Risk assessment of floodplain mining pits in the mid-Goulburn Valley

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This report was written by Jacobs and Moroka for Goulburn Broken Catchment Management Authority (CMA) with input from Project Steering Committee which included:

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- Richard Whiting – DELWP, Planning
- Namiko Ranasinghe – Department of Economic Development, Jobs, Transport and Resources (DEDJTR), Earth Resources Development
- David Whitehouse – DEDJTR, Earth Resources Regulation
- Fergal Grahame – Environmental Protection Authority
- Neil Repacholi and Laura Bradley – Goulburn-Murray Water
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0008	20/07/2015	Final Desktop and Field Based Risk Assessment	D. Judd	P Sandercock	20/07/2015

Contents

Executive Summary

Scope of report

This report provides an assessment of the impacts and risks associated with floodplain mining in the mid-Goulburn Valley. The assessment has been informed by an international literature review of the range of impacts and risks that floodplain mining poses to rivers, and the management strategies that have been used to mitigate against these risks (Jacobs and Moroka 2014).

Risk assessment framework

A systematic method for identifying, analysing and evaluating risks associated with floodplain mining has been followed that broadly follows the process outlined in the National Emergency Risk Assessment Guidelines (National Emergency Management Committee 2010). A risk assessment was undertaken based on desktop information and field investigations of extraction operations in the mid-Goulburn Valley.

Identified risk scenarios

Three main risk scenarios have been identified that have the potential to result in pit capture (Jacobs and Moroka 2014):

1. Lateral migration of river channel into the pit
2. Sub-surface piping into pits and subsequent failure of pit walls
3. Flow of water into and through the pit and subsequent erosion of the buffer strip between the channel and the excavated pit

This risk assessment analyses the risks to the physical environment and infrastructure located in the mid-Goulburn Valley as a result of pit capture by the mechanisms outlined in the above three risk scenarios. The consequences and likelihood of each risk scenario have been assessed for nine work authorities, three of these have surrendered their operations and six remain current.

Consequences of pit capture

The consequences of pit capture for the six current work authority operations are assessed as major to extreme (WA516, WA45, WA1443, WA1189, WA781, WA232). The physical changes that would accompany an avulsion into the pit would result in significant impacts on the ecological condition of the waterway, degrading water quality and the aquatic communities. Any infrastructure which traverses the impacted area is at risk of being damaged. The physical and infrastructure damages (i.e. change in river alignment, road and railway bridge collapse, property and building damages, severing of services) would be expected to receive extensive media coverage. Sustained widespread concern from key stakeholders and government regarding industry, regulators and referral agencies capability could be expected.

Likelihood of pit capture

Pit capture arising as a result of the flow of water into and through the pit and subsequent erosion of the buffer strip between the channel and the excavated pit is almost certain to occur at the six current work authority operations. The basement of the pits extend below the level of the invert of the Goulburn River which increases the likelihood of pit capture by the Goulburn River. A review of flood modelling indicates that the 20 year flood would inundate the floodplain and result in flow into surrendered and current operations. Sub-surface piping into pits and subsequent failure of pit walls was also assessed as having a high likelihood at five of the six current work authority operations. This is due to the proximity of palaeochannels, anabranches and tributaries that are near the pits. These watercourses will hold water during a flood and potentially initiate failure of pit walls through sub-surface piping into pits. Lateral migration of the Goulburn River into the pit was assessed as a moderate likelihood at one of the surrendered work authority operations (WA141) and two of the current work authority operations (WA781 and WA232).

Evaluation of risks

The likelihood and consequence scores combine to provide an overall rating of risk of pit capture for the three different risk scenarios. The risk scenario that presents the greatest risk to the physical environment and infrastructure assets in the mid-Goulburn Valley is Risk Scenario 3, the flow of water into and through the pits during a flood and subsequent erosion of the buffer strip between the channel and the excavated pit. All of the current work authority operations were assessed as a critical risk for this risk scenario. Risk Scenario 2, sub-surface piping into pits and subsequent failure of pit walls was also assessed as either a high or critical risk at current work authority operations.

In evaluating the risks, the level of risk is compared with what is considered acceptable in reference to existing statutory and planning requirements. It is clear that management of floodplain mining operations does not meet current planning objectives and requirements and that these operations present an intolerable risk to the physical environment and infrastructure assets in the mid-Goulburn Valley. Seven of the nine work authority operations were assessed as having intolerable risks. These correspond with those sites in the risk analysis that were assessed as having a high or critical risk rating. This includes all of the current work authority operations and one of the surrendered operations (WA141).

Risk treatment options

A number of potential management options have been recommended to treat risks. These include:

- Construction of a levee to prevent flow of water into and through the pits (WA141, WA516, WA45, WA1443, WA781)
- Construction of a partial levee and grade control structures that convey flow into and out of the pits (WA141, WA516, WA45, WA1443, WA781)
- Construction of levee along edge of Goulburn River and through gap in railway bridge to prevent flow of water into and through the pit (WA1189)
- Construction of partial levee to allow water to fill pits from downstream end but prevent flow of water into and through the pits (WA232 and WA1189)
- Partial fill of pits to a level above the invert of the Goulburn River (WA141, WA516, WA45, WA1443, WA1189, WA781, WA232)
- Construction of a waterway for section of Island Creek to increase the setback from existing pits (WA45, WA1443)
- Development of system to provide emergency warning of scour at the rail bridge near Seymour (WA1189)
- Vegetated buffer to increase the resistance of the floodplain areas between the pits and river (WA781, WA232)

This risk assessment is a first step in identifying risks at extraction operations. It is recommended that detailed site specific assessments are required to evaluate the risk and mitigation options in more detail. Further investigation of management options is required to ensure they are effective. Particular issues include the potential for unintended adverse consequences of levees and structural works, potential failure of structural measures, requirement of structural measures to have a long design life given that pits are permanent floodplain features, the difficulty of repairing structural measures during a flood event and the time required for vegetated buffers to become effective.

It is the depth of the pits relative to the Goulburn River and their size that are a particular concern. It is well documented in the literature that the risks of pit capture are high where the pit depth extends below the depth of the surrounding waterways (Bureau of Reclamation 2005, Kondolf 1997, Langer 2003, Norman et al. 1998, Packer et al. 2005), which is why industry guidelines recommend that the maximum depth of pit should remain above the invert of an adjacent waterway (Department of Irrigation and Drainage 2009).

Urgent management interventions are required at the six current work authority sites to reduce the risks of pit capture (WA516, WA45, WA1443, WA1189, WA781, WA232). Any further deepening or extension of the areas will only further heighten the risks. For a number of current work authorities (WA516, WA1189, WA781), alteration of approval conditions will be required to address these risks.

The outcomes of this risk assessment provide further justification for the development of a planning framework to assist the Goulburn Broken CMA, Councils, the Department of Economic Development, Jobs, Transport and Resources (DEDJTR) and proponents with decision making about sustainable sand and gravel extraction. It is expected that the planning framework will include specific recommendation that the maximum depth of pits remains above the invert of the Goulburn River and adjacent anabranches and tributaries. The framework will also include recommendations on the dimensions of the pits as well as guidance on the position of pits in relation to surrounding waterways.

1. Introduction

1.1 Context

The Goulburn Broken Catchment Management Authority (CMA) in association with the Department of Environment, Land, Water and Planning (DELWP) has commissioned a study into the sustainability of sand and gravel extraction from the floodplain of the Goulburn Valley. The output of this study is to provide a planning framework for sustainable extraction, and to identify legacy issues and treatments associated with existing and abandoned extraction operations.

1.2 Study objectives

The objectives of the study as set out by Goulburn Broken CMA are to inform agencies of:

- The sustainable scale and location of gravel extraction in the Goulburn Valley
- The risks associated with legacy issues at existing and abandoned sand and gravel pits

In addition, the study will develop a planning framework to ensure sustainable mining. This is likely to involve the development of a planning scheme amendment(s) to assist decision making about sand and gravel extraction in the Goulburn Valley.

1.3 Outline of this risk assessment

Section 1 describes the broader context for this study, study objectives and a description of the study approach with reference to the six project stages.

Section 2 provides an overview of the risk management framework, the context and sources of information for the risk assessment. The process for identifying risks and risk scenarios, risk analysis, evaluation and treatment of risks is explained.

Section 3 presents the outcomes of the risk assessment and priority risks associated with floodplain mining operations in the mid-Goulburn Valley.

2. Risk management framework

2.1 Risk management process

The process for the management of risks is described in AS/NZS IS0 31000:2009 and the National Emergency Risk Assessment Guidelines (National Emergency Management Committee 2010). This is a systematic method for identifying, analysing and evaluating risks and leads to the development of risk-treatment strategies. The process is shown in Figure 2-1.

The process comprises five main elements:

- establishing the context;
- identifying the risks;
- analysing the risks,
- evaluating the risks, and;
- treating the risks.

Communicating and consulting, and monitoring and review also apply to each of the major elements of the process. The following sections describe the steps that have been taken in applying this framework to assess the risks associated with floodplain mining in the mid-Goulburn Valley.

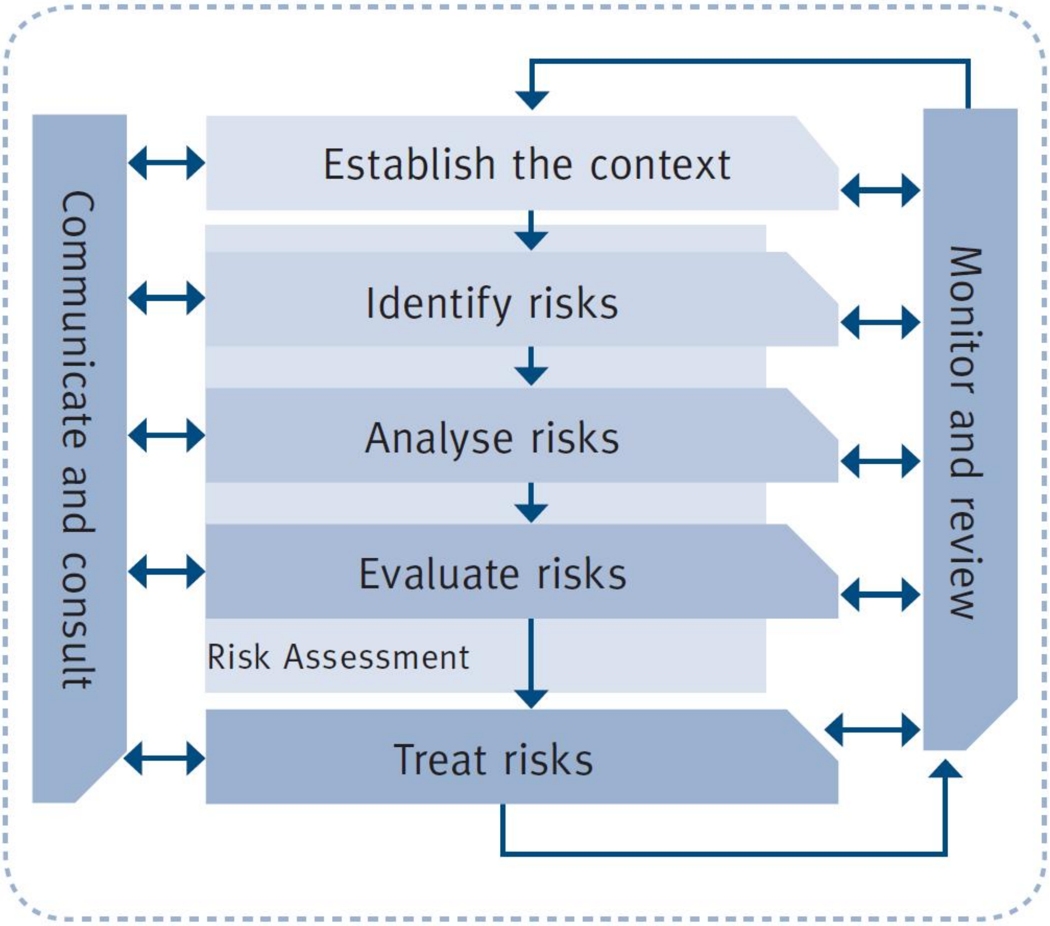

Figure 2-1: Risk management process (from National Emergency Management Committee 2010).

2.2 Establishing the context

2.2.1 Floodplain mining

Floodplain mining increases the landscape's vulnerability to change during floods by altering the natural patterns of water flow and sediment transport. Sometimes, these changes lead to dramatic changes in stream alignment, through pit capture and associated erosion of the stream bed, banks and floodplain (e.g. Mossa & Marks 2011).

The potential impacts of floodplain mining are complex and varied. In some cases, mining pits can sit in fluvial landscapes for many years with seemingly little change. In other cases, the pit may be captured by the stream during a flood (or floods) giving rise to a channel avulsion – where the old channel is abandoned in favour of a new channel entering and exiting the pit. When considered in general terms, the indications from the literature are that pit capture is a highly likely outcome of floodplain mining. Norman et al. (1998) wrote that "in the long term, stream capture by gravel pits is a near certainty. Because the gravel pits have a lower base elevation, there is a risk of rapid channel change into the pits during high flows". Similarly, Kondolf (1997) concluded that "in general, pit capture is inevitable for floodplain pits …"

Table 2.1 provides an overview of some of the potential impacts caused by floodplain pit capture. Pit capture impacts on a river's geomorphic characteristics, sediment transport, hydraulics, hydrology, water quality and aquatic habitat, with these impacts extending upstream and downstream of the pit as well as the area of the pit itself.

Table 2.1: Summary of potential impacts caused by floodplain pit capture (after Bureau of Reclamation 2005).

Elements of Avulsion	Nature of Impact		
	Upstream	Local	Downstream
Geomorphic characteristics	· Incision of channel · Increased gradient · Coarsening of bed · Undercutting and erosion of banks · +/- lateral migration rates	· Alluvial fan development · Reshaping of pits · Loss of natural channel geometry · Increased open water area	· Increased lateral migration · Increased channel width · Incision
Sediment transport	· Increased sediment transport capacity · Reduction in bed load deposition	· Deposition of sediment in pits · Short-term increase in turbidity · Erosion of gravel pit banks	· Reduced sediment supply · Erosion of bed · Coarsening of bed · Increased bank erosion · Short term increase in fine sediment supply
Hydraulics	· Increased slope · Increased velocities · Decreased normal depth · Increased bed roughness	· Decreased slope · Increased channel depth · Increased channel width · Reduced bed roughness	· Increased bed roughness
Hydrology		· Increased flood storage · Increased evaporation · Altered groundwater flow patterns	· Reduction of flood levels · Attenuation of flood peaks · Changes in summer low flows · Lower riparian groundwater levels due to bed lowering
Water Quality		· Temperature increase · Short-term increase in turbidity · Alteration of hyporheic zone	· Temperature increase · Short-term increase in turbidity

Elements of Avulsion	Nature of Impact		
	Upstream	Local	Downstream
Aquatic Habitat	· Habitat disruption or loss due to channel incision · Potential conversion of habitat type/quality · Short and long term habitat instability	· Conversion of free flowing habitat to still water habitat · Potential capture of fish following floods · Potential release of non-native species from captured pits · Alteration of hyporheic zone · Short and long term habitat instability	· Habitat disruption or loss due to erosion of bed · Habitat loss due to altered sediment supply · Potential conversion habitat type/quality · Short and long term habitat instability

Typically, channels newly formed by avulsion are straighter and steeper than their older counterparts. River adjustments to new channel alignments include bed degradation and aggradation, bank erosion and channel widening; with physical impacts often extending many kilometres away from the pit. Infrastructure (road crossings, electricity, telecommunication, water, gas, sewer, etc.) that lie within the area of physical impact may also be damaged or destroyed. There are many examples of floodplain mining leading to pit capture in the literature, with physical impacts leading to significant infrastructure damage. Several examples are presented in Table 2.2 which are illustrative of the range of physical and infrastructure impacts that are associated with river channel changes caused by floodplain mining.

Table 2.2: Documented physical and infrastructure impacts resulting from river channel changes caused by floodplain mining.

River	Physical Impacts	Infrastructure Impacts	Reference
Goulburn Valley, Victoria	Capture of Island Creek tributary (piping failure of bank) caused a knickpoint to progress upstream 340 m, substantial bank collapse and widening, toppled multiple mature red gums (Figure 2.2).	Destroyed a road crossing (Figure 2.2).	Craigie (2012)
Georges River, NSW	Many gravel pits have been captured by the river, increasing tidal velocities and causing channel erosion.		Warner and Mclean (1977)
Tangipahoa River, Louisiana	Six gravel mining pits located within 150 m of the channel, up to 15 m deep were captured by the river between 1980 and 2004. Up to 6 m of bed degradation occurred upstream of pit captures, with aggradation downstream.	A highway bridge failed because of the bed degradation (Figure 2.3).	Mossa and Marks (2011)
Big Escambia Creek, Florida	Avulsion through several pits shortened the length and shifted the creeks junction with the Ecambia River 1.2 km upstream.	Damages led to a $7.7 million (USD) stream restoration project.	U.S. Army Corps of Engineers Mobile District (2000)
Rogue River, Oregon	Floods progressively eroded the bank and flow entered the pit.	Bank erosion progressed upstream onto a residential property and downstream to a powerline which was lost.	Klingman (1998)
Clackamas River, Oregon	High flows led to the capture of an off-channel pit and resulted in 2 m of incision that extended 1 km upstream.	Incision and bank erosion caused undermining of a building at the gravel mine site.	Kondolf (1997)

A Victorian example that demonstrates the impact that river channel changes caused by floodplain mining can have is provided by the capture of Island Creek in the Goulburn Valley. Island Creek is an anabranch of the Yea and Goulburn Rivers. In August 2010, the creek diverted into a sand and gravel extraction pit as a result of piping failure. The diversion caused substantial incision and bank erosion along the creek, with an erosion knickpoint progressing 340 m upstream (Craigie 2012). As this knickpoint progressed upstream the incision and consequent bank erosion destroyed a recently constructed road crossing and riparian vegetation (Figure 2.2).

