ovens River (North East CMA, 2004) – Lead investigator and principal author for the fluvial geomorphic investigation of the post European settlement evolution of the Ovens River and the processes important to contemporary physical form. Recommendations to manage the future evolution of the Ovens River were made.
- Research into sediment transport and turbidity (EPA Queensland, 2005 - 2006) – Researcher for the investigation of sediment transport and what components of sediment transport are described by turbidity in a program looking at the impact of sediment on the Great Barrier Reef.
- Water savings in wetlands along the Murray River (NSW Department of Water and Energy, 2005) - Assessment of the morphology and hydraulics of wetlands on the Murray River between Lake Hume and Swan Hill to determine interactions with river flows and the potential to isolate from unseasonal summer flows.

Monash University

- Review of the lower Goulburn Floodplain Rehabilitation Project (Monash International Pty Ltd, 2004) – Fluvial geomorphologist providing the technical input into the review of the value of the lower Goulburn Rehabilitation Project for the federal government.
- Unsteady state hydrology and hydraulic modelling of Ruffey's Wetland (Department of Civil Engineering, Monash University, 2005) - Unsteady state modelling of numerous gauged flow events to determine the impact of unsteady flow and detention on hydraulic parameters as inputs into the water treatment provided by this wetland.

ID&A Pty Ltd

- Manual for Small Scale Watercourse Erosion Control Works (Onkaparinga Catchment Water Management Board, 2000) – Co-authored the manual to provide an overview of geomorphic processes that lead to erosion. The different erosion processes were reviewed in detail and strategies proposed to address these processes.
- Isaac River Mine Subsidence Strategy (Goonyella Riverside Mine, 2000) - Conducted the review of the impact of mine subsidence on sediment transport on the Isaac River. Developed strategies to limit the deterioration of the physical form of the river in response to subsidence.

River Management

SKM Pty Ltd

- Erosion Control Structures (North Central CMA, 2011). – Assessment of the failure mechanisms of erosion control structures in the catchments of the Campaspe and Loddon Rivers after the 2010 and 2011 floods. Quantification and risk based prioritisation of rehabilitation works.

Water Technology Pty Ltd

- Fire Recovery Projects (Goulburn Broken CMA, 2009 - 2010). – Senior waterway engineer examining the impacts of the 2009 fires on the Steavenson, Taggerty and Big Rivers. The impacts of the fires and associated sediment transport on stream health and stability and public infrastructure was investigated and management actions identified.

- Flood Recovery Project (East Gippsland CMA, 2009) – Senior waterway engineer for two major stream stabilisation sites. Undertaking the detailed design for longitudinal profile stabilisation and providing conceptual design and checking for alignment training and the potential development of an avulsion.

- Monitoring Program for the Murray River (NSW Office of Water, 2010) – Development of a monitoring program designed to facilitate the adaptive management of river health on the Murray River.

- The Diversion of Deep and Burngrove Creeks (BMA Coal, Blackwater Mine, 2008 - 2010) – Project manager and senior waterway engineer for the development of functional designs for the diversion of Deep and Burngrove Creeks at the Blackwater Mine. Assisted in the testing of a range of hydraulic and geomorphic criterion to design stable stream morphology.

- The Management of the Parlour and Common Creek anabranch system on the Murray River (New South Wales Office of Water, 2009 - 2010) – Hydraulic engineer and fluvial geomorphologist providing specialist advice and review for the development and two-dimensional hydraulic modelling of conceptual designs.

- Yackandandah Creek and King River Waterway Action Plans (North East CMA, 2009). – Fluvial geomorphologist providing specialist input on geomorphic issues such as sediment transport, aggradation, degradation, fire related impacts and the development of anabranches for the preparation of strategic waterway management plans for these catchments.

Monash University

- Undergraduate teaching in Waterway Engineering, Hydrology, Hydraulics, Surveying and River Behaviour and Processes (Monash University, 2002 – 2005) – Post graduate research scholar conducting tutorial classes in the above subjects; including hydraulic laboratory experiments and supervising surveying practice classes. This involvement in the core curriculum for Civil and Environmental Engineering at Monash University over a period of three years helped attain an in-depth understanding of the physical sciences that support river management.