Figure 2.2: Diversion of Island Creek into a gravel pit on the Goulburn River floodplain (A) caused upstream bed and bank erosion (B) destroying bridge and toppling riparian trees (C). Source: Craigie (2012).

Figure 2.3: Looking downstream to the bridge failure at State Highway 10 near Arcola along the Tangipahoa River in Louisiana, ISA. Mossa and Marks (2011) attribute this bridge failure to mining related degradation.

2.2.2 Strategic requirement for risk assessment

Goulburn Broken CMA has identified sand and gravel extraction in the Goulburn Valley as a significant issue, because of the scale of existing mining activities, legacy issues from old mines and the potential for mining to increase to meet demands of Melbourne's northward expansion. A range of significant environmental values have been identified in the valley and if mining were to occur to the extent identified in the Extractive Industries Interest Areas, there would be a significant environmental impact for the valley as a whole.

The Goulburn Broken CMA is seeking to develop a new planning framework to assist themselves, Councils, Department of Economic Development, Jobs, Transport and Resources (DEDJTR) and proponents with decision making about sustainable sand and gravel extraction in the Goulburn Valley. As part of Stage 2 of this project, Jacobs (2014) completed a review of the existing planning framework and permitting conditions for managing sand and gravel extraction. This review was informative in developing a clear and legislated understanding of the expectations in relation to the environmental management of sand and gravel extraction in the Goulburn Valley.

The following is a list of key requirements and objectives that industry, regulators and referral agencies need to consider in managing floodplain mining operations in the Goulburn Valley:

- Public land along the Goulburn River between Lake Eildon and the Murray River is listed as a Heritage River in Victoria for its significant nature conservation, recreation, scenic and cultural heritage attributes (*Heritage Rivers Act 1992*). Attributes of the Goulburn River as identified by the *Heritage River Act 1992* are to be protected.
- Planning for rural areas should consider: the location of earth resources; the potential for future extraction of earth resources; and minimising impacts on sensitive uses and the environment (State Planning Policy Framework, Clause 11.10).
- In regard to environmental risks, planning should adopt a best-practice environmental management and risk management approach which aims to avoid or minimise environmental degradation and hazards (State Planning Policy Framework, Clause 13).
- The objective of floodplain management is to assist the protection of floodplain areas of environmental significance or of importance to river health, and to protect life, property and community infrastructure from flood hazard (State Planning Policy Framework, Clause 13.02).
- Planning should provide for long term protection of waterways and water quality as natural resources (State Environmental Protection Policy, Clauses 33 and 35; State Planning Policy Framework, Clause 14).
- Planning should ensure that development maintains or improves river and wetland health, waterway protection and floodplain health (Victorian Planning Provisions Land Subject to Overlay, Clause 44.04; Floodway Overlay, Clause 44.03).
- Development on floodplains should protect areas prone to erosion, landslip and other degradation processes and prevent inappropriate development in unstable areas or areas prone to erosion (State Planning Policy Framework, Clause 13).
- Rehabilitation plans need to take into account the special characteristics of the land, the surrounding environment, the need to stabilise the land and any potential for long term degradation of the environment (Mineral Resources (Sustainable Development) Act, 1990, Section 79).
- Planning should ensure that use and development of land for stone extraction does not adversely affect the environment or amenity of the area during or after extraction and that excavated areas can be appropriately rehabilitated (State Planning Policy Framework, Clause 52.09).

These planning controls serve to provide general guidance on floodplain management, the protection of waterways and requirements of rehabilitation plans. They do not however provide technical guidance that can assist in assessing any proposal for sand and gravel extraction. There is a lack of technical information readily available that can be used by the industry, regulators and referral agencies with decision making about sand and gravel extraction operations in the Goulburn Valley. A clearer understanding is required of the potential risks that these operations may have on the valley. This will then be used to develop criteria that outline under what conditions floodplain mining may be permitted to occur to meet the planning requirements.

2.2.3 Scope of risk assessment

The earlier *Review of floodplain mining impacts and risk*s (Jacobs and Moroka 2014) provided an understanding of physical and infrastructure impacts that have resulted from floodplain mining as documented in case studies from around the world, the risks that are associated with floodplain mining and a broad review of management strategies that have been used to address these risks.

There has already been one example on the Goulburn Floodplain where Island Creek diverted into a sand and gravel extraction pit as a result of piping failure; a road crossing and riparian vegetation were destroyed (Craigie 2012). The potential impacts to the physical environment and infrastructure assets associated with an avulsion of the Goulburn River and change in its alignment are far greater (Jacobs and Moroka 2014). It was also noted, that the scale of these impacts on the Goulburn River could be further compounded due to the presence of Lake Eildon and the influence it has had in reducing the availability of sediment along the river. If pit capture were to occur, the time it takes for the river to recover and the extent of the impacts could be far greater as the system has a limited sediment supply as a result of flow regulation (Jacobs and Moroka 2014).

In this report, the learnings from the earlier planning and technical reviews are combined with an understanding of the topographic, hydrological and geomorphological setting of the Goulburn Floodplain to complete a risk assessment of surrendered and current sand and gravel extraction sites in the mid-Goulburn Valley. This risk assessment specifically considers the risks that sand and gravel operations pose to the surrounding physical environment and infrastructure assets. Its purpose is to identify which operations represent a risk and provide a rationale of why or why not this is the case.

The risk assessment has been completed in two stages:

- An initial desktop assessment to identify existing extraction operations that were likely to represent an unacceptable level of risk. A technical workshop was convened as part of this desktop assessment to develop the risk criteria.
- A more detailed risk assessment of sites identified as potentially representing an unacceptable level of risk. This detailed risk assessment is based on a field inspection of selected sites.

2.2.4 Data/information

There are nine existing mines in the Goulburn Valley, three of these have surrendered the work authority and six remain current. Data/information for each of these pits has been collated from a number of sources:

- Goulburn Broken CMA and the Department of Economic Development, Jobs, Transport and Resources (DEDJTR) have provided information on the status of work authority, the number of pits, existing and final approved areal extent and depth of pit operations.
- Aerial and Light Detection and Ranging (LiDAR) Imagery have been used to determine the elevation in metres (AHD) of the floodplain and the basement level for the pits. 100 Year flood level data were provided by Goulburn Broken CMA and this has been used to provide an estimate of depth of flow over the floodplain adjacent to the pits.
- Invert values (bed levels) for the Goulburn River adjacent to pit operations were estimated by reviewing available cross-section and bathymetry data published in Water Technology (2008) or by subtracting 1.5 m from water surface values captured by the 2010 LiDAR.
- Modelled flood depths, water surface elevations depths and velocities were provided for recent modelling of 20, 50 and 100 year ARI floods.

Table 2-3 outlines data collated for the nine mines used as input to this risk assessment. A map showing the general location of the floodplain mines is presented in Figure 2-4.

One of the key variables that is important in assessing risk of floodplain pit capture is the depth of the pit relative to nearby waterways. The risk of pit capture is high in situations where the depth of the pit is greater than the surrounding waterways (Bureau of Reclamation 2005, Kondolf 1997, Langer 2003, Norman et al. 1998, Packer et al. 2005). Figure 2-5 highlights differences in the range of existing and approved pit depths for each Work

Authority assessed in the Goulburn Valley, showing that approved pit depths range from 5 m to 30 m. Seven out of nine of the pits have approval to extract to depths greater than 10 m, which is significant given that the bed of the Goulburn River is generally 5 to 10 m below the adjacent floodplain surface. With the exception of WA1443, a pit approved under the code of practice, all the remaining pits with work authorities have approval to extend to depths below the elevation of the Goulburn River invert (Figure 2-6). Approved pit depths for work authority WA1189 and WA516, extend greater than 20 m below the invert of the Goulburn River. This raises significant concerns, as approval to extract to these depths has already been given. Also of note, is the range in area of pit extractions that have been approved as shown in Figure 2-7.

Table 2-3: Information on floodplain mining pits in the Goulburn Valley.

Work Authority	Status	Number of Pits		Pit setback from waterway (m)	Pit Areal Extent (Hectares)		Floodplain Level (m AHD)[2]	Pit Depth (m) / Basement Level (m AHD)		100 Year Flood Level (m AHD)	100 Year Flow Depth (m)[4]	Goulburn Invert (m AHD)		Basement of Pit minus Goulburn Invert Using Survey Data (m)		Basement of Pit minus Goulburn Invert Using LiDAR Data (m)	
		Existing	Final Approved		Existing	Final Approved		Existing	Final Approved			Survey[5]	LIDAR[6]	Existing	Final Approved	Existing	Final Approved
WA374	Surrendered	2	2	100	0.6	-	202.4	10 / 192.4[3]	10 / 192.4[3]	203	0.6	No Data	196-197	No Data	No Data	-3.7 to -5.0	-3.7 to -5.0
WA151	Surrendered	1	1	500	0.9	-	182.4	14.3 / 168.1[3]	14.3 / 168.1[3]	183.6	1.2	174-177	178-180	-5.9 to -9	-5.9 to -8.9	-9.7 to -11.5	-9.7 to -11.5
WA141	Surrendered	1	1	50	2.8	-	161	13.5 / 147.5[3]	13.5 / 147.5[3]	163.5	2.5	154-160	157-159	-6.5 to -12.5	-6.5 to -12.5	-9.3 to -11.5	-9.3 to -11.5
WA516	Current	1	1	500	3.8	3.8	161	10 / 151	30 / 121	162.5	1.5	154-160	156-157	-3 to -9	-33 to -39	-4.8 to -6.0	-24.8 to -26.0
WA45	Current	5	5	30 / 800[1]	20	20	156	23 / 133	23 / 133	158	2	144-149	149-152	-11 to -16	-11 to -16	-15.8 to -18.9	-15.8 to -18.9
WA1443	Current	1	1	30 / 800[1]	4.8	4.8	155	5 /150	5 / 150	158	3	144-149	149-152	+1 to +6	+1 to +6	1.2 to -1.9	1.2 to -1.9
WA1189	Current	1	2	100	13.1	33	138	20 / 118	28 / 110	139	1	125-132	131	-7 to -14	-15 to -22	-12.6 to -12.8	-20.6 to -20.8
WA781	Current	2	7	50	13.5	56	134.5	15 / 120	15 / 120	135.2	0.7	125-132	127-128	-5.5 to -12.5	-5.5 to -12.5	-7.2 to -8.4	-7.2 to -8.4
WA232	Current	2	2	40	5.5	5.5	132	15 / 117	15 / 117	133.7	1.7	125-132	126	-8 to -12	-8 to -15	-8.7 to -9.3	-8.7 to -9.3

[1] 30 m setback from Island Creek and 800 m from Goulburn River.

[2] Selected value derived from LiDAR data adjacent to pit.

[3] Depth has been assumed based on the area of the pit and a 3H:1V batter.

[4] Calculated from data on 100 year flood level and floodplain surface level.

[5] Invert values derived from a review of cross section and bathymetry data published in Water Technology (2008).

[6] Invert values derived from a review of Goulburn River water surface values 2010 LiDAR. 1.5 m was subtracted from the water surface value to gain an approximate estimate of bed level.

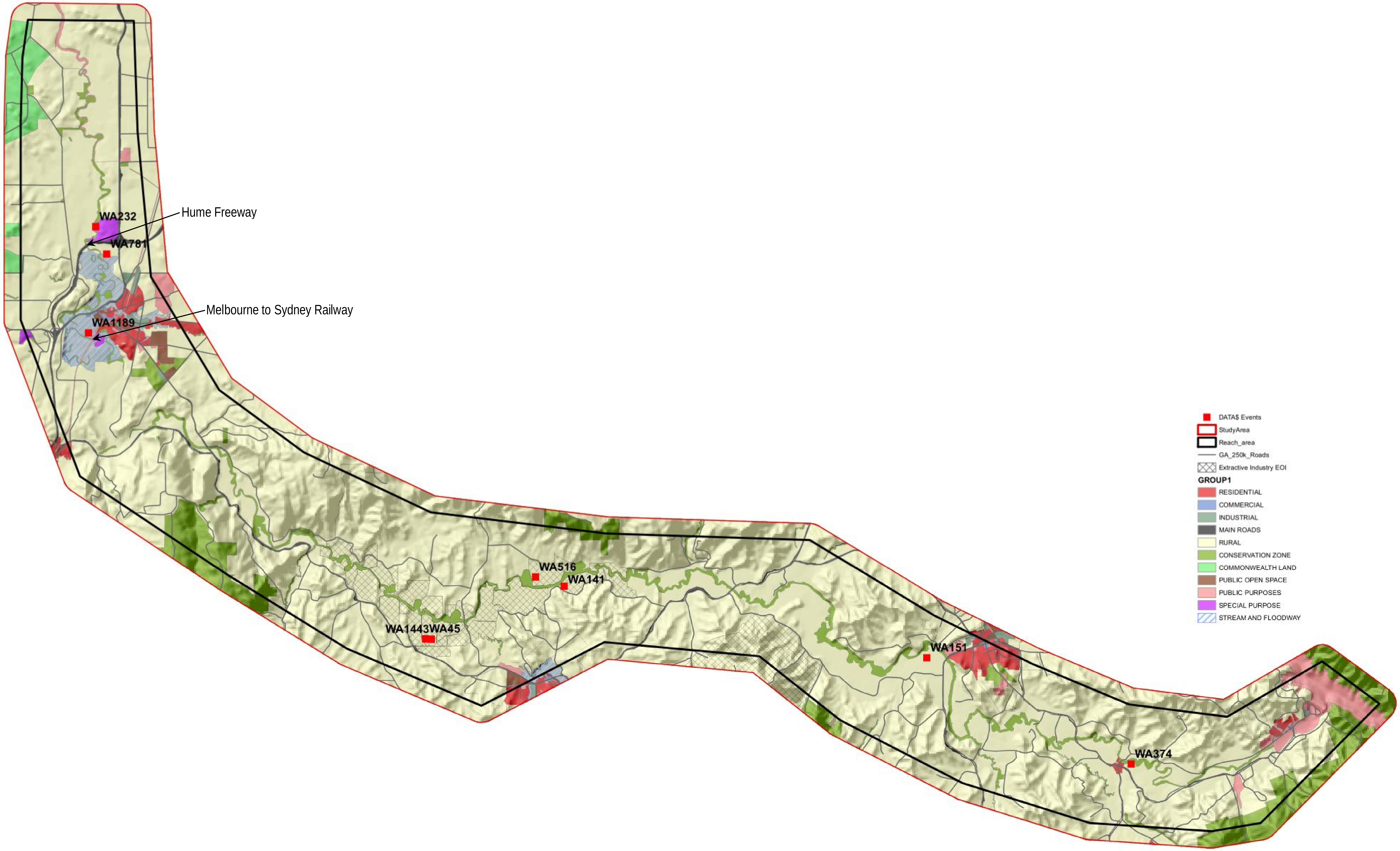

Figure 2-4: Map showing location of floodplain mining pits.

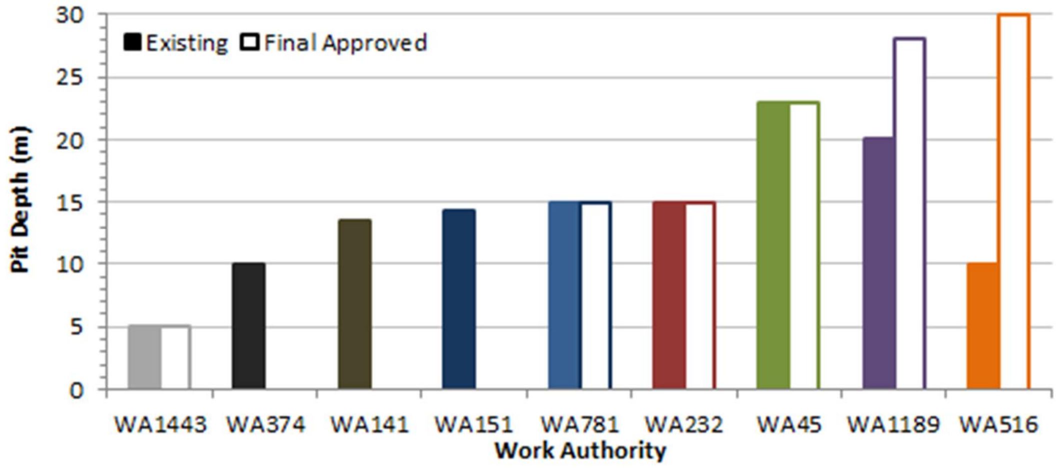

Figure 2-5: Existing and final approved depth of pit.

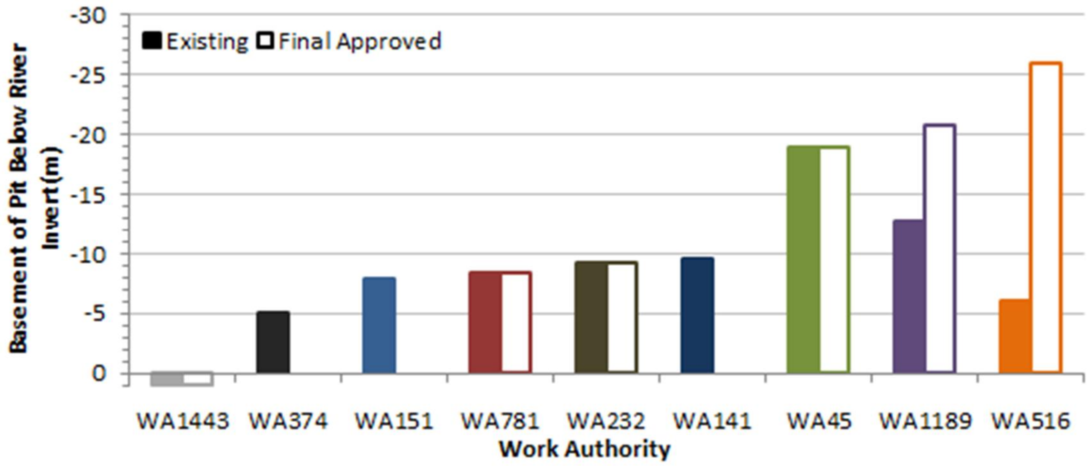

Figure 2-6: Existing and final basement of pit below Goulburn River invert.

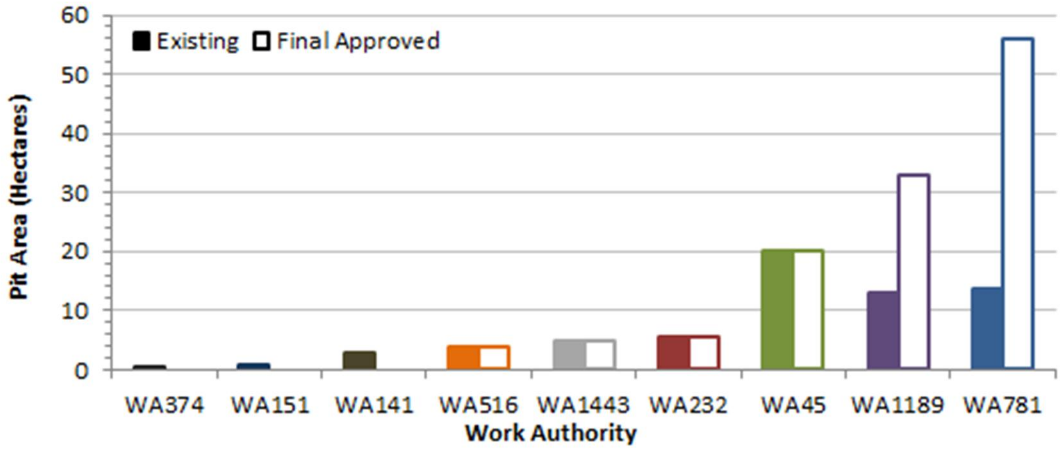

Figure 2-7: Existing and final approved pit area.

2.3 Identify risks

A simple review of the data presented in the preceding section alone is enough to raise the level of concern about existing sand and gravel operations on the floodplain of the Goulburn River. It is important in this study that risks are clearly identified and analysed.

The process of identifying risks is based on:

- an understanding of the processes that lead to pit capture;
- an understanding of the topography, hydrology and geomorphology of the Goulburn River floodplain;
- information provided on the position and geometry of the pits from available information and field inspection;
- an understanding of the factors that influence the likelihood and consequences of pit capture; and,
- identification of assets that could be impacted should pit capture occur.

Three main risk scenarios have been identified that have the potential to result in pit capture (Jacobs and Moroka 2014).

1. <u>Lateral migration of river channel into the pit.</u>
   Pit capture occurs when the strip of land separating the pit from the channel is breached by lateral channel erosion and migration of the channel into the pit (Kondolf 1997). A diagram showing the sequence in which a river channel migrates laterally into the pit is presented in Figure 2.8.

2. <u>Sub-surface piping into pit and subsequent failure of pit walls</u>.
   Piping can occur where the water surface in the river or an adjacent depression is higher than that in the pit. Seepage from the river into the floodplain can exfiltrate from the pit walls into the pit. Prolonged seepage often occurs along preferred pathways to weaken the local substrate resulting in erosion and failure of material (Figure 2.9). Piping failure was the cause of breaching at Island Creek in the Goulburn Valley, where the pit setback from the waterway was 30 m (Craigie 2012).

3. <u>Flow of water into and through the pit and subsequent erosion of the buffer strip between the channel and the excavated pit.</u>
   If floodwaters have access to pit areas, the pit will present an area of decreased flow resistance. This low resistance combined with the pit geometry, which often results in a shortened flow path for flood flows, will increase hydraulic conveyance, and lead to hydraulic drawdown and subsequent acceleration of flow towards the pit. These hydraulic conditions cause the sediment transport capacity of the flow to increase above the incoming rate of sediment supply, resulting in erosion (e.g. Galay 1983). Local turbulent flow around obstructions such as trees on the bank of extraction pits can also initiate knickpoints that develop into avulsions (Gibling et al. 1998, Tooth & Nanson 1999).

   There is a distinction between the processes that operate at the initial stages in which the pit is filling in with floodwater from the processes operating in the later stages of a flood, where the pit has already filled with water. In the early stage of the flood, erosion may be initiated by supercritical flow and the associated hydraulic jump as floodwater cascades into the pit filling it with water (Figure 2.10). Once the water level in the pit reaches floodplain level, the decreased flow resistance associated with the pit area will result in increased hydraulic conveyance, leading to hydraulic drawdown and acceleration of flow towards the pit and potentially erosion (Figure 2.11).

   There must be erosion of the buffer strip between the upstream channel and the pit for diversion of the channel into the excavated pit. An entry and exit channel are required for an avulsion to occur. If an outlet channel from the floodplain pit does not develop, no avulsion occurs, only a diversion and the creation of a backwater in the floodplain pit. Cutoffs may also occur where individual meander loops or multiple loops are abandoned by erosion of a channel through a pit on the inside of the loop (Erskine et al. 1992).

This risk assessment analyses risks to the physical environment and to infrastructure located in the Goulburn Valley as a result of pit capture by the mechanisms outlined in the above three risk scenarios.

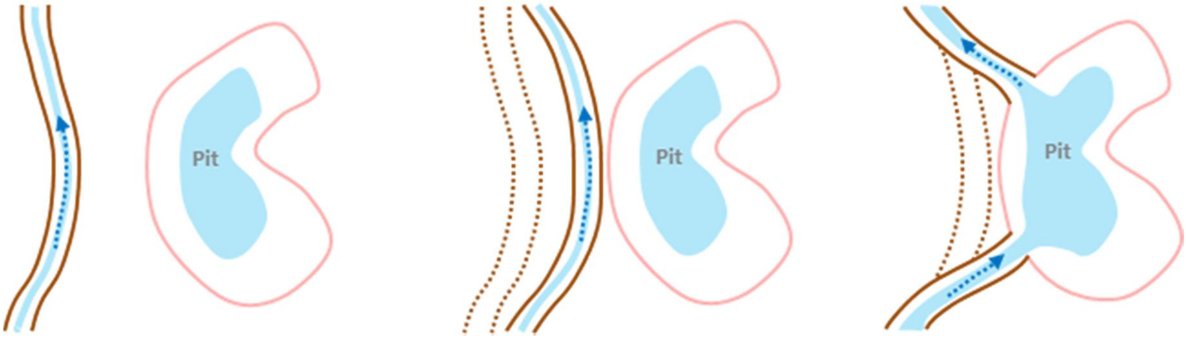

Figure 2.8: Lateral migration of river channel into the pit.

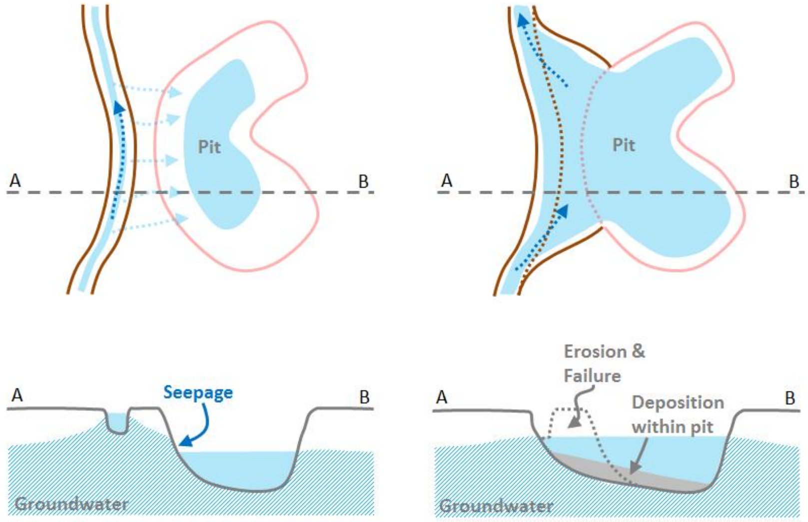

Figure 2.9: Sub-surface piping into pits and subsequent failure of pit walls.

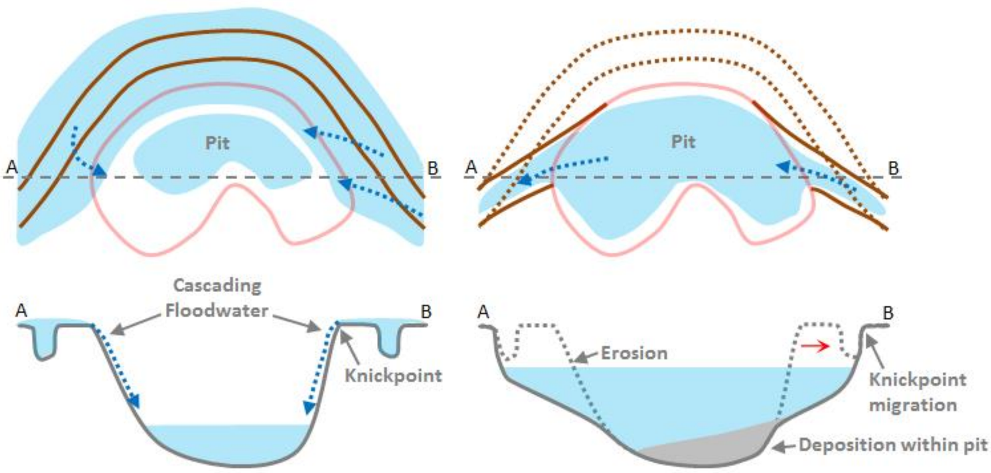

Figure 2.10: Flow of water into and through the pit and subsequent erosion of the buffer strip between the channel and the excavated pit. Erosion may be initiated by supercritical flow and associated hydraulic jump as floodwater cascades and fills the pit with water.

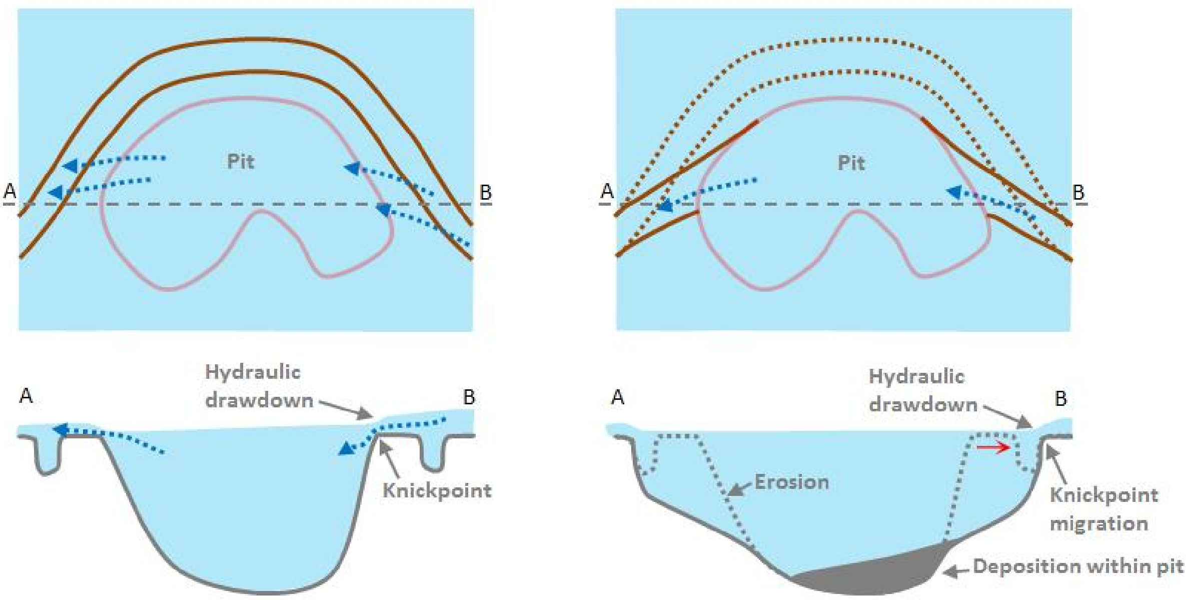

Figure 2.11: Flow of water into and through the pit and subsequent erosion of the buffer strip between the channel and the excavated pit. Once the floodwater is at floodplain the increased conveyance across the pit will lead to hydraulic drawdown, acceleration of flow and potentially erosion.

2.4 Analyse risks

In analysing risk, consideration is given to both the consequence and likelihood of physical and infrastructure impacts arising from each of the three risk scenarios.

2.4.1 Consequence

The consequences of pit capture depend on the relative scale of the mining operations and the river and the infrastructure that is located within the impact area. The larger and deeper the captured pit, the greater the potential river change (Mossa & Marks 2011, Norman et al. 1998).

The physical processes of pit capture have been well documented from case studies: incision upstream and downstream of the pit are expected, with bed adjustments continuing until the river establishes a new equilibrium and grade. Where a pit wall is breached and an avulsion occurs, the knickpoint (where the river enters the pit) migrates upstream, scouring and deepening the new channel across the floodplain until it intersects the old river course. This scouring lowers the bed of the river and progressively works its way upstream as it attempts to establish a new equilibrium and grade.

Bank erosion may also occur. Eroded sediments will be deposited in the pit, and while this is occurring there will be little transport of material past the pit to downstream areas. This leads to a discontinuity in sediment transport, and the downstream channel consequently will erode if not replenished from upstream (Norman et al. 1998). The time it takes for a river to readjust depends on the size and depth of the pit, the river's ability to transport sediment and the availability of sediment. The consequences of river readjustment processes are compounded from the reduced sediment from upstream sources following the construction of Eildon Dam. Any infrastructure which traverses the impacted area is at risk of being damaged during this period of adjustment.

Consequence criteria developed for this risk assessment are listed in Table 2.4. The physical consequences of pit capture are assessed with consideration to the scale of physical impact. Physical consequences range from 'Insignificant' with no significant impact at site or beyond the site of occurrence to 'Extreme' where there is a severe impact on the length, grade and dimensions of the river/tributary.

Infrastructure consequences are assessed by identifying the assets that lie within the physical impact area. Infrastructure consequences range from 'Insignificant' where there are no significant infrastructure assets in the impact area to 'Extreme' where an asset of high value, such as a highway or rail bridge is impacted with damage costs in the order of $1-3 million. Loss of a bridge has an extreme consequence not just due to the replacement cost but also loss of service and potential loss of life.

Table 2.4: Consequence criteria to assess physical and infrastructure impacts.

Consequences		Physical	Infrastructure
1	Insignificant	No significant impact at site or beyond site of occurrence	No significant infrastructure assets
2	Minor	Minor impact not extending beyond the originating disturbance.	Asset of minor value ($10,000) (e.g. ford or culvert crossing, fencing)
3	Moderate	Moderate impact extending beyond the originating disturbance (e.g. cutoff of a bend)	Asset of medium value ($100,000) (e.g. local road bridge over creek, past erosion control structure)
4	Major	Long term major impact affecting significant length of river / tributary (e.g. a short avulsion).	Asset of major value ($100,000 to $500,000) (e.g. a house)
5	Extreme	Severe impact on length, grade and dimensions of river / tributary (e.g. a long avulsion).	Asset of high value ($1-3 million) (e.g. highway or rail bridge)

2.4.2 Likelihood

The magnitude, duration and frequency of flows that fill the channel and inundate the floodplain drive the hydraulic and sediment transport processes of natural river change and, ultimately, the likelihood of pit capture. During floods, however, local variations in floodplain hydraulics and the relative strength of the floodplain substrate and characteristics of vegetation cover are the prime determinants of the extent and location of bed, bank, or floodplain erosion. In general, pits in close proximity to a waterway and where extraction has continued to a depth lower than the invert of the adjacent waterway will pose a greater risk than pits that are positioned further away from the waterway where extraction does not extend below the level of the invert (Bureau of Reclamation 2005, Langer 2003, Packer et al. 2005). Pit capture is considered more likely when water flowing through a pit offers the river a shorter course than the currently active channel (Kondolf 1997).