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- Strategic Works Review for Management of the Hume to Yarrawonga (Lake Mulwala) Reach of the Murray River (NSW Department of Water and Energy, 2007) – Senior waterway engineer for this review of the efficacy of river management works on the Murray River and the development of recommendations for modifying current strategies.
- Scoping study for the management of Merricks Creek (Melbourne Water, 2006) - Project manager and senior waterway engineer for the field work and desktop evaluations to scope the strategic direction that restoration of the Merricks Creek Catchment should take.
- The diversion of New Chum Creek and rehabilitation of Spring Creek (BMA Coal, 2006) - Project manager and senior waterway engineer for the approval process, detailed design to construct two river diversions at Poitrel Mine and rehabilitate Spring Creek at Saraji Mine.

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- Scoping Study for Waterway Management of the Murray River, Hume to Yarrawonga (MDBC, 2001) - Project manager responsible for the technical and consultation aspects of the project that aimed to guide waterway management along this large and important reach of the Murray River.
- North East Catchment Management Authority River Health Strategy (North East CMA, 2001) - Senior waterway engineer responsible for the risk based assessment of strategic priorities for the management of river health in the North East Region of Victoria.
- Upper Goulburn Catchment Recreational Waterway Strategy (Goulburn Broken CMA, 2001) – Senior waterway engineer for field work and community consultation, assessing the impact of recreation on river health and developing management actions to mitigate these impacts.
- Audit of Waterway Management Assets (North East CMA, 2000) – Project manager for the assessment of the condition and threats to structural works on waterways throughout the North East Region. Maintenance works were costed and prioritised within a risk framework.
- Mitta Mitta River Waterway Management Strategy (North East CMA, 1999) – Senior waterway engineer for the Mitta Mitta River Waterway Management

Strategy. Conducted community consultation, liaison, press conference and a presentation to the community.

- Assessment of Barmah Forest anabranches (DSE, 2001) - Project manager and senior waterway engineer for the assessment of the stability of Black Engine and Cutting Creeks, anabranches of the Murray River. The findings of this assessment were presented to the Barmah-Milawa Forum.

- Waterway Action Plans (North East CMA, 1999 - 2001) – Project manager and lead investigator for nine Waterway Action Plans for the North East CMA. These plans involved community consultation, condition assessments, investigation of waterway management issues, risk based prioritisation of interventions, and the costing and formulation of an action plan.

- Jordan's Bend Meander Cut-off (Goulburn Broken CMA, 2001) – Modelling and detailed design of a weir at Jordan's Bend, Shepparton to distribute flows around an abandoned meander loop on the Goulburn River.

- Felltimber Creek Wetland (North East CMA, 2000) – Project manager and designer of the hydraulics and hydrology of the Felltimber Creek wetland. Wetland was designed and constructed for retrofit to an existing urban area.

- Oxley Creek stream degradation (Santos Pty Ltd, 1999) – Project manager and lead investigator for the impact of sand and gravel extraction on stream degradation along Oxley Creek, a tributary of the Brisbane River.

Floodplain Management

Goulburn Broken CMA

- Mansfield Floodplain Management Study. – Flood mapping through two-dimensional hydraulic modelling. Report and mapping prepared for planning scheme amendment and to derive flood levels for land use planning.

- ENRC Parliamentary Enquiry into Floodplain Infrastructure. - Provided the technical review of issues for the CMA's submission. Presented to a hearing of the parliamentary enquiry.

- N & S Garrett -v- Strathbogie Shire. – Made representations to the Victorian Civil and Administrative Tribunal on behalf of the Goulburn Broken CMA.

- King Parrot Creek Floodplain Management Study. – Flood mapping through one and two-dimensional hydraulic modelling. Mapping and flood intelligence developed for a number of event probabilities. Report and mapping prepared for planning scheme amendment.

- Nagambie Flood Study. - Undertaking the two-dimensional hydraulic modelling on behalf of the CMA's consultant BMT WBM Pty Ltd.

- Floodplain Management. – Preparation of funding bids and project briefs for flood studies and floodplain management plans. Preparation of tender documentation, involvement in steering committees and review of flood study outcomes.

- Statutory Planning. – Completion of referrals across the full range of statutory functions conferred on the Goulburn Broken CMA. Assisted with permitting, compliance and audit functions for Works on Waterways.

Environmental Flows and Climate Change

Goulburn Broken CMA

- Victorian Environmental Flows Monitoring and Assessment Program. – Technical direction for the physical form assessment project on the Goulburn River, Broken River and Broken Creek.