For this risk assessment, the likelihood of pit capture is considered over a 100 year planning horizon. A 100 year planning horizon has been chosen as this aligns with that which is widely accepted as the period over which planning decisions are made for river floodplains. This is based on a service life of 100 years for roads and bridges and is probably a suitable design life to have for a change in course of Goulburn River.

Likelihood criteria developed for this risk assessment are listed in Table 2.5 and Table 2.6. The pits are all located on the Goulburn River floodplain. A review of flood modelling indicates that the 20 year flood would inundate the floodplain and result in flow into the pits. The likelihood of flood waters entering the pit is ranked as almost certain to occur over a 100 year planning horizon.

The likelihood of pit capture will also vary depending on which of the three risk scenarios is being assessed. The likelihood criteria for lateral migration of river channel into the pit are based on an average annual bank erosion rate of 0.5 m. This is based on a review of analysis of channel changes in the Goulburn River over a 150 year period (Wilson et al. 2005). At this rate, over 100 years, 50 m of bank erosion could be expected, which we categorise as a moderate likelihood whereas 10-20 m of bank erosion is categorised as almost certain.

Similarly, the likelihood criteria for sub-surface piping into pit and subsequent failure of pit walls have been developed with consideration to the distance from the edge of the pit to a waterway or depression (i.e. palaeochannel) that would hold water for a sustained period of time.

DSDBI (2015) provide guidance on the determination of geotechnical risk zones around the perimeter of open pit mines and quarries. As a guideline, DSDBI (2015) recommend an offset distance of three times the batter height plus a minimum buffer zone of 20 m to limit potentially significant ground movements. Based on batter height of 10 m, 50 m is the recommended setback to mitigate against geotechnical risks. For a batter height of 20 m, 80 m is the recommended setback.

We have chosen to be conservative and set 100 m as a minimum setback to prevent this scenario from occurring. We recognise that the setback required is likely to vary with pit depth, and this can be determined through detailed geotechnical analysis. Likelihood will also vary depending on the operations at a pit. Likelihood will be higher for dry pit operations, where the hydraulic head is typically much higher than wet pit operations, especially for deep pits. A 100 m setback from the river or palaeochannel is assessed as having a rare likelihood of failure, whereas a failure is almost certain with 10-20 m setback.

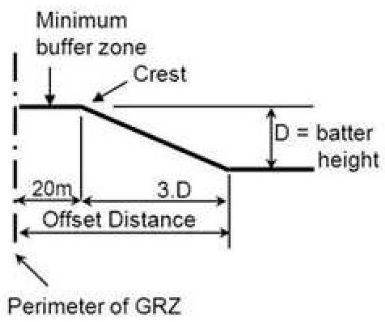

Figure 2.12: Criteria for determining the geotechnical risk zone for batter heights up to 20 m (DSDBI 2015).

The likelihood criteria for flow of floodwater into and through the pit and subsequent erosion of the buffer strip between the channel and the excavated pit have been developed based on the understanding that the risk of pit capture is high where the basement of the pit is lower than the level of the bed of the waterway (Bureau of Reclamation 2005, Langer 2003, Packer et al. 2005). On large rivers, where major floods persist for a long duration, the completion of large scale avulsions in a single flood is quite typical (Brizga & Finlayson 1990). In the middle Goulburn, floodplain avulsions can develop in one large flood, such as the Acheron Breakaway (Erskine et al. 1993). Hence, a pit that is not in close proximity to the river does not have a substantively reduced likelihood of capture on the Goulburn River and there are increased consequences in terms of the length of river that avulses. A moderate likelihood of pit capture as a result of flow of water into and through the pit is scored where the basement of the pit is the same elevation of the invert of the river. Pit capture is assessed as almost certain where the basement of the pit is more than 5 m lower than the river.

Table 2.5: Likelihood criteria to assess pit capture based on probability of flow entering pit.

Likelihood		Probability	Example flood frequency
1	Rare	< 5% chance of flow entering pit within a 100 year planning horizon	5% chance of at least one 2000 year ARI event[1] occurring within a 100 year planning horizon
2	Unlikely	5-10% chance of flow entering pit within a 100 year planning horizon	10% chance of at least one 1000 year ARI event occurring within a 100 year planning horizon
3	Moderate	10 to 50% chance of flow entering pit within a the 100 year planning horizon	28% chance of at least one 300 year ARI event occurring within a 100 year planning horizon
4	Likely	50 to 80% chance of flow entering pit within a 100 year planning horizon	63% chance of at least one 100 year ARI event occurring within a 100 year planning horizon
5	Almost certain	>80% chance of flow entering pit within a 100 year planning horizon	87% chance of a 50 year ARI flood occurring within a 100 year planning horizon

[1] Note: key critical infrastructures such as bridges are normally designed for the 2000 year ARI event.

Table 2.6: Likelihood criteria to assess pit capture for each risk scenario.

Likelihood		Lateral migration of river channel into the pit	Sub-surface piping into pit and subsequent failure of pit walls	Flow of floodwater into and through the pit and subsequent erosion of the buffer strip between the channel and the excavated pit
1	Rare	80-100 m bank erosion over 100 years	80-100 m from edge of waterway	Basement of pit more than 5 m higher than invert of river
2	Unlikely	60-80 m bank erosion over 100 years	60-80 m from edge of waterway	Basement of pit 1-5 m higher than invert of river
3	Moderate	40-60 m bank erosion over 100 years	40-60 m from edge of waterway	Basement of pit at same elevation as invert of river
4	Likely	20-40 m bank erosion over 100 years	20-40 m from edge of waterway	Basement of pit 1-5 m lower than invert of river
5	Almost certain	10-20 m bank erosion over 100 years	10-20 m from edge of waterway	Basement of pit more than 5 m lower than invert of river

2.4.3 Risk matrix

The risk assessment matrices outlined in Figure 2-13 are used to combine the likelihood and consequence scores and provide an overall risk rating.

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

Low	Medium	High	Critical
Low risk that does not necessarily require intervention	Moderate risk that with intervention may be reduced to more acceptable levels	High risk requiring intervention to reduce risk to an acceptable level	Critical risk that should be addressed through management intervention

Figure 2-13: Risk assessment matrices for assessing risk and prioritisation of risk mitigation strategies.

2.5 Evaluate risks

Risk evaluation is the process of comparing the results of the risk analysis with risk criteria to determine whether the risk and/or its magnitude is acceptable or tolerable. Its purpose is to assist decision making on which risks require further detailed analysis and/or need treatment, and the priority for implementation of measures to modify risk (National Emergency Management Committee 2010). The evaluation of risks takes into account the risk identification and analysis.

The ALARP (as low as reasonably practicable) principle is applied to define boundaries between risk that are generally intolerable, tolerable or broadly acceptable. This helps to prioritise risk and determine which ones require action and which do not (Figure 2.14). Those that are broadly acceptable require little, if any, action while risks that are at an intolerable level require attention to bring them to a tolerable level. For a risk to be acceptable it needs to fall in the broadly acceptable region of the ALARP diagram. Some risks may be tolerated, subject to being as low as practically possible, and these fall within the tolerable region (subject to ALARP).

Two factors to be considered when determining whether risks are generally intolerable, tolerable subject to ALARP or broadly acceptable are the risk rating and the confidence level. These interrelationships are noted in tolerability matrices (National Emergency Management Committee 2010). For this assessment we have adopted a medium level of confidence in evaluating a particular issue, using Table 2.7.

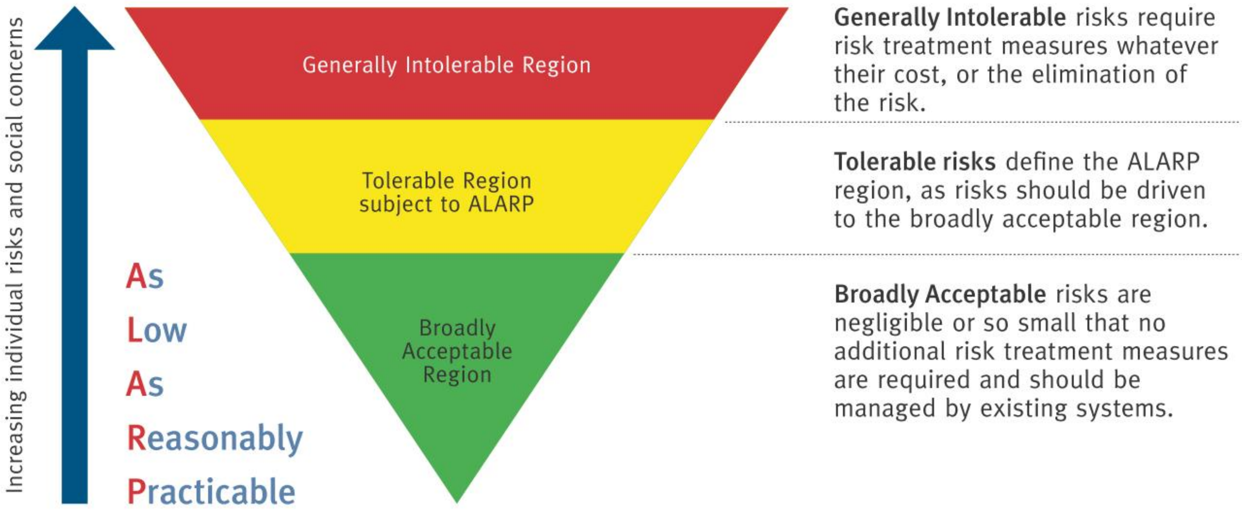

Figure 2.14: Use of the ALARP principle to identify whether risks are generally intolerable, tolerable or broadly acceptable (National Emergency Management Committee 2010).

Table 2.7: Evaluation table – medium confidence level.

	Consequence Level				
Likelihood Level	Insignificant	Minor	Moderate	Major	Extreme
Almost certain	Acceptable	Tolerable	Intolerable	Intolerable	Intolerable
Likely	Acceptable	Tolerable	Tolerable	Intolerable	Intolerable
Moderate	Acceptable	Acceptable	Tolerable	Tolerable	Intolerable
Unlikely	Acceptable	Acceptable	Acceptable	Tolerable	Tolerable
Rare	Acceptable	Acceptable	Acceptable	Acceptable	Tolerable

During risk evaluation, the level of risk is compared with that which is considered acceptable in reference to existing statutory and planning requirements. The desired outcome of risk evaluation is a decision concerning which risks need treatment and treatment priorities. Using the ALARP principle, high and critical risk ratings fall into the generally intolerable region, these risks require treatment measures whatever their cost, or the elimination of the risks. Moderate risk ratings fall in the tolerable region, further actions are required to lower the risk ratings so that they fall in the broadly acceptable region.

Note, for engineered structures such as bridges the acceptable level of risk is already established in the Australian Standards. For the scour processes set off by quarry pits, bridges would normally be designed for the 2000 year ARI flood (or rarer event) which equates to a 5% chance of collapse over the 100 year service life of the bridge.

2.6 Treatment of risks

Risk treatment is the process of selecting and assessing measures to modify risk. Risk treatment aims to determine and implement the most appropriate action(s) in response to the identified need to treat the risks (National Emergency Management Committee 2010). For sites assessed in the field, we have developed potential management options to prevent further development of the risks identified. These are outlined for each individual work authority in the following sections:

- WA141 - Section 3.1.2.1
- WA516 - Section 3.1.2.2
- WA45 - Section 3.1.2.3
- WA1443 - Section 3.1.2.4
- WA1189 - Section 3.1.2.5
- WA781 - Section 3.1.2.6
- WA232 - Section 3.1.2.7

Further discussion of management approaches to treat risks associated with floodplain mining is provided in Section 3.3.

3. Outcomes of risk assessment

3.1 Risk analysis

3.1.1 Overview

Table 3.1 presents a summary of the outcomes of the risk assessment for selected sand and gravel operations in the Goulburn Valley.

The consequences of pit capture for the six current work authority operations are assessed as major to extreme. The physical changes that would accompany an avulsion into a pit would result in significant impacts to the ecological condition of the waterway, degrading water quality and aquatic communities. The physical and infrastructure damages (i.e. change in river alignment, bridge collapse and potential loss of life) would be expected to receive extensive media coverage. Sustained widespread concern from key stakeholders and government regarding approval authority’s capability could be expected.

The likelihood of pit capture occurring by each of the three risk scenarios is described here:

1. Lateral migration of the river channel into the pit.
   Six of the nine work authorities have existing pits setback at least 100 m from the Goulburn River. The likelihood that the Goulburn River will erode its banks and migrate laterally into an existing pit with this minimum setback was considered rare or unlikely. A moderate likelihood of lateral migration of the river channel into an existing pit was assessed for the remaining three work authorities that have pits located within 50 m of the river (WA141, WA781, WA232).

2. Sub-surface piping into pit and subsequent failure of pit walls.
   The likelihood that pit capture and an avulsion of the Goulburn River would be caused by sub-surface piping into pits and subsequent failure of pit walls was assessed as rare or unlikely for only two of the nine work authorities (WA374, WA151). A moderate likelihood was assessed for WA232, which has a pit located within 40 m of the river. The remaining six work authorities were assessed as having a high likelihood (WA141, WA516, WA45, WA1443, WA1189, WA781). This is due to proximity of palaeochannels, anabranches or tributaries that are near to the pits (< 30 m setback). These watercourses will hold water during a flood and potentially initiate failure of pit walls through sub-surface piping into pits.

3. Flow of water into and through the pit and subsequent erosion of the buffer strip between the channel and the excavated pit.
   It is this third risk scenario, which is considered the most likely to occur. The likelihood that pit capture and an avulsion of the Goulburn River would be caused as a result of flood water flowing into and through the pit and subsequent erosion was assessed as likely at one work authority (WA141) and almost certain at six work authorities (WA516, WA45, WA1443, WA1189, WA781, WA232). This is due to the depth of the pits extending below the invert of the Goulburn River. The size of the pit also influences the likelihood score. A review of flood modelling indicates that the 20 year flood would inundate the floodplain and result in flow into surrendered and current operations. WA374 and WA151 were assessed as unlikely to initiate a pit capture. While the base of these two pits may extend > 5 m below the elevation of the Goulburn River invert, an avulsion is considered unlikely due to the small areal extent of the pit (0.6 and 0.9 hectares).

The risk of pit capture to the physical environment and infrastructure assets as a result of lateral channel migration is generally assessed as low to medium. Two exceptions to this are WA781 and WA232. Lateral channel migration leading to pit capture was assessed a high risk to the Hume Freeway at WA781 and WA232.

The risk of pit capture to the physical environment and infrastructure assets as a result of sub-surface piping into the pit causing failure of pit walls ranges from low, medium, high and critical across the work authority sites. The risks are heightened where a palaeochannel or tributary lies in close proximity to the pit, as is the case for seven out of the nine work authority sites (WA141, WA516, WA45, WA1443, WA1189, WA781, WA232).

The risk scenario that presents the greatest risk to the physical environment and infrastructure assets in the Goulburn Valley is the flow of water into and through the pits during a flood and subsequent erosion of the buffer strip between the channel and the excavated pit. Risk levels range from low to critical, a brief explanation of their ratings is provided here:

- Low risk: WA374 is a relatively small pit, 0.6 hectares. The work authority has been surrendered. The likelihood of a pit capture is unlikely and if it was to occur its impacts would be restricted to a relatively localised area comprising agricultural land.
- Medium risk: WA151 is another small pit, 0.9 hectares, the work authority has also been surrendered. The likelihood of pit capture is unlikely, however, if it were to occur it would impact on a 2.5 km length of river, a high voltage power line, residential houses and Maroondah Road.
- High risk: WA141 has been surrendered, however its larger size (2.8 Hectares), depth (the basement of the pit may be up to 9.5 m below the invert of the Goulburn River) and potential for pit capture to result in the formation of a longer avulsion channel lead to a high risk rating.
- Critical risk: WA516, WA45, WA1443, WA1189, WA781 and WA232 all have pits that have been identified a critical risk to the physical environment and infrastructure assets of the Goulburn Valley. Pit capture threatens significant infrastructure, including the Hume Highway, Melbourne to Sydney Railway, Ghin Ghin Road and the water supply for the North-South Pipeline.

Figure 3-1 and Figure 3-2 plot the outcomes of the risk assessment against a number of variables. Data is presented in this way to highlight variables such as pit depth, area and setback from the Goulburn River. The plots help to provide a summary of values and risk ratings against existing conditions and what has been approved.

Figure 3-1 plots existing pit depth against pit area, to highlight the affect that both of these variables have on the level of risk for Risk Scenario 3, flow of water into and through the pits during a flood and erosion of the buffer strip between the channel and the excavated pit. The deeper the pit and the larger the area affected, the greater are the risks to the physical environment and infrastructure assets. Highlighted on this plot are the six work authorities that have been identified as having critical risks requiring urgent management interventions at the site (work authority sites within red shaded polygon). Also highlighted is the final approved pit depth and area for WA516, WA1189 and WA781. The approved pit depths and areas will only further heighten the critical risks that have been identified in the assessment of existing conditions. An amendment to the Work Authority conditions is required to address these risks.

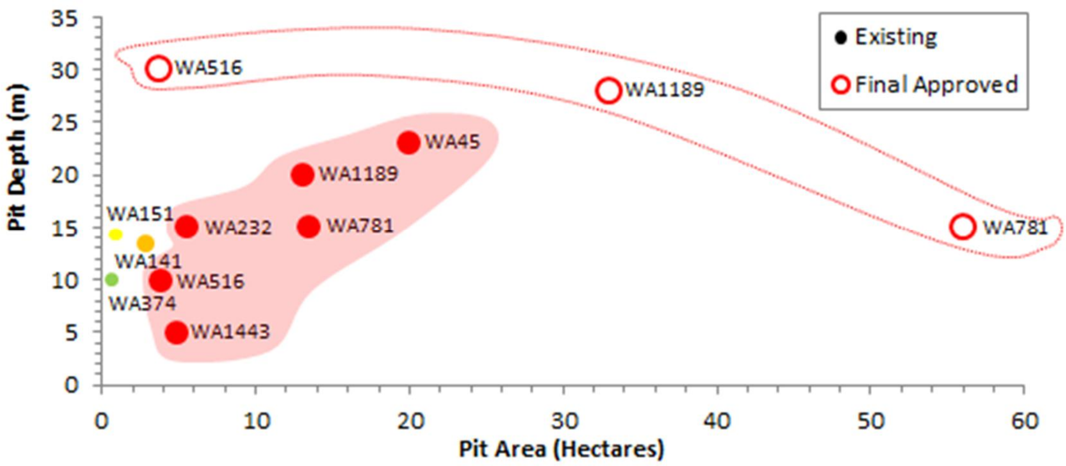

Figure 3-1: Summary plot of pit depth and area with risk ratings for Risk scenario 3, pit capture due to flow of water into and through the pit and subsequent erosion of the buffer strip between the channel and the excavated pit. Colours represent different risk rating levels (Red, Critical; Orange, High; Yellow, Moderate; Green, Low).

Figure 3-2 plots basement of pit below river invert against setback from the river for Risk Scenario 3. The setback from the River is less influential on risk ratings. This is because a long duration flood can result in the capture of pits located further away from the floodplain, and this risk will be heightened where the depth of the pit is lower than the invert of the river. Similarly to Figure 3-1, the plot highlights the six work authorities that have been identified as having critical risks requiring urgent management interventions at the site (work authority sites within red shaded polygons). Also plotted is the final approved depth of the pit relative to the Goulburn River invert for WA516 and WA1189. The conditions of approval will further heighten the critical risks that have been identified in the assessment of existing conditions. An amendment to the Work Authority conditions is required to address these risks.

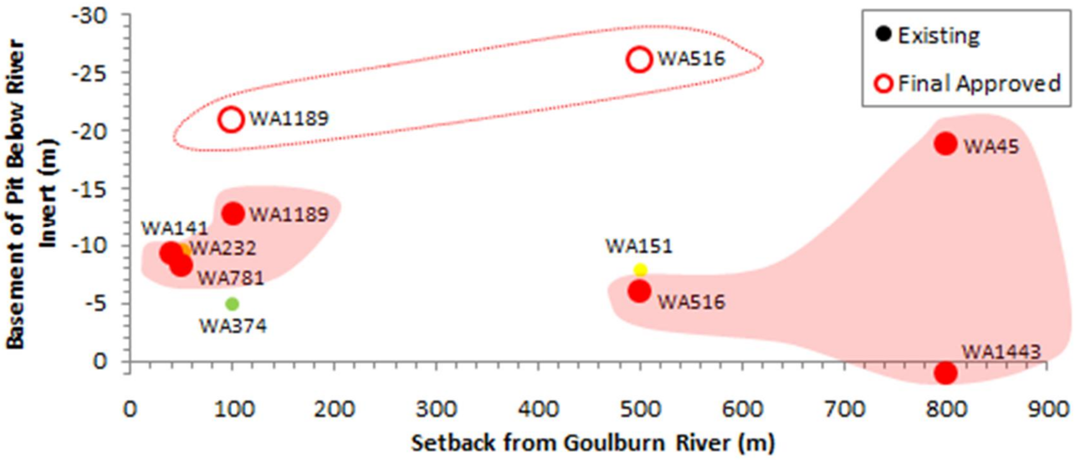

Figure 3-2: Summary plot of pit depth relative to Goulburn River and setback distance with risk ratings for Risk scenario 3, pit capture due to flow of water into and through the pit and subsequent erosion of the buffer strip between the channel and the excavated pit. Colours represent different risk rating levels (Red, Critical; Orange, High; Yellow, Moderate; Green, Low).

Table 3.1: Outcomes of risk assessment.

Pit	Risk Scenario	Physical Impacts			Infrastructure Impacts			Description of potential impacts
		Consequence	Likelihood	Risk Rating	Consequence	Likelihood	Risk Rating	
WA374	1. Lateral migration of the river channel into the pit	Moderate	Unlikely	Low	Minor	Unlikely	Low	Pit capture and avulsion could result in the creation of a new channel 600 m in length and abandonment of 800 m section of river. Avulsion would sever local access tracks, split properties, result in damages to agricultural assets (i.e. fences) and land capability. While the base of the pit may extend > 5 m below the elevation of the Goulburn River invert, an avulsion is considered unlikely due to the small areal extent of the pit (0.6 hectares).
	2. Sub-surface piping into pit and subsequent failure of pit walls	Moderate	Rare	Low	Minor	Rare	Low	
	3. Flow of water into and through the pit and subsequent erosion	Moderate	Unlikely	Low	Minor	Unlikely	Low	
WA151	1. Lateral migration of the river channel into the pit	Major	Rare	Low	Major	Rare	Low	Pit capture and avulsion could result in the creation of a new channel 2 km in length and abandonment of 2.5 km section of river. Potential impacts include damages to a high voltage line, two houses, agricultural assets, Maroondah Road and local access tracks. While the base of the pit may extend > 5 m below the elevation of the Goulburn River invert, an avulsion is considered unlikely due to the small areal extent of the pit (0.9 hectares).
	2. Sub-surface piping into pit and subsequent failure of pit walls	Major	Rare	Low	Major	Rare	Low	
	3. Flow of water into and through the pit and subsequent erosion	Major	Unlikely	Medium	Major	Unlikely	Medium	
WA141	1. Lateral migration of the river channel into the pit	Major	Moderate	Medium	Moderate	Moderate	Medium	Pit capture and avulsion could result in the creation of a new channel 2 km in length and abandonment of 3 km section of river. Avulsion would sever local access tracks, split properties, result in damages to agricultural assets (i.e. fences) and land capability.
	2. Sub-surface piping into pit and subsequent failure of pit walls	Major	Likely	High	Moderate	Likely	Medium	
	3. Flow of water into and through the pit and subsequent erosion	Major	Likely	High	Moderate	Likely	Medium	
WA516	1. Lateral migration of the river channel into the pit	Major	Rare	Low	Moderate	Rare	Low	Pit capture and avulsion could result in the creation of a new channel 3 km in length and abandonment of 3.5 km section of river. Avulsion would impact on water supply for the North-South Pipeline as the pump station is located on the section of river that would be abandoned. Avulsion would also sever local access tracks, split properties, result in damages to agricultural assets (i.e. fences) and land capability.
	2. Sub-surface piping into pit and subsequent failure of pit walls	Major	Likely	High	Moderate	Likely	Medium	
	3. Flow of water into and through the pit and subsequent erosion	Major	Almost certain	Critical	Extreme	Almost certain	Critical	
WA45	1. Lateral migration of the river channel into the pit	Extreme	Rare	Medium	Major	Rare	Low	Pit capture and avulsion could impact > 5 km of river. Requires floodwater to pass through the pit for a long duration. Avulsion would sever local access tracks, split properties, result in damages to agricultural assets (i.e. fences) and land capability. Ghin Ghin Road may also be impacted.
	2. Sub-surface piping into pit and subsequent failure of pit walls	Extreme	Likely	Critical	Major	Likely	Critical	
	3. Flow of water into and through the pit and subsequent erosion	Extreme	Almost certain	Critical	Major	Almost certain	Critical	
WA1443	1. Lateral migration of the river channel into the pit	Extreme	Rare	Medium	Major	Rare	Low	Same impacts as outlined for WA45, due to close proximity with deeper pits. Pit capture and avulsion could impact > 5 km of river. Requires floodwater to pass through the pit for a long duration. Avulsion would sever local access tracks, split properties, result in damages to agricultural assets (i.e. fences) and land capability. Ghin Ghin Road may also be impacted.
	2. Sub-surface piping into pit and subsequent failure of pit walls	Extreme	Likely	Critical	Major	Likely	Critical	
	3. Flow of water into and through the pit and subsequent erosion	Extreme	Almost certain	Critical	Major	Almost certain	Critical	
WA1189	1. Lateral migration of the river channel into the pit	Major	Rare	Low	Extreme	Rare	Medium	Deep pit, close to river. Pit capture could lead to formation of new river alignment with a river length of 2 km. Extreme consequences for infrastructure assets and private property. The Railway Lines are at threat, with damages/failure of the bridges. Any services attached to railway bridges or that traverse the floodplain will also be damaged or destroyed.
	2. Sub-surface piping into pit and subsequent failure of pit walls	Major	Likely	High	Extreme	Likely	Critical	
	3. Flow of water into and through the pit and subsequent erosion	Major	Almost certain	Critical	Extreme	Almost certain	Critical	
WA781	1. Lateral migration of the river channel into the pit	Major	Moderate	Medium	Extreme	Moderate	High	Pit capture could lead to formation of new river alignment that could range in length from 700 m to >3 km and abandonment of existing sections of the river. Potential impacts include damages to Hume Freeway and bridge that crosses the Goulburn River. Local access tracks would be severed, splitting properties, with damages to agricultural assets (i.e. fences) and land capability.
	2. Sub-surface piping into pit and subsequent failure of pit walls	Major	Likely	High	Extreme	Likely	Critical	
	3. Flow of water into and through the pit and subsequent erosion	Major	Almost certain	Critical	Extreme	Almost certain	Critical	
WA232	1. Lateral migration of the river channel into the pit	Major	Moderate	Medium	Extreme	Moderate	High	Pit capture could lead to formation of new shorter straighter river alignment with existing meander bends left abandoned. Potential impacts include damages to Hume Freeway and bridge that crosses the Goulburn River. Local access tracks would be severed, splitting properties, with damages to agricultural assets (i.e. fences) and land capability.
	2. Sub-surface piping into pit and subsequent failure of pit walls	Major	Moderate	Medium	Extreme	Moderate	High	
	3. Flow of water into and through the pit and subsequent erosion	Major	Almost certain	Critical	Extreme	Almost certain	Critical	

3.1.2 Individual Work Authority Risk Assessments

A more detail description and justification of the risk assessments are prepared for a selected number of Work Authority sites. These sites were identified as areas of high risk during the initial desktop assessment and selected for further investigation through field inspections.

3.1.2.1 WA141

WA141 is positioned east of the Goulburn River at Killingworth. The work authority includes a single pit with a total area of 2.8 hectares. The pit is set back 50 m from the Goulburn River and we have estimated, based on the dimensions of the pit and an assumed batter slope, that it has a maximum depth of 13.5 m. This depth needs to be confirmed at a later stage. It is estimated that the basement of the pit lies 9.5 m below the invert of the Goulburn River. The floodplain is also traversed by a series of palaeochannels, which during floods would act as preferred flow paths.

Figure 3.3 shows an aerial image of the Goulburn Floodplain within the vicinity of WA141. Annotated on this image are arrows showing flow paths and avulsion channels that could form if pit capture were to occur. These arrows generally follow the course of palaeochannels. A review of modelling by Water Technology indicates that the 20 year flood would inundate the floodplain and result in flow into the pit.

Figure 3.3: Preferred flow and potential avulsion paths and points of flow entry and exit into WA141 pit.

The outcomes of this risk assessment for WA141 are presented in Table 3.2. Table 3.3 presents a list of infrastructure assets that would be impacted by pit capture, primary failure mechanism, consequence, likelihood and risk rating.

Pit capture would have major consequences to the physical environment, potentially leading to the formation of a new shorter river alignment 2 km in length and abandonment of the existing 3 km river alignment. Following pit capture erosion would occur upstream and downstream degrading the physical form of the floodplain and connecting river. Incision and widening along the avulsion channel would result in the removal of vegetation and habitat, with trees toppling into the channel. The Goulburn River would be expected to experience high rates of bed and bank erosion for many months and years, impacting on water quality downstream.

Pit capture would have moderate consequences to infrastructure assets and private property. Local access tracks would be severed, splitting properties, with damages to agricultural assets (i.e. fences) and land capability.

Lateral migration of the river channel into the current pit is assessed as having a moderate likelihood. Sub-surface piping into the pit and subsequent failure of pit walls is also assessed as likely. During a flood, palaeochannels that traverse the floodplain will function as preferred flow paths. Sub-surface piping is a likely scenario where these watercourses run close to the pit (within 30 m). Flow of water into and through the pit during a flood and subsequent erosion of the buffer strip between the channel and the pit is assessed as likely to occur, although the depth of the pit needs to be determined to confirm if this likelihood is correct. Overall, lateral migration of the river channel into the pit is assessed as a medium risk. Failure of pit walls as a result of sub-surface piping is assessed as a medium/high risk. Flow of water into and through the pit and subsequent erosion of the buffer strip between the channel and the pit is a medium/high risk. Potential management options to treat assessed risks are outlined in Table 3.4.

Table 3.2: WA141 Outcomes of risk assessment.

Asset	Risk scenario	Consequence	Likelihood	Risk Rating
Physical environment	1. Lateral migration of the river channel into the pit	Major	Moderate	Medium
	2. Sub-surface piping into pit and subsequent failure of pit walls	Major	Likely	High
	3. Flow of water into and through the pit and subsequent erosion	Major	Likely	High
Infrastructure assets	1. Lateral migration of the river channel into the pit	Moderate	Moderate	Medium
	2. Sub-surface piping into pit and subsequent failure of pit walls	Moderate	Likely	Medium
	3. Flow of water into and through the pit and subsequent erosion	Moderate	Likely	Medium

Table 3.3: WA141 List of infrastructure assets at risk.

Infrastructure assets	Primary failure mechanisms	Consequence	Likelihood	Risk Rating
Local access tracks and fences	Flow of water into and through the pit and subsequent erosion Sub-surface piping into pit and subsequent failure of pit walls	Moderate	Likely	Medium

Table 3.4: WA141 Potential management options to treat risks.

Potential management options
Construction of levee to prevent flow of water into and through the pits
Construction of partial levee and grade control structures that convey flow into and out of the pits
Partial fill of pit to level above the invert of the Goulburn River

3.1.2.2 WA516

WA516 is located on the northern floodplain of the Goulburn River. The work authority includes a single pit with a total area of 3.8 hectares. The pit is setback 500 m from the Goulburn River and has a maximum depth of 10 m. It is estimated that the basement of the pit lies 6 m below the invert of the Goulburn River. The final approved plan is for a pit depth of 30 m. The basement of the pit would then lie -26 m below the invert of the Goulburn River.

Figure 3.4 shows an aerial image of the Goulburn Floodplain within the vicinity of WA516. Annotated on this image are arrows showing flow paths and avulsion channels that could form if pit capture were to occur. These arrows generally follow the course of palaeochannels. Figure 3.5 presents a cross-section of the floodplain developed from LiDAR. The approximate level for the 100 year flood is also shown to highlight the extent of flooding across the floodplain. A review of modelling by Water Technology indicates that the 20 year flood would inundate the floodplain and result in flow into the pits.

Figure 3.4: Preferred flow and potential avulsion paths and points of flow entry and exit into WA516 pit.

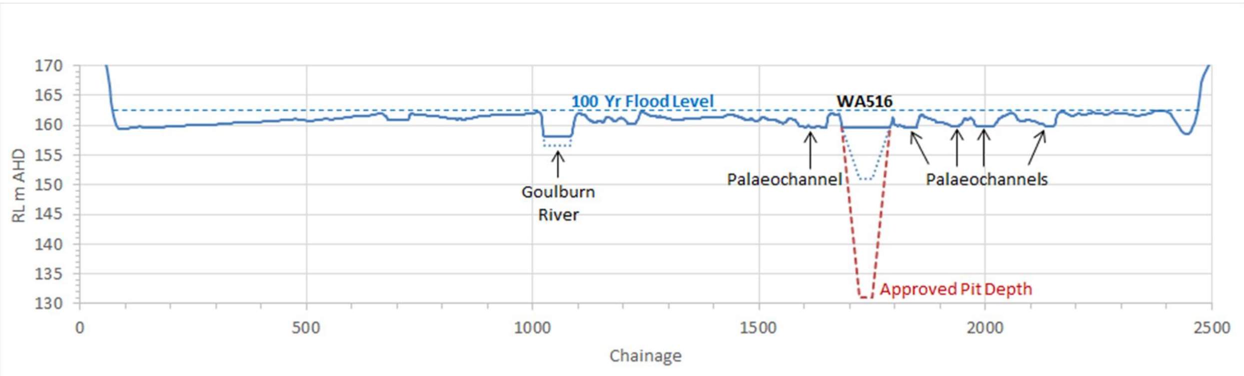

Figure 3.5: Floodplain cross-section from LiDAR showing the relief of the Goulburn River floodplain.