Water Technology Pty Ltd

- Climate change impacts on coastal infrastructure (Melbourne Water, 2009). Investigated the geologic setting of sites and Holocene evolution of coastal morphology to identify recent geomorphic processes and assess the risk of shoreline progradation or recession on key coastal infrastructure under climate change scenarios.

- Tomahawk coastal hazard risk assessment (Connell Wagner, 2008). Coastal hazard assessment related to a proposed eco-tourism development at Ringarooma Bay, Tasmania. Reviewed the geomorphic and geologic setting, providing input to the risk assessment for coastal recession.

- Fire Recovery Projects (Goulburn Broken CMA, 2009 - 2010). – Senior waterway engineer examining the impacts of the 2009 fires on the Steavenson, Taggerty and Big Rivers. The impacts of the fires and associated sediment transport on stream health and stability and public infrastructure was investigated and management actions prioritised in a risk framework.

Earth Tech Pty Ltd

- Avon River Environmental FLOWS Project (West Gippsland CMA, 2006) - Managed the FLOWS process for the Avon River and provided the geomorphic expertise to the Technical Panel, developing a scientific basis for geomorphology under the FLOWS method.

- Kiewa River Environmental FLOWS Project (North East CMA, 2007) - Managed the FLOWS process and provided the geomorphic expertise to the Technical Panel.

- Inglis and Flowerdale Rivers Environmental FLOWS Project (Cradle Coast Natural Resource Management Committee, 2007) - Provided the geomorphic expertise to the Technical Panel.

Environmental Assessment

Earth Tech Pty Ltd

- Huddleston's Weir (Wimmera CMA, 2007) – Expert witness providing evidence to the Victorian Civil and Administrative Tribunal on the impacts of proposed alterations to Huddleston's Weir on the health of the Wimmera River and the provision of environmental flows.
- Goldfields Superpipe (Coliban Water, 2007) – Senior waterway engineer and fluvial geomorphologist providing over sight to the strategies used for crossing rivers and streams. Site inspections with design staff and construction contractors to provide technical advice.
- Morwell River Diversion Environmental Effects Statement (International Power, 2003) - Author and assessor of the geomorphic and water quality impacts of diverting the Morwell River and its tributaries around future expansion of open cut mining at Hazelwood Power Station.

ID&A Pty Ltd

- Works on Waterways Assessments (North East CMA, 1999 - 2001) – Senior waterway engineer for numerous assessments of works on waterways across the North East Region.

Relevant publications

Ladson, A.R., and Judd, D.A., 2014. A review of the effect of floodplain gravel mining on river stability. 7th Australian Stream Management Conference, Townsville, Australia.

Martin, J., Lauchlan Arrowsmith, C., Bishop, W. and Judd, D.A., 2010. Hydraulic implications associated with the placement of timber snags in a developing anabranch. 17th Congress of the Asia and Pacific Division of the International Association of Hydraulic Engineering and Research, Auckland, New Zealand.

Judd, D.A., 2009. Propagation of an avulsion by knickpoint migration on the Ovens River, Victoria, Australia. 7th International Conference on Geomorphology, 6-11 July, Melbourne.

Judd, D.A., Rutherfurd, I.D., Tilleard, J.W. and Keller, R.J., 2007. A case study of the processes displacing flow from the anabranching Ovens River, Victoria, Australia. Earth Surface Processes and Landforms, 32(14): 2120-2132.

Martin, J. and Judd, D.A., 2007. Anabranch management on a regulated reach of the Murray River. In: A. Wilson et al. (Editors), Proceedings of the 5th Australian Stream Management Conference. Australian rivers: making a difference. Institute for Land Water and Society, Charles Sturt University, Thurgoona, New South Wales, pp. 259-264.

Judd, D.A., 2005. How a river anabranch forms: a process study on the Riverine Plain of south-eastern Australia. Thesis, Doctor of Philosophy. Monash University.

Judd, D.A., Keller, R.J., Rutherfurd, I.D. and Tilleard, J.W., 2004. The initiation of an avulsion. In: I.D. Rutherfurd, I. Wiszniewski, M. Askey-Doran and R. Glazik (Editors), Proceedings of the 4th Australian Stream Management Conference. Department of Primary Industries, Water and Environment, Launceston, Tasmania, pp. 326-332.