The outcomes of this risk assessment for WA141 are presented in Table 3.5. Table 3.6 presents a list of infrastructure assets that would be impacted by pit capture, primary failure mechanism, consequence, likelihood and risk rating.

Pit capture would have major consequences to the physical environment, potentially leading to the formation of a new shorter river alignment 3 km in length and abandonment of the existing 3.5 km river alignment. Following pit capture erosion would occur upstream and downstream degrading the physical form of the floodplain and connecting river. Incision and widening along the avulsion would result in the removal of vegetation and habitat, with trees toppling into the channel. The Goulburn River would be expected to experience high rates of bed and bank erosion for many months and years, impacting on water quality downstream.

Pit capture would have extreme consequences to infrastructure assets and private property. The North-South Pipeline pump station is located on the southern bank of the Goulburn River. The pipeline is to be used in times of water shortage or when needed for local fire fighting. Avulsion pathways will take the water supply away from the pump station. Local access tracks would also be severed, splitting properties, with damages to agricultural assets (i.e. fences) and land capability.

Lateral migration of the river channel into the current pit is assessed as having a rare likelihood. The setback of the pit from the river is sufficient to protect the river from this risk scenario. Sub-surface piping into the pit and subsequent failure of pit walls is assessed as likely. During a flood, palaeochannels that traverse the floodplain will function as preferred flow paths. Sub-surface piping is a likely scenario where these watercourses run close to the pit (within 30 m). Flow of water into and through the pit during a flood and subsequent erosion of the buffer strip between the channel and the pit is assessed as almost certain to occur. Overall, lateral migration of the river channel into the pit is assessed as a low risk. Failure of pit walls as a result of sub-surface piping is assessed as a medium/high risk. Flow of water into and through the pit and subsequent erosion of the buffer strip between the channel and the pit is a critical risk. Potential management options to treat assessed risks are outlined in Table 3.7.

Table 3.5: WA516 Outcomes of risk assessment.

Asset	Risk scenario	Consequence	Likelihood	Risk Rating
Physical environment	1. Lateral migration of the river channel into the pit	Major	Rare	Low
	2. Sub-surface piping into pit and subsequent failure of pit walls	Major	Likely	High
	3. Flow of water into and through the pit and subsequent erosion	Major	Almost certain	Critical
Infrastructure assets	1. Lateral migration of the river channel into the pit	Moderate	Rare	Low
	2. Sub-surface piping into pit and subsequent failure of pit walls	Moderate	Likely	Medium
	3. Flow of water into and through the pit and subsequent erosion	Extreme	Almost certain	Critical

Table 3.6: WA516 List of infrastructure assets at risk.

Infrastructure assets	Primary failure mechanisms	Consequence	Likelihood	Risk Rating
North-South Pipeline Pump Station, local access tracks and fences	Flow of water into and through the pit and subsequent erosion	Extreme	Almost certain	Critical

Table 3.7: WA516 Potential management options to treat risks.

Potential management options
Construction of levee to prevent flow of water into and through the pit
Construction of partial levee and grade control structures that convey flow into and out of the pit
Partial fill of pit to level above the invert of the Goulburn River

3.1.2.3 WA45

WA45 is positioned south of the Goulburn River. The work authority includes five pits with a total area of 20 hectares. The pits are setback 800 m from the Goulburn River and have a maximum depth of 23 m. It is estimated that the basement of the pits lie a maximum of 12.8 m below the invert of the Goulburn River. The floodplain is also traversed by a series of palaeochannels, which during floods would act as preferred flow paths.

Figure 3.6 shows an aerial image of the Goulburn Floodplain within the vicinity of WA45. Annotated on this image are arrows showing flow paths and avulsion channels that could form if pit capture were to occur. Many of these arrows follow the course of palaeochannels. Figure 3-7 presents a cross-section of the floodplain developed from LiDAR. The approximate level for the 100 year flood is also shown to highlight the extent of flooding across the floodplain. A review of modelling by Water Technology indicates that the 20 year flood would inundate the floodplain and result in flow into the pits.

Figure 3.6: Preferred flow and potential avulsion paths and points of flow entry and exit into WA45 and WA1443 pits.

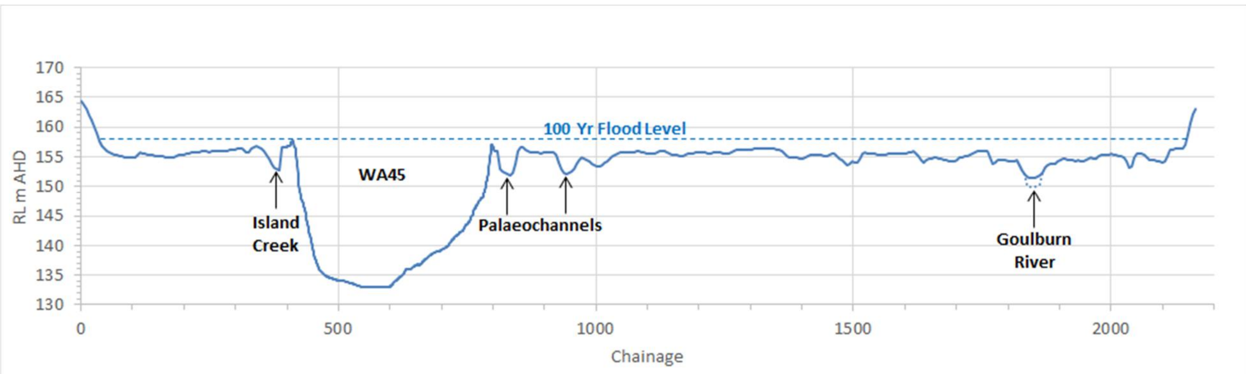

Figure 3-7: Floodplain cross-section from LiDAR showing the relief of the Goulburn River floodplain.

Island Creek is an anabranch of the Yea and Goulburn Rivers. In August 2010, the creek avulsed into one of the pits. This capture was caused by sub-surface piping into the pit and subsequent failure of pit walls (Craigie 2012, Goulburn Broken CMA 2014). The avulsion caused substantial incision and bank erosion along the creek, with an erosion knickpoint progressing 340 m upstream (Craigie 2012), destroying a recently constructed road crossing and riparian vegetation (Figure 2.2).

The outcomes of this risk assessment for WA45 are presented in Table 3.8. Table 3.9 presents a list of infrastructure assets that would be impacted by pit capture, primary failure mechanism, consequence, likelihood and risk rating.

Pit capture would have extreme consequences to the physical environment, potentially leading to the formation of a new river alignment 5 km in length and abandonment of the existing river alignment. There are multiple alternate courses along which pit capture may occur, with erosion progressing upstream and downstream degrading the physical form of the floodplain and connecting river. Incision and widening along the avulsion would result in the removal of vegetation and habitat, with trees toppling into the channel. The Goulburn River would be expected to experience high rates of bed and bank erosion for many months and years, impacting on water quality downstream.

Pit capture would have major consequences to infrastructure assets and private property. The Ghin Ghin Road may be impacted by pit capture, as erosion upstream of the pits could result in severing of the road and damage/failure of the bridge that crosses the Goulburn River. Local access tracks would be severed, splitting properties, with damages to agricultural assets (i.e. fences) and land capability. Lateral migration of the river channel into each pit is assessed as having a rare likelihood. The setback of the pits from the river is sufficient to protect the river from this risk scenario. Sub-surface piping into one or more pits and subsequent failure of pit walls is assessed as likely. During a flood event, Island Creek and other anabranches/palaeochannels that traverse the floodplain will function as preferred flow paths. Sub-surface piping is a likely scenario where these watercourses run within 30 m of an existing pit of WA45 or WA1443. Flow of water into and through the pits during a flood and subsequent erosion of the buffer strip between the channel and the pit leading to pit capture and consequences outlined is assessed as almost certain to occur. Overall, lateral migration of the river channel into the pits is assessed as a low/medium risk. Failure of pit walls as a result of sub-surface piping and flow of water into and through the pits and subsequent erosion are assessed as critical risks. Potential management options to treat assessed risks are outlined in Table 3.10.

Table 3.8: WA45 Outcomes of risk assessment.

Asset	Risk scenario	Consequence	Likelihood	Risk Rating
Physical environment	1. Lateral migration of the river channel into the pit	Extreme	Rare	Medium
	2. Sub-surface piping into pit and subsequent failure of pit walls	Extreme	Likely	Critical
	3. Flow of water into and through the pit and subsequent erosion	Extreme	Almost certain	Critical
Infrastructure assets	1. Lateral migration of the river channel into the pit	Major	Rare	Low
	2. Sub-surface piping into pit and subsequent failure of pit walls	Major	Likely	Critical
	3. Flow of water into and through the pit and subsequent erosion	Major	Almost certain	Critical

Table 3.9: WA45 List of infrastructure assets at risk.

Infrastructure assets	Primary failure mechanisms	Consequence	Likelihood	Risk Rating
Ghin Ghin Road	Flow of water into and through the pit Sub-surface piping into pit and subsequent failure of pit walls	Major	Almost certain	Critical

Table 3.10: WA45 Potential management options to treat risks.

Potential management options
Construction of levee to prevent flow of water into and through the pits

Potential management options
Construction of partial levee and grade control structures that convey flow into and out of the pits
Partial fill of pits to level above the invert of the Goulburn River
Construction of waterway diversion for section of Island Creek

3.1.2.4 WA1443

WA1443 is positioned south of the Goulburn River and adjacent to WA45. The work authority includes a single pit, with a total area of 4.8 hectares and a maximum depth of 5 m. It is estimated that the base of the pit lies 1 m above the invert of the Goulburn River. This pit has been developed as a Code of Practice Pit (< 5 hectares in area and 5 m in depth).

Figure 3.6 shows an aerial image of the Goulburn Floodplain within the vicinity of WA45. Annotated on this image are arrows showing flow paths and avulsion channels that could form if pit capture were to occur. Many of these arrows follow the course of palaeochannels. A review of modelling by Water Technology indicates that the 20 year flood would inundate the floodplain and result in flow into this pit.

The outcomes of this risk assessment for WA1443 are presented in Table 3.11. Table 3.12 presents a list of infrastructure assets that would be impacted by pit capture, primary failure mechanism, consequence, likelihood and risk ratings.

The close proximity of the WA1443 pit to the WA45 pits and the greater depth and dimensions that are associated with the WA45 pits, mean that the consequence, likelihood and risk ratings remain the same for WA1443. The pits that form part of the two work authorities are not spaced far enough apart to prevent capture of one pit from impacting on the other. As WA1443 is positioned upstream of WA45, should WA45 be captured first, it is likely that erosion will progress upstream through WA1443. Alternatively, if WA1443 captures flow first, erosion downstream will progress through WA45.

Pit capture would have extreme consequences to the physical environment, potentially leading to the formation of a new river alignment 5 km in length and abandonment of the existing river alignment. Pit capture could occur at multiple locations, with erosion progressing upstream and downstream degrading the physical form of the floodplain and connecting river. Incision and widening along the avulsion would result in the removal of vegetation and habitat, with trees toppling into the channel. The Goulburn River would be expected to experience high rates of bed and bank erosion for many months and years, impacting on water quality downstream.

Pit capture would have major consequences to infrastructure assets and private property. The Ghin Ghin Road may be impacted by pit capture, as erosion upstream of the pits could result in severing of the road and damage/failure of the bridge that crosses the Goulburn River. Local access tracks would be severed, splitting properties with damages to agricultural assets (i.e. fences) and land capability.

Lateral migration of the river channel into each pit is assessed as having a rare likelihood. The setback of the pits from the river is sufficient to protect the river from this risk scenario. Sub-surface piping into pits and subsequent failure of pit walls is assessed as likely. During a flood event, Island Creek and other anabranches/palaeochannels that traverse the floodplain will function as preferred flow paths. Sub-surface piping is a likely scenario where these watercourses run close to the pits (within 30 m). Flow of water into and through the pits during a flood leading to pit capture and subsequent erosion of the buffer strip between the channel and the pits and consequences outlined is assessed as almost certain to occur. Overall, lateral migration of the river channel into the pits is assessed as a low/medium risk. Failure of pit walls as a result of sub-surface piping and flow of water into and through the pits and subsequent erosion are assessed as critical risks. Potential management options to treat assessed risks are outlined in Table 3.11. These are the same as those outlined for WA45.

Table 3.11: WA1443 Outcomes of risk assessment.

Asset	Risk scenario	Consequence	Likelihood	Risk Rating
Physical environment	1. Lateral migration of the river channel into the pit	Extreme	Rare	Medium
	2. Sub-surface piping into pit and subsequent failure of pit walls	Extreme	Likely	**Critical**
	3. Flow of water into and through the pit and subsequent erosion	Extreme	Almost certain	**Critical**
Infrastructure	1. Lateral migration of the river channel into the pit	Major	Rare	Low

Asset	Risk scenario	Consequence	Likelihood	Risk Rating
assets	2. Sub-surface piping into pit and subsequent failure of pit walls	Major	Likely	Critical
	3. Flow of water into and through the pit and subsequent erosion	Major	Almost certain	Critical

Table 3.12: WA1443 List of infrastructure assets at risk.

Infrastructure assets	Primary failure mechanisms	Consequence	Likelihood	Risk Rating
Ghin Ghin Road	Flow of water into and through the pit and subsequent erosion Sub-surface piping into pits and subsequent failure of pit walls	Major	Almost certain	Critical

Table 3.13: WA1443 Potential management options to treat risks.

Potential management options
Construction of levee to prevent flow of water into and through the pits
Construction of partial levee and grade control structures that convey flow into and out of the pits
Partial fill of pits to level above the invert of the Goulburn River
Construction of waterway diversion for section of Island Creek

3.1.2.5 WA1189

WA1189 is located north of the Goulburn River, immediately downstream from two Melbourne to Sydney Railway Line Bridges. The work authority includes two pits. Current operations are restricted to a single pit, with an area of 13.1 hectares and pit depth of 20 m. It is estimated that the basement of the pit lies 12.8 m below the invert of the Goulburn River. This pit is setback 100 m from the Goulburn River. The final approved plan is for a total area of 33 hectares across two pits with a pit depth of 28 m. The basement of the pits would then lie 22 m below the invert of the Goulburn River.

Figure 3.8 shows an aerial image of the Goulburn Floodplain within the vicinity of WA1189. Annotated on this image are arrows showing potential flow paths and avulsion channels that could form if pit capture were to occur. The approximate position of the proposed Seymour town levee is also shown. Figure 3.9 presents a cross-section of the floodplain developed from LiDAR and information known about the depth of the pits. The approximate level for the 100 year flood is also shown to highlight the extent of flooding across the floodplain. A review of modelling by Water Technology indicate that the 20 year flood would inundate the floodplain and result in flow into the pits.

The outcomes of the risk assessment for WA1189 are presented in Table 3.14. Table 3.15 presents a list of infrastructure assets that would be impacted by pit capture, primary failure mechanism, consequence, likelihood and risk ratings.

Pit capture would have major consequences to the physical environment, potentially leading to the formation of a new river alignment with a length of 2 km. The avulsion could potentially create a shorter straighter alignment, with existing meander bends left abandoned. Pit capture could occur at multiple locations, with erosion progressing upstream and downstream degrading the physical form of the floodplain and connecting river. Incision and widening along the avulsion would result in the removal of vegetation and habitat, with trees toppling into the channel. The Goulburn River would be expected to experience high rates of bed and bank erosion for many months and years, impacting on water quality downstream.

Pit capture would have extreme consequences to infrastructure assets and private property. Erosion upstream of the pit could result in severing of the Melbourne to Sydney Railway Lines and damage/failure of the bridges that cross the Goulburn River. Any services that are attached to the railway bridges or traverse the floodplain in the area impacted would also be damaged or destroyed (i.e. electricity, telecommunications, water, gas, sewer). The town levee, although not yet constructed may also be damaged. Emily Street and other roads could potentially be severed. Any buildings that lie within the area may also be impacted.

Lateral migration of the river channel into the current pit is assessed as having a rare likelihood. Sub-surface piping into pit and subsequent failure of pit walls is also assessed as likely. During a flood, palaeochannels that traverse the floodplain will function as preferred flow paths. Sub-surface piping is a likely scenario where these watercourses run close to the pit (within 30 m). Flow of water into and through the pit during a flood and subsequent erosion of the buffer strip between the channel and the pit is assessed as almost certain to occur. Overall, lateral migration of the river channel into the pit is assessed as a low/medium risk. Failure of pit walls as a result of sub-surface piping is assessed as a high/critical risk. Flow of water into and through the pit and subsequent erosion is a critical risk. Potential management options to treat assessed risks are outlined in Table 3.16.

Figure 3.8: Preferred flow and potential avulsion paths and points of flow entry and exit into pit at WA1189. The approximate proposed levee alignment is also shown.

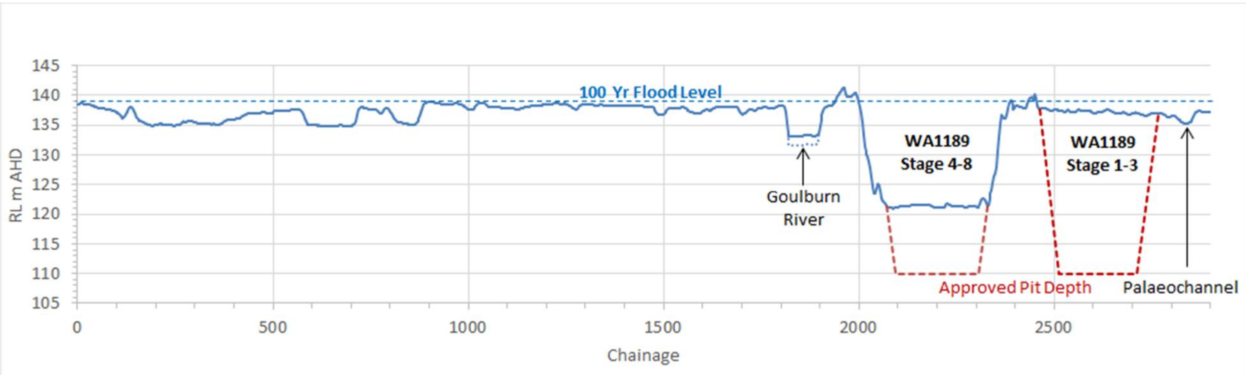

Figure 3.9: Floodplain cross-section from LiDAR showing the relief of the Goulburn River Floodplain, WA1189 Current and Approved Pits.

Table 3.14: WA1189 Outcomes of risk assessment.

Asset	Risk scenario	Consequence	Likelihood	Risk Rating
Physical environment	1. Lateral migration of the river channel into the pit	Major	Rare	Low
	2. Sub-surface piping into pit and subsequent failure of pit walls	Major	Likely	**High**
	3. Flow of water into and through the pit and subsequent erosion	Major	Almost certain	**Critical**
Infrastructure	1. Lateral migration of the river channel into the pit	Extreme	Rare	Medium

Asset	Risk scenario	Consequence	Likelihood	Risk Rating
assets	2. Sub-surface piping into pit and subsequent failure of pit walls	Extreme	Likely	Critical
	3. Flow of water into and through the pit and subsequent erosion	Extreme	Almost certain	Critical

Table 3.15: WA1189 List of infrastructure assets at risk.

Infrastructure assets	Primary failure mechanism	Consequence	Likelihood	Risk Rating
Melbourne to Sydney Railway Line	Flow of water into and through the pit and subsequent erosion Sub-surface piping into pit and subsequent failure of pit walls	Extreme	Almost certain	Critical
Services (Electricity, Gas, Water etc.)	Flow of water into and through the pit and subsequent erosion Sub-surface piping into pit and subsequent failure of pit walls	Extreme	Almost certain	Critical
Roads	Flow of water into and through the pit and subsequent erosion Sub-surface piping into pit and subsequent failure of pit walls	Extreme	Almost certain	Critical
Buildings	Flow of water into and through the pit and subsequent erosion Sub-surface piping into pit and subsequent failure of pit walls	Extreme	Almost certain	Critical
Seymour town levee	Flow of water into and through the pit and subsequent erosion Sub-surface piping into pit and subsequent failure of pit walls	Extreme	Almost certain	Critical

Table 3.16: WA1189 Potential management options to treat risks.

Potential management options
Construction of levee along edge of Goulburn River and through gap in railway bridge to prevent flow of water into and through the pit
Construction of partial levee to allow water to fill pits from downstream end but prevent flow of water into and through the pit
Development of system to provide emergency warning of scour at the rail bridge (i.e. pressure sensor)
Partial fill of pit to level above the invert of the Goulburn River

3.1.2.6 WA781

WA781 is located east of the Goulburn River, 1 km upstream of the Hume Freeway. The work authority includes two existing pits with a total area of 13.5 hectares, with approval to mine seven pits with a total area of 56 hectares. The smaller of the two existing pits is setback 50 m from the Goulburn River and has a maximum depth of 15 m. This pit is no longer being mined. The second existing pit is setback further from the Goulburn River and has a maximum depth of 15 m. It is estimated that the basement of both existing pits lie 8.4 m below the invert of the Goulburn River. It is noted that the approved work plan does not explicitly limit the depth of the extraction pits to 15 m. It only refers to 15 m as a batter height.

The floodplain is also traversed by a series of palaeochannels, which during floods would act as preferred flow paths. Figure 3-10 shows an aerial image of the Goulburn Floodplain within the vicinity of WA781. Annotated on this image are arrows showing potential flow paths and avulsion channels that could form if pit capture were to occur. Many of these arrows follow the course of palaeochannels. Figure 3-11 presents a cross-section of the floodplain developed from LiDAR and information known about the depth of the pits. The approximate level for the 100 year flood is also shown to highlight the extent of flooding across the floodplain. A review of modelling by Water Technology indicate that the 20 year flood would inundate the floodplain and result in flow into the pits.

Review of aerial imagery and ground inspection showed that the western and northern battered banks of the smaller pit are covered with vegetation, however the southern and western batter banks, which are closest to the Goulburn River are relatively bare and lacking in vegetation (see Figure 3-10 and Figure 3-11A). A palaeochannel/drainage line also traverses between the two pits (Figure 3-11B). An assessment of this drainage line between the two pits in the field showed this to have experienced some piping and scour of the embankments of the smaller pit (Figure 3-11C, D). While the erosion observed is relatively minor, it does highlight that material is readily eroded and that relatively minor flows along this drainage line will spill into the smaller pit. A review of 2011 aerial imagery and LiDAR indicates that the 2011 floods resulted in flow into both the smaller and larger pit, capturing this drainage line. Figure 3.13 shows a panoramic photograph taken of the larger pit. Vegetation has established in areas at the base of the pit and the lower batters. The upper batters are generally bare and lacking in vegetation cover.

The outcomes of the risk assessment for WA781 are presented in Table 3.17. Table 3.18 presents a list of infrastructure assets that would be impacted by pit capture, primary failure mechanism, consequence, likelihood and risk ratings.

Pit capture would have major consequences to the physical environment, potentially leading to the formation of a new river alignment that could range in length from 700 m to > 3 km. Pit capture could occur at multiple locations, with erosion progressing upstream and downstream degrading the physical form of the floodplain and connecting river. Incision and widening along the avulsion would result in the removal of vegetation and habitat, with trees toppling into the channel. The avulsion may follow the alignment of an existing palaeochannel or potentially create a shorter, straighter path to the Goulburn River, with the abandonment of existing sections of the river. The Goulburn River would be expected to experience high rates of bed and bank erosion for many months and years, impacting on water quality downstream.

Pit capture would have major consequences to infrastructure assets and private property. The Hume Freeway may be impacted by pit capture, as erosion downstream of the pits could result in severing of the freeway and damage/failure of the bridge that crosses the Goulburn River. Local access tracks would be severed, splitting properties, with damages to agricultural assets (i.e. fences) and land capability.

Lateral migration of the river channel into the smaller pit is assessed as having a moderate likelihood. Continued erosion of the Goulburn River bank could result in the river being captured by the pit. Sub-surface piping into either of the two pits and subsequent failure of pit walls is considered likely. During a flood, palaeochannels that traverse the floodplain will function as preferred flow paths. Sub-surface piping is a likely scenario where these watercourses run close to the pits (within 30 m). Flow of water into and through the pits during a flood and subsequent erosion of the buffer strip between the channel and the pitsleading to pit capture and consequences outlined is assessed as almost certain to occur.

Figure 3-10: Preferred flow and potential avulsion paths and points of flow entry and exit into two pits at WA781.

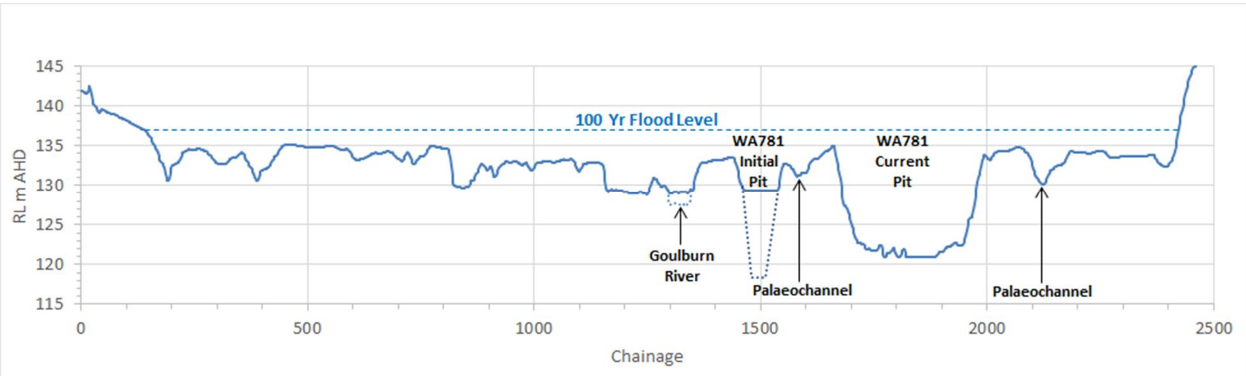

Figure 3-11: Floodplain cross-sections from LiDAR showing the relief of the Goulburn River Floodplain and WA781 Pits.

Figure 3.12: Photographs taken within the vicinity of initial smaller pit at WA781. (A) Pit lake with vegetated eastern batters but bare southern batters (B) Looking upstream along palaeochannel/drainage line between two pits (C) Pipe erosion along edge of drainage line (D) Pipe erosion and collapse affecting pit batter.

Figure 3.13: Panoramic photograph taken looking at dimensions of current larger pit at WA781.

Overall, lateral migration of the river channel into the smaller pit is assessed as medium /high risk, sub-surface piping into both pits and subsequent failure of pit walls a high/critical risk and flow of water into and through both pits and subsequent erosion is a critical risk. Potential management options to treat assessed risks are outlined in Table 3.19.

Table 3.17: WA781 Outcomes of risk assessment.

Asset	Risk scenario	Consequence	Likelihood	Risk Rating
Physical environment	1. Lateral migration of the river channel into the pit	Major	Moderate	Medium
	2. Sub-surface piping into pit and subsequent failure of pit walls	Major	Likely	High
	3. Flow of water into and through the pit and subsequent erosion	Major	Almost certain	Critical
Infrastructure assets	1. Lateral migration of the river channel into the pit	Extreme	Moderate	High
	2. Sub-surface piping into pit and subsequent failure of pit walls	Extreme	Likely	Critical
	3. Flow of water into and through the pit and subsequent erosion	Extreme	Almost certain	Critical

Table 3.18: WA781 List of infrastructure assets at risk.

Infrastructure assets	Primary failure mechanisms	Consequence	Likelihood	Risk Rating
Hume Freeway	Flow of water into and through the pit and subsequent erosion Sub-surface piping into pit and subsequent failure of pit walls	Extreme	Almost certain	Critical

Table 3.19: WA781 Potential management options to treat risks.

Potential management options
Construction of a levee to prevent flow of water into and through the pit
Construction of partial levee and grade control structures that convey flow into and out of the pits
Vegetated buffer on river side of smaller pit
Partial fill of pits to level above the invert of the Goulburn River

3.1.2.7 WA232

WA232 is located east of the Goulburn River, 1 km downstream of the Hume Freeway. The pit is setback from the river 40 m with a total area of 5.5 hectares. There is a narrow low lying embankment that divides the pit into two areas. Both areas have a maximum depth of 15 m, are at their deepest nearest to the river, becoming more shallow towards the eastern boundary of the pit where they only reach 5-6 m in depth, with bedrock at the base. It is estimated that the basement of the pit lies up to 9.3 m below the invert of the Goulburn River. The pit is no longer being mined.

Figure 3.14 shows an aerial image of the Goulburn Floodplain from the Hume Freeway downstream to WA232. Annotated on this image are arrows showing potential flow paths and avulsion channels that could form if pit capture were to occur. A review of modelling by Water Technology indicates that the 20 year flood would inundate the floodplain and result in flow entry into the pit. The flooding pattern is such that as the river rises, water backs up into the downstream pit area first, with water following the path of a palaeochannel that connects with the pit.

Figure 3.14: Potential avulsion paths and points of flow entry and exit into WA232 pit.

The outcomes of the risk assessment for WA232 are presented in Table 3.20. Table 3.21 presents a list of infrastructure assets that would be impacted by pit capture, primary failure mechanism, consequence, likelihood and risk ratings.

Pit capture would have major consequences to the physical environment, potentially leading to the formation of a new river alignment. Pit capture could occur at multiple locations, with erosion progressing upstream and downstream degrading the physical form of the floodplain and connecting river. Incision and widening along the avulsion would result in the removal of vegetation and habitat, with trees toppling into the channel. The avulsion could potentially create a shorter straighter alignment, with existing meander bends left abandoned. The Goulburn River would be expected to experience high rates of bed and bank erosion for many months and years, impacting on water quality downstream.

Pit capture would have major consequences to infrastructure assets and private property. The Hume Freeway may be impacted by pit capture, as erosion upstream of the pits could result in severing of the freeway and damage/failure of the bridge that crosses the Goulburn River. Local access tracks would be severed, splitting properties, with damages to agricultural assets (i.e. fences) and land capability.

Lateral migration of the river channel into the pit is assessed as having a moderate likelihood. Continued erosion of the Goulburn River bank could result in the river being captured by the pit. Sub-surface piping into pit and subsequent failure of pit walls is also assessed as having a moderate likelihood. Flow of water into and through the pit during a flood and subsequent erosion of the buffer strip between the channel and the pit and consequences outlined is assessed as almost certain to occur. Overall, lateral migration of the river channel into the pit and failure of pit walls as a result of sub-surface piping is assessed as a medium/high risk. Flow of water into and through both pits and subsequent erosion is a critical risk. Potential management options to treat assessed risks are outlined in Table 3.22.

Table 3.20: WA232 Outcomes of risk assessment.

Asset	Risk scenario	Consequence	Likelihood	Risk Rating
Physical environment	1. Lateral migration of the river channel into the pit	Major	Moderate	Medium
	2. Sub-surface piping into pits and subsequent failure of pit walls	Major	Moderate	Medium
	3. Flow of water into and through the pit and subsequent erosion	Major	Almost certain	**Critical**
Infrastructure assets	1. Lateral migration of the river channel into the pit	Extreme	Moderate	High
	2. Sub-surface piping into pits and subsequent failure of pit walls	Extreme	Moderate	High
	3. Flow of water into and through the pit and subsequent erosion	Extreme	Almost certain	**Critical**

Table 3.21: WA232 List of infrastructure assets at risk.

Infrastructure assets	Primary failure mechanisms	Consequence	Likelihood	Risk Rating
Hume Freeway	Flow of water into and through the pit and subsequent erosion	Extreme	Almost certain	**Critical**

Table 3.22: Potential management options to treat risks.

Potential management options
Construction of partial levee to allow water to fill pits from downstream end but prevent flow of water into and through the pits
Vegetated buffer between southern edge of pit and the Goulburn River
Partial fill of pits to level above the invert of the Goulburn River

3.2 Evaluation of risks

In risk evaluation, the level of risk is compared with what is considered acceptable in reference to existing statutory and planning requirements. A list of the key planning requirements and objectives that industry, regulators and referral agencies need to consider in managing floodplain mining operations in the Goulburn Valley, was presented earlier in Section 2.2.1 when describing the strategic requirements for this risk assessment. These planning controls provide general guidance on floodplain management, the protection of waterways and requirements of rehabilitation plans.

Table 3.23 lists key planning requirements and objectives and assesses the extent to which the management of floodplain mining operations meet these controls. It can be clearly seen from this assessment that existing and legacy floodplain mining operations present an intolerable risk to the physical environment and infrastructure assets in the Goulburn Valley. What is most concerning is that for every planning requirement and objective listed in Table 3.23, there are clear indications that the floodplain mining industry is not being managed so that these planning controls are upheld.

Table 3.23: Evaluation of the management of floodplain mining operations against key planning requirements and objectives.

Key planning requirements and objectives	Assessment of management of floodplain mining operations
Public land along the Goulburn River between Lake Eildon and the Murray River is listed as a Heritage River in Victoria for its significant nature conservation, recreation, scenic and cultural heritage attributes (*Heritage Rivers Act 1992*). Attributes of the Goulburn River as identified by the *Heritage River Act 1992* are to be protected.	The attributes of the Goulburn River as identified by the *Heritage Rivers Act 1992* are threatened by pit capture and changes in river alignment. The physical changes that would accompany an avulsion into a pit would result in significant impacts on the ecological condition of the waterway and associated floodplain environments, degrading water quality and aquatic communities, leaving an unstable erosion feature devoid of riparian vegetation.
Planning for rural areas should consider: the location of earth resources; the potential for future extraction of earth resources; and minimising impacts on sensitive uses and the environment (State Planning Policy Framework, Clause 11.10).	Planning for rural areas has not adequately addressed the issues that are associated with extraction of sand and gravel from the floodplain. Pit capture and avulsions will have significant impact on land users, in particular the capability of the land as large areas of floodplain will be affected.
In regard to environmental risks, planning should adopt a best-practice environmental management and risk management approach which aims to avoid or minimise environmental degradation and hazards (State Planning Policy Framework, Clause 13).	Existing and proposed operations do not have adequate strategies in place to avoid or minimise environmental degradation and hazards. A best practice environmental management and risk management approach would require a limit on extraction depths to be set relative to the Goulburn River invert so that risk of pit capture is addressed.
The objective of floodplain management is to assist the protection of floodplain areas of environmental significance or of importance to river health, and to protect life, property and community infrastructure from flood hazard (State Planning Policy Framework, Clause 13.02).	Flood hazard is increased as a result of current and proposed sand and gravel extraction operations. Pit capture and avulsion is a threat to life, property and community infrastructure. Impacts include damage/failure of railway and road bridges, property values and community infrastructure (i.e. telecommunications, gas, water).
Planning should provide for long term protection of waterways and water quality as natural resources (State Environmental Protection Policy, Clauses 33 and 35; State Planning Policy Framework, Clause 14).	The current status of management of sand and gravel extraction industries in the Goulburn Valley does not provide for long term protection of waterways and water quality as natural resources. Pit capture and changes in channel alignment will result in long term degradation of waterways and water quality.
Planning should ensure that development maintains or improves river and wetland health, waterway protection and floodplain health (Victorian Planning Provisions Land Subject to Overlay, Clause 44.04; Floodway Overlay, Clause 44.03).	Development of sand and gravel extraction resources in the Goulburn Valley poses a risk to river and wetland health, waterway protection and floodplain health. Pit capture and avulsion is a critical risk that results from the development of deep and large pits.

Key planning requirements and objectives	Assessment of management of floodplain mining operations
Development on floodplains should protect areas prone to erosion, landslip and other degradation processes and prevent inappropriate development in unstable areas or areas prone to erosion (State Planning Policy Framework, Clause 13).	Avulsions are a natural process along the Goulburn River. This process is commonly initiated by floodwaters spilling into floodplain depressions. The floodplain pits that are created by sand and gravel extraction operations are substantially deeper and wider than natural depressions and therefore represent a greater threat to the stability of the river.
Rehabilitation plans need to take into account the special characteristics of the land, the surrounding environment, the need to stabilise the land and any potential for long term degradation of the environment (Mineral Resources (Sustainable Development) Act, 1990, Section 79).	The special characteristics of the Goulburn River and its floodplain, with respect to avulsions and the risks that creating deep and large depressions has on heightening these risk have not been fully considered in rehabilitation plans. In particular, rehabilitation plans do not address the risks associated with flow into and through the pit.
Planning should ensure that use and development of land for stone extraction does not adversely affect the environment or amenity of the area during or after extraction and that excavated areas can be appropriately rehabilitated (State Planning Policy Framework, Clause 52.09).	Major and extreme physical and infrastructure consequences are almost certain to occur in response to the current level of sand and gravel extraction in the valley. The ability to rehabilitate these areas may be limited due to the significant depth and size of the pits.

The ALARP principle has been applied to the risk analysis of individual work authority sites to distinguish between those risks that are intolerable, tolerable or acceptable (Table 3.24). Seven of the nine work authority sites have intolerable risks, where treatment measures are required to address the risks. These correspond with those sites in the risk analysis that were assessed as having a high or critical risk rating. Note the assessment of risks at WA141 should be considered provisional at this stage. Assessment of the depth of the pit is required to finalise the level of risk. Two work authority sites were identified as having tolerable or acceptable risks (WA374 and WA151). These correspond with those sites in the risk analysis that were assessed as having a low or medium risk rating.

Table 3.24: Evaluation of risks for work authority sites assessed in the Goulburn Valley.

Risk Scenario	Work Authority	Evaluation
1. Lateral migration of the river channel into the pit	WA516, WA781, WA232	Intolerable
2. Sub-surface piping into pit and subsequent failure of pit walls	WA141, WA516, WA45, WA1443, WA1189, WA781, WA232	
3. Flow of water into and through the pit	WA141, WA516, WA45, WA1443, WA1189, WA781, WA232	
1. Lateral migration of the river channel into the pit	WA141, WA45, WA1443, WA1189	Tolerable
2. Sub-surface piping into pit and subsequent failure of pit walls		
3. Flow of water into and through the pit	WA151	
1. Lateral migration of the river channel into the pit	WA374, WA151, WA516	Acceptable
2. Sub-surface piping into pit and subsequent failure of pit walls	WA374,WA151	
3. Flow of water into and through the pit	WA374	

The avulsion processes potentially initiated by WA232, WA781, WA1189 and WA45 represent ultimate limit state failure modes for the associated bridges. As the consequences of a bridge reaching the ultimate limit state are unacceptable, bridge standards require this failure mode to have a low likelihood over the service life of the structure (e.g. 2,000-5,000 year ARI). Generally the likelihood of a bridge reaching ultimate limit state should be in the rare category (Table 2.6). The quarries at WA232, WA781, WA1189 and WA45 have effectively shifted the likelihood of an ultimate limit state failure from what was probably the rare category when the bridge was constructed to the likely or almost certain category now (Table 2.6).

3.3 Risk treatment

There are two main approaches to reducing river related risks associated with floodplain mining.

1. Locate the pits away from the river on terraces or higher floodplain surfaces above the 100-year flood level so that there is lower risk of pit capture (Langer 2003, Mossa & Marks 2011, Norman et al. 1998, Packer et al. 2005, Woodward-Clyde 1980).
2. Implement controls to reduce the risks of floodplain mines to acceptable levels, *viz*.:
    a. levees;
    b. grade control structures;
    c. vegetated buffers;
    d. pit setbacks from existing waterways;
    e. limiting the depth of the pits; and
    f. construction of waterway diversions

The management strategies available to address these risks will vary depending on whether it is a new pit that is proposed or an existing pit with legacy issues.

3.3.1 Management strategies for new pits

It is recommended that all new pits are located away from the river on terraces or higher floodplain surfaces above the 100-year flood level. For the Goulburn Valley, mines should be located outside of the Urban Floodway Zone, Floodway Overlay and Land Subject to Inundation Overlay and preferably in upland areas if possible. Pits need to be stable without levees and grade control structures because:

- such infrastructure would need to be owned and maintained in the long term;
- integrity of inlet/outlet structures during floods is questionable, particularly during the long duration floods that occur on the Goulburn River; and
- levees change the flooding behaviour of the floodplain, which may in turn create flooding or erosion issues at other locations.

Floodplain mining operations should also be compatible with existing planning requirements and any recommended criteria for the location of extraction sites and geometry of the pit which are in the process of being developed as part of this project. This will include specific guidance on pit setbacks, maximum pit depths, pit area and spacing and placement of stockpiles.

Positioning pits at a distance away from waterways can assist in lowering the risk of pit capture through lateral channel migration and sub-surface piping. An appropriate setback from the waterway can be determined with reference to data on channel migration rates and a geotechnical assessment of pit batter slopes that explicitly considers potential for failure of pit walls due to sub-surface piping.

Provision of a waterway setback has less influence in lowering the risk of pit capture due to flow into and through the pit and subsequent erosion of the buffer strip between the channel and the pit. Pit capture through flood water entering into the pit may occur where pits are located close to or far away from a waterway. Pits located far away from a waterway may still be at high risk of capture, particularly during long duration floods and where the depth of the pit extends below the depth of the waterway.

Limiting the depth of pits is an important risk mitigation measure. Limiting the depth so that the pit basement lies above the invert of surrounding watercourses, thereby limits the potential for pit capture.

3.3.2 Management strategies for existing pits

This risk assessment has identified seven operations with pits that have legacy issues where risks are considered intolerable and treatment measures are required to address the risks. Potential management options to treat the assessed risks have been outlined. These involve the construction of levees or partial levees and grade control structures, vegetation buffers, waterway diversions and or partial fill of pits. These may assist in addressing risks at existing pits, however further investigations would be required to ensure that structures are effective and do not cause other adverse consequences. There are also other issues such as who is responsible for owning and maintaining structures in the long term that need to be considered.

Levees can be constructed to keep water from entering and flowing through a pit. Partial levees have also been used elsewhere, the intent being to allow for a pit to fill in from the downstream end of the pit. Langer's (2003) view is that levees should be constructed with armoured spillways that control where the levee will be "breached" by the stream during flooding. The spillway allows water to leave the channel and temporarily flow over the floodplain but keeps the stream from creating a new channel and keeps the bedload in the stream. However, levees change the flooding behaviour of the floodplain which may in turn create flooding or erosion issues at other locations.

Grade control structures that convey flow into and out of extraction pits are cited as another option in the literature (Bureau of Reclamation 2005, JE Fuller/Hydrology and Geomorphology Inc. 2004, Langer 2003, Schnitzer et al. 1999). Grade control structures require detailed engineering design to ensure that structures remain stable for the range of flows expected. A high rate of energy dissipation must be allowed for at the point where flow enters the pit to prevent scour at the toe of the grade control structure. The batters of the grade control structure also need to be sufficiently protected, taking care to tie these into stable non-erosive surface to prevent flanking. Schnitzer et al. (1999) acknowledge that retrofitting sites where extraction is deeper than the channel is difficult, due to the significant height and gradient over which the structures must convey flow. On the Goulburn River this is particularly difficult as the structures will need to endure long duration flood events during which repair work will not be possible.

Vegetated buffers may reduce the potential of stream capture for existing floodplain pits (Mossa & Marks 2011). The intent here is that the vegetation increases the resistance of floodplain areas between the pit and river to erosion, and therefore limits the potential for lateral migration or channel avulsion to occur. Bank revetments either on the river side, or as treatments on the battered slopes of pit (i.e. rock armouring or beaching), can also increase the resistance of these surfaces to erosion (Klingman 1998). Norman et al. (1998) stated that while vegetative buffers may reduce the probability of a river avulsion in the near term, they may only serve to delay the inevitable capture of the pit. From a process perspective, vegetation is not an effective treatment for the headward erosion that develops from floodplain flow through the pit. Vegetation helps secure the floodplain surface against erosion, thereby helping to maintain a vertical knickpoint that will undermine the vegetation and continue to erode upstream.

Construction of a waterway diversion may assist in diverting a section of waterway away from a pit, increasing the setback between the pit and waterway, thereby lowering the risk of pit capture through lateral channel migration and sub-surface piping.

Partial filling of the pit to a level above the invert of surrounding watercourses would assist in lowering the risk of pit capture through flow of water into and through the pit and subsequent erosion of the buffer strip between the channel and the pit.

4. Summary

This report provides an assessment of the impacts and risks associated with floodplain mining in the Goulburn Valley. The assessment has been informed by an international literature review of the range of impacts and risks that floodplain mining poses to rivers, and the management strategies that have been used to mitigate against these risks (Jacobs and Moroka 2014). A systematic method for identifying, analysing and evaluating risks associated with floodplain mining has been followed, that broadly follows the process outlined in the National Emergency Risk Assessment Guidelines (National Emergency Management Committee 2010).

Three main risk scenarios have been identified that have the potential to result in pit capture (Jacobs and Moroka 2014):

1. Lateral migration of river channel into the pit
2. Sub-surface piping into pit and subsequent failure of pit walls
3. Flow of water into and through the pit and subsequent erosion of the buffer strip between the channel and the excavated pit

This risk assessment analyses the risks to the physical environment and infrastructure located in the mid-Goulburn Valley as a result of pit capture by the mechanisms outlined in the above three risk scenarios. The consequences and likelihood of each risk scenario have been assessed for nine work authorities, three of these have surrendered their operations and six remain current.

The consequences of pit capture for the six current work authority operations are assessed as major to extreme (WA516, WA45, WA1443, WA1189, WA781, WA232). The physical changes that would accompany an avulsion into the pit would result in significant impacts on the ecological condition of the waterway, degrading water quality and the aquatic communities. Any infrastructure which traverses the impacted area is at risk of being damaged. The physical and infrastructure damages (i.e. change in river alignment, road and railway bridge collapse, property and building damages, severing of services) would be expected to receive extensive media coverage. Sustained widespread concern from key stakeholders and government regarding industry, regulators and referral agencies capability could be expected.

Pit capture arising as a result of the flow of water into and through the pit is almost certain to occur at the six current work authority operations. The basement of the pits extend below the level of the invert of the Goulburn River which increases the likelihood of pit capture by the Goulburn River. A review of flood modelling indicates that the 20 year flood would inundate the floodplain and result in flow into surrendered and current operations. Sub-surface piping into pits and subsequent failure of pit walls was also assessed as having a high likelihood at five of the six current work authority operations. This is due to the proximity of palaeochannels, anabranches and tributaries that are near the pits. These watercourses will hold water during a flood and potentially initiate failure of pit walls through sub-surface piping into pits. Lateral migration of the Goulburn River into the pit was assessed as a moderate likelihood at one of the surrendered work authority operations (WA141) and two of the current work authority operations (WA781 and WA232).

The likelihood and consequence scores combine to provide an overall rating of risk of pit capture for the three different risk scenarios. The risk scenarios that present the greatest risk to the physical environment and infrastructure assets in the Goulburn Valley is Risk Scenario 3, the flow of water into and through the pits during a flood and subsequent erosion of the buffer strip between the channel and the excavated pit. All of the current work authority operations were assessed as a critical risk for this risk scenario. Risk Scenario 2, sub-surface piping into pits and subsequent failure of pit walls was also assessed as either a high or critical risk at current operations.

In evaluating the risks, the level of risk is compared with what is considered acceptable in reference to existing statutory and planning requirements. It is clear that management of floodplain mining operations does not meet current planning objectives and requirements and that these operations present an intolerable risk to the physical environment and infrastructure assets in the Goulburn Valley. Seven of the nine operations were assessed as having intolerable risks. These correspond with those sites in the risk analysis that were assessed as having a high or critical risk rating. This includes all of the current work authority operations and one of the surrendered operations (WA141).

A number of potential management options have been recommended to treat risks. These include:

- Construction of a levee to prevent flow of water into and through the pit (WA141, WA516, WA45, WA1443, Construction of a levee to prevent flow of water into and through the pits (WA141, WA516, WA45, WA1443, WA781)
- Construction of a partial levee and grade control structures that convey flow into and out of the pits (WA141, WA516, WA45, WA1443, WA781)
- Construction of levee along edge of Goulburn River and through gap in railway bridge to prevent flow of water into and through the pit (WA1189)
- Construction of partial levee to allow water to fill pits from downstream end but prevent flow of water into and through the pits (WA232 and WA1189)
- Partial fill of pits to a level above the invert of the Goulburn River (WA141, WA516, WA45, WA1443, WA1189, WA781, WA232)
- Construction of a waterway for section of Island Creek to increase the setback from existing pits (WA45, WA1443)
- Development of system to provide emergency warning of scour at the rail bridge near Seymour (WA1189)
- Vegetated buffer to increase the resistance of the floodplain areas between the pits and river (WA781, WA232)

This risk assessment is a first step in identifying risks at extraction operations. Detailed site specific assessments are required to evaluate the risk and mitigation options in more detail. Further investigation of management options is required to ensure they are effective. Particular issues include the potential for unintended adverse consequences of levees and structural works, potential failure of structural measures, requirement of structural measures to have a long design life given that pits are permanent floodplain features, the difficulty of repairing structural measures during a flood event and the time required for vegetated buffers to become effective.

It is the depth of the pits relative to the Goulburn River and their size that are a particular concern. It is well documented in the literature that the risks of pit capture are high where the pit depth extends below the depth of the surrounding waterways (Bureau of Reclamation 2005, Kondolf 1997, Langer 2003, Norman et al. 1998, Packer et al. 2005), which is why industry guidelines recommend that the maximum depth of pit should remain above the invert of an adjacent waterway (Department of Irrigation and Drainage 2009).

Urgent management interventions are required at the six current work authority sites to reduce the risks of pit capture (WA516, WA45, WA1443, WA1189, WA781, WA232). Any further deepening or extension of the areas will only further heighten the risks. For a number of work authorities (WA516, WA1189, WA781), alteration of approval conditions will be required to address these risks.

The outcomes of this risk assessment provide further justification for the development of a planning framework to assist the Goulburn Broken CMA, Councils, the Department of Economic Development, Jobs, Transport and Resources (DEDJTR) and proponents with decision making about sustainable sand and gravel extraction. It is expected that the planning framework will include specific recommendation that the maximum depth of pits remains above the invert of the Goulburn River and adjacent anabranches and tributaries. The framework will also include recommendations on the dimensions of the pit as well as guidance on the position of pits in relation to surrounding waterways.

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Important note about this report

The sole purpose of this report and the associated services performed by Jacobs is to undertake a review of the impacts of floodplain mining on river systems in accordance with the scope of services set out in the contract between Jacobs and the Goulburn Broken CMA. That scope of services, as described in this report, was developed with the Goulburn Broken CMA.

Jacobs derived the data in this report from information sourced from the Goulburn Broken CMA and/or available in the public domain at the time or times outlined in this report. The passage of time, manifestation of latent conditions or impacts of future events may require further examination of the project and subsequent data analysis, and re-evaluation of the data, findings, observations and conclusions expressed in this report. Jacobs has prepared this report in accordance with the usual care and thoroughness of the consulting profession, for the sole purpose described above and by reference to applicable standards, guidelines, procedures and practices at the date of issue of this report. For the reasons outlined above, however, no other warranty or guarantee, whether expressed or implied, is made as to the data, observations and findings expressed in this report, to the extent permitted by law.

